CG-D-69-78

REF. NO. 1.

LOW FRICTION HULL COATINGS FOR ICEBREAKERS

PHASE III TECHNICAL REPORT

S.J. Calabrese and F.F. Ling
Department of Mechanical Engineering,
Aeronautical Engineering & Mechanics
Rensselaer Polytechnic Institute

OCTOBER 1978

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22151

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

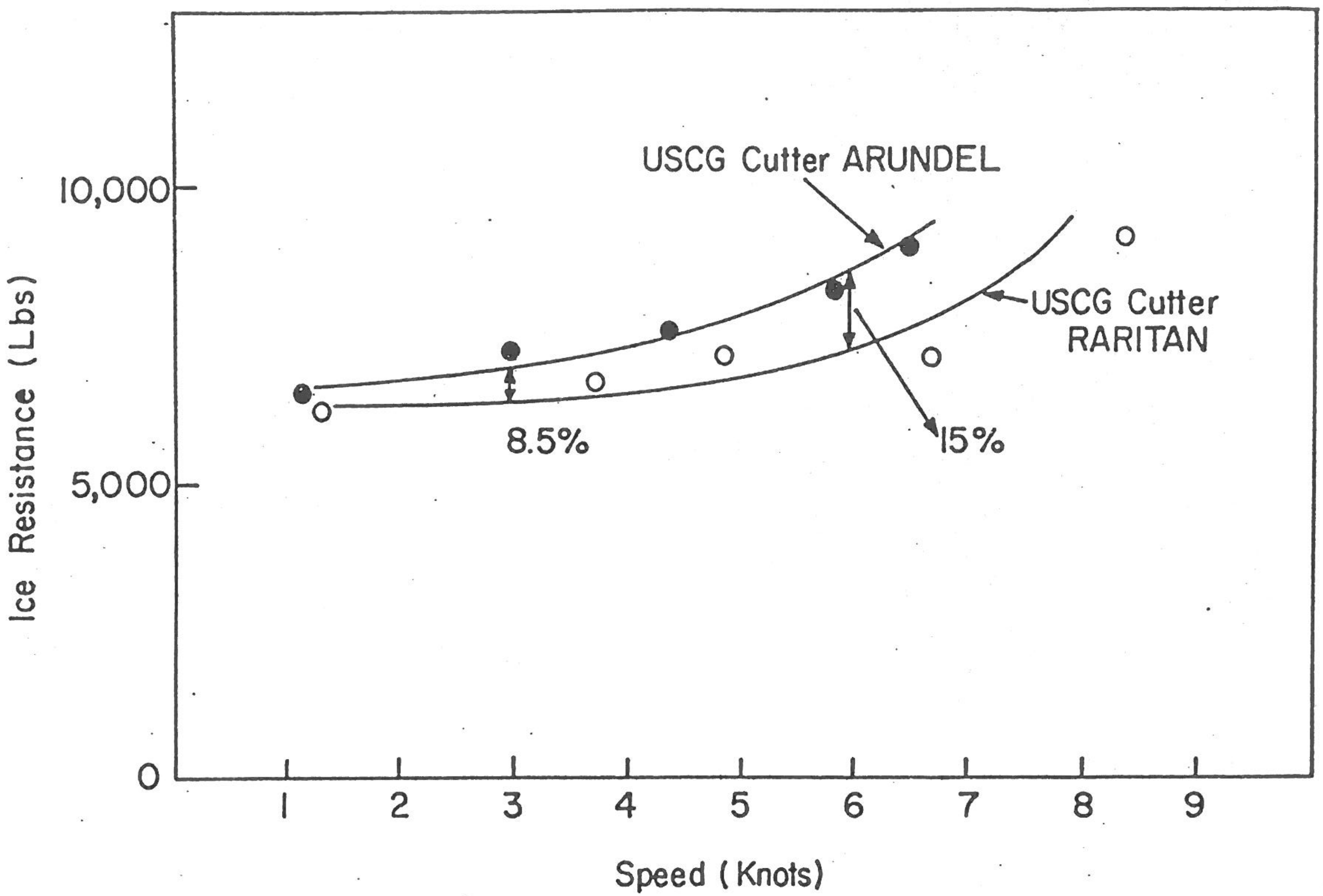


Figure 5 Results of Full-Scale Tests in Brash Ice

4.8 Foreign Icebreaker Tests

Several Finnish icebreakers have been coated with the Inerta 160 over the past few years. A visit was made to Turco, Finland to examine the hull of the KAHRU, a commercial icebreaker, and gather coating data in June 1976. The ship is 240 ft long and had seen approximately 800 hours of icebreaking during the previous season. The condition of the hull can be seen in Figure 13. The coating was removed near the bow and midship water line. The coating beneath the water line had several areas where corrosion was evident. The corrosion was evident at the top of asperities and in the weld areas. Approximately 90% of the hull was still coated but the 10% where corrosion had started was on random areas throughout the hull surface. As an experiment, two coats of Inerta had been applied on one area of the ship. In this area the coating had delaminated and a white scum formed between the two layers. The scum was a result of the absorption of CO_2 by the amine component in the Inerta 160. The CO_2 can unite with moisture forming a barrier which prohibits adhesion between coats.

4.9 Conclusions

Both nonsolvented coatings appear to have adequate properties to withstand icebreaking conditions. Both materials show wear patterns at the bow area near the water line. Hulls coated with Inerta 160 had several areas beneath the water line where rust was apparent. These areas include welds and the top of asperities near pits or other discontinuities. The Zebron coated vessels show no signs of rust leaching through the coating on the underside of the hulls. It is, however, apparent that an icebreaker can be coated with one of the above coatings and survive several years of service without significant damage or corrosion to the hull. In the case of the RARITAN the coating has protected the hull for four years of icebreaking service. That is certainly a significant improvement over the few hours of icebreaking that a conventional hull coating can survive.

- Zebron on primed aluminum
- Zebron on primed steel
- Zebron on unprimed aluminum
- Zebron on unprimed polyethylene
- Zebron on primed polyethylene
- Transite control panel.

The specimens were placed in the water for 11 months and exposed to fouling conditions. Figure 14 shows the condition of the panels as removed from the water. The upper photograph shows the severity of fouling as removed from the water while the lower photograph shows the panels after the specimens were cleaned. As expected, the Zebron had fouled severely. The surfaces contained both hard and soft-shelled organisms. There were some areas where organisms had built up to the point where they could not support their own weight and eventually fell from the urethane surface. The unusual characteristic about this material is its ability to be cleaned without surface damage. The specimens were cleaned with a wooden spatula and heavy wire brushes. Most of the organisms were removed from the surface without damage to the coating surface. Only the upper half of the panels were cleaned and only the coatings on the steel and aluminum were evaluated.

Photographs of the cleaned specimen are shown in Figure 14 (lower). There were some very small edge chips on the coated steel and aluminum specimens. The surfaces however were completely intact with no borer holes or evidence of any other damage.

The coated polyethylene had failed catastrophically. They had warped and the coating had separated from the surface. It was evident that little if any bond existed between the polyethylene and polyurethane. The transite control specimen disintegrated after removal from the water. Before placing the specimens back into the water, a line was scribed on the surface of all metal-coated specimens. The scratch was made so that the metal surface would be exposed. This was done to determine if fouling organisms could lift the coating after the metal surface was exposed. The scribe line is shown in the lower photograph of Figure 14.

The specimens were placed back in the water for approximately six months. Upon removal, it was found that they had fouled severely similar to the previous 11-month exposure. The attached fouling was slightly harder to remove this time, had worn .002" for the filled material and .0015" for the unfilled. The original coating thickness for both materials was .060".

The W2 epoxy gave poor results. The surface had worn .004"; some coating spalled at the edge and middle portion of the surface. The surface roughness increased from 60 μ" CLA to 128 μ" CLA.

The solvented polyurethane gave very low wear rate in the center of the test specimens (less than .001"). However, the edges had worn down to the steel surface. The surface roughness increased from 9 μ" CLA to 110 μ" CLA.

The Inerta 160 wore completely through at the end of the test. It should be noted that after 840 hours of testing the coating was completely intact. Once the coating started to wear, the wear rate had increased drastically until it had worn down to the steel substrate. The original coating thickness was .015".

A tabulation of the test results is given in Table 10. Photographs of the specimens are shown in Figure 21.

It is apparent from these tests that for light abrasion, the nonsolvented polyurethane gave the lowest wear rate and the least amount of damage. The solvented polyurethane which also gave a low wear rate, has a disadvantage in that the coating can only be applied to a thin dry film thickness (less than .010").

6.6 New Materials

Efforts to obtain new materials which would be suitable for use on hulls of icebreakers continued throughout the program. The materials which had been most successful to date were the nonsolvented coatings. This was attributed to their increased bond strength and wear resistance. Therefore, the emphasis was placed on nonsolvented coatings during this Phase of the program. There are many nonsolvented resin systems available on the market but few are sprayable or low enough in viscosity to be applied under dry dock conditions.

The materials which were examined are Aquacoat 28.05, manufactured by Citosan Ltd., Canada, glass-filled epoxy, manufactured by International Paint Company, copper cladded steel, developed by Copper Development Association, Inc. In addition, the data on Inerta 160 which was not generated during the Phase II portion of this program was completed.

Results of Long Term Wear Test

	100% Urethane	High Solids Epoxy
Surface Roughness Before Test (u inches)	34	9
Surface Roughness After Test (u inches)	102	185
Original Film Thickness (inches)	.030	.015
Wear Depth Specimen Center (inches)	.0015	.015
Remarks	No chipping evident	Material in the center section completely removed

TABLE 12

FRICTIONAL BEHAVIOR OF COATING MATERIALS

Material	30 lbs			50 lbs			90 lbs			150 lbs			200 lbs			Surface Roughness CLA	
	Breakaway	Static	Kinetic	Breakaway	Static	Kinetic	Breakaway	Static	Kinetic	Breakaway	Static	Kinetic	Breakaway	Static	Kinetic	Before Test (μ")	After Test (μ")
Aquacoat 28.05	.3	.25	.1	.3	.25	.1	.27	.24	.09	.29	.25	.09	.3	.26	.1	25.0	38.0
Glass-filled epoxy	.5	.4	.12	.45	.35	.1	.45	.35	.11	.42	.36	.12	.43	.33	.1	75.0	150.0
Copper clad steel	.4	.35	.11	.45	.3	.11	.5	.35	.1	.42	.25	.09	.45	.25	.09	0.6	4.5
Inerta 160	.3	.21	.08	.25	.21	.09	.26	.25	.09	.28	.25	.09	.32	.25	.09	65.0	68.0
Zebron (Phase II)	.12	.10	.04	.11	.11	.03	.11	.11	.04	.11	.11	.04	.12	.11	.04	75.0	75.0

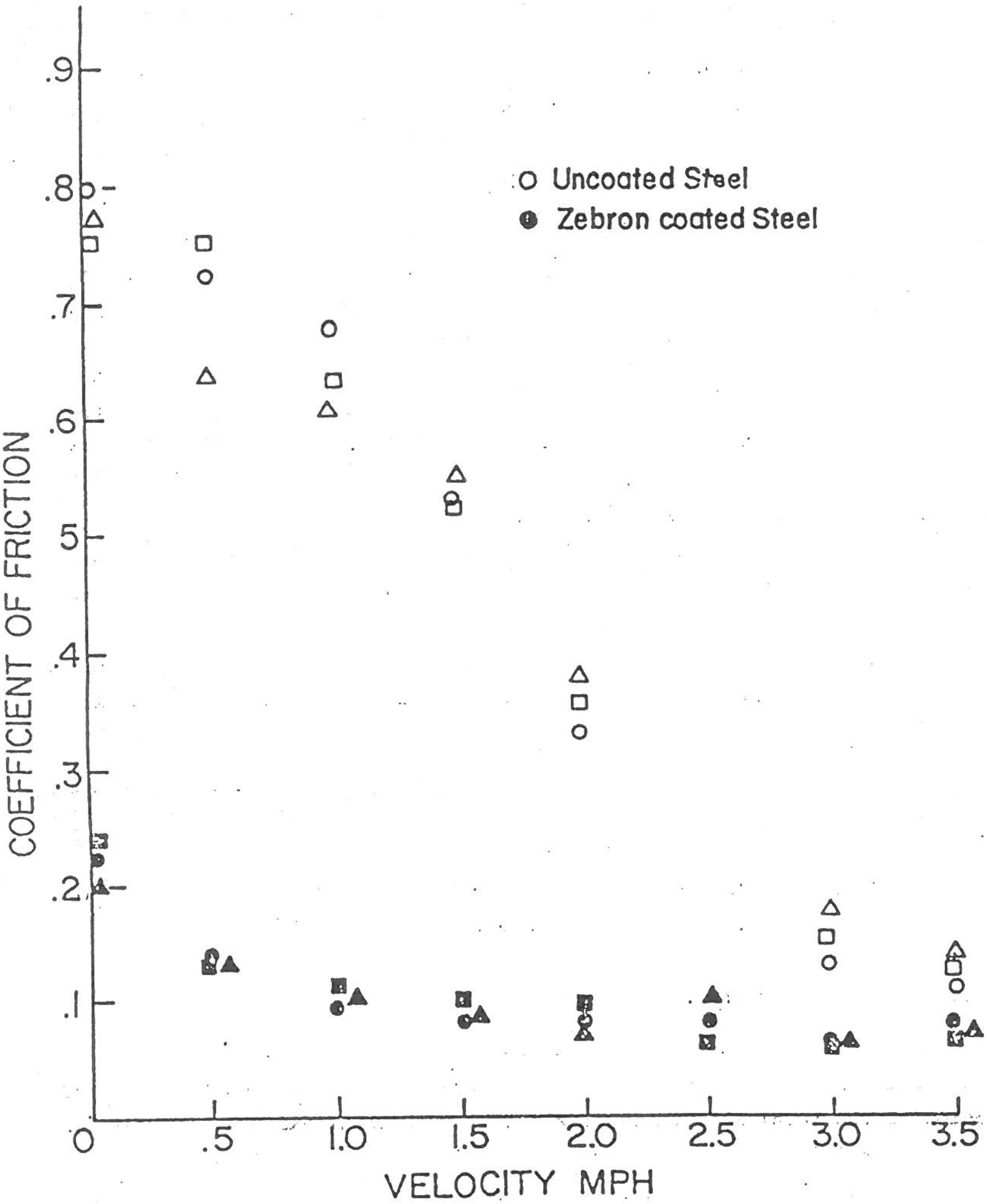


Figure 22 Comparison of the Friction Coefficient of Zebron Coated Steel and Uncoated Hull Plating as a Function of Velocity

8.2.1 Fuel Consumption

The fuel consumption for each operation mode can be calculated by the following formula:

$$FC = SFC \times BHP \times HRS/2240 \qquad (8\text{-}1)$$

where

FC - Fuel consumption (tons)

SFC - Specific fuel consumption (lbs/BHP/hr)

BHP - Brake horsepower

HRS - Time engine in operation (hours)

2240 - For changing dimension lbs - tons.

The annual fuel consumption for each icebreaker is tabulated in Table 15. The fuel consumption values shown after coating are based on x = 0.1 reduction in open water resistance and y = 0.3 reduction in ice resistance for old ships. This reduction could vary depending on the friction coefficient, and therefore a sensitivity analysis was performed on these variables.

TABLE 15

*NOTE → ANNUAL FUEL CONSUMPTION

Ship	Year In Cycle	Fuel Consumption Uncoated	Fuel Consumption Coated	Percent Saved
GLACIER	First	3305 (tons)	2851 (tons)	14.
(3 year cycle	Second	5249 (tons)	4582 (tons)	13.
operating scenario)	Third	3302 (tons)	2932 (tons)	11.
POLAR STAR	First	4479 (tons)	3909 (tons)	13.
(3 year cycle)	Second	6741 (tons)	5779 (tons)	14.
	Third	4075 (tons)	3568 (tons)	12.
POLAR SEA	First	4075 (tons)	3568 (tons)	12.
(3 year cycle)	Second	4479 (tons)	3909 (tons)	13.
	Third	6751 (tons)	5921 (tons)	12.
110' Class (1 year cycle)	First	519 (tons)	419 (tons)	19.
140' Class (1 year cycle)	First	1297 (tons)	1047 (tons)	19.

THE SOCIETY OF NAVAL ARCHITECTS
AND MARINE ENGINEERS
74 TRINITY PLACE
NEW YORK, N.Y. 10006

1 MAY 1975

COMMENTS ON PAPER "INFLUENCE OF FRICTION ON ICE RESISTANCE"
PRESENTED AT ICE TECH 75

We are encouraged by Wartsila's full scale test results and find that they are in general agreement with our own low friction coatings for icebreakers research program as documented in part by Report No. AD 784361 available from the National Technical Information Service.

The U. S. Coast Guard through its contractor, Rensselaer Polytechnic Institute, began in 19[illegible] with thorough laboratory testing of approximately 150 coatings of all types. These tests identified polyurethanes and polyphenylene oxide as potential icebreaker coatings.

Subsequent field tests on USCG icebreakers have demonstrated at least one coating system as being viable. Poor weather conditions during application of three other coatings probably contributed to their inferior performance and this emphasizes the importance of having good weather or a controlled environment during application. The successful coating was a solventless polyurethane marketed by Zenex Corporation, which was tested on the USCGC RARITAN, a 110 foot length cutter operating in the Great Lakes. It is interesting to note that the epoxy coating that Wartsila had success with is also solventless. The RARITAN tests not only showed that the solventless polyurethane could withstand the abrasive ice environment, but they also indicated a resistance reduction of up to approximately 25% in ice and some reduction in open water.

We are proceeding in our field test program by coating the USCGC MACKINAW with the same solventless polyurethane system. In order to prepare the rough bare hull which has pitting as deep as 1/4 inch, we will first trowel on the coating to smoothen the hull, and then apply a top coating up to 1/4 inch thich in high abrasion areas such as the bow and ice line. At this time we do not know what thickness is necessary, and we may experiment with a thinner coating on parts of the hull to help determine the minimum thickness necessary.

As indicated in Wartsila's paper, friction will vary with environmental conditions and vessel speed. Our lab tests have shown that there are three regimes of [illegible] breakaway, static, and kinetic, each with different fric[illegible]es for different surfaces. For a given surface, the coeffic[illegible]tion is dependent on roughness, temperature, and veloc[illegible] instance, we have found that for steel surfaces of 40 mic[illegible]LA roughness, the friction decreases sharply with increasing [illegible]ure from approximately - 8° to -3°C. Conversely, for stee[illegible]th 130 micro inch CLA roughness, a more realistic hull roughness[illegible]n ship friction first decreases and then increases sharply with increasing temperature from - 8° to - 3°C. Laboratory tests of the effect of velocity on kenetic friction have shown that for velocities less than about 1 1/2 mph, the <u>kinetic</u> coefficient of friction increases significantly.

The results of these tests further verify that the coefficient of friction, an important factor in icebreaker resistance, must be carefully simulated and controlled during model tests. We feel that there may also be a scaling effect on the coefficient of friction during model tests. That is [illegible] may not be appropriate to assume or indeed try to model the [illegible] coefficient for model tests as exist in the full scale or vice versa. Indeed, it may be incorrect to assume that the friction acting on an icebreaker can be expressed as coulomb friction, where the friction force is simply proportional to the normal force. We are pursuing laboratory and theoretical studies in this area.

To get a better handle on the [illegible] ent of friction acting on an icebreaker, we will be making [illegible] measurements during the upcoming USCGC POLAR STAR ice trials. [illegible] special test rig that allows measurement directly on the [illegible] hull at different locations with ice samples drawn from the test area will be used.

In conclusion, we must agree with Wartsila that special low friction coatings can significantly improve icebreaker performance. As constructive criticism on their paper, we would only suggest that they give more quantitative data on the temperatures and hull roughness existing during their full scale tests.

As promised by telecon 4/6-75.

G. ALMOND, B.Sc., C.Eng.
PRINCIPAL SHIP SURVEYOR FOR CANADA

LLOYD'S REGISTER OF SHIPPING
SUITE 50, 400 CRAIG STREET WEST
MONTREAL

849-4291

RALPH BUXTON
Project Officer
Office of Research and Development
U.S. Coast Guard

REF. NO. 2.

OTC 3157

THE OPERATING AND MAINTENANCE BENEFITS OF ABRASION RESISTANT LOW FRICTION HULL COATINGS

by Gordon D. Marsh and Robert W. Gulick, U.S. Coast Guard, and S.J. Calabrese, Rensslear Polytechnic Institute

This paper was presented at the 10th Annual OTC in Houston, Tex., May 8-11, 1978. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words.

DISCLAIMER

The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Commandant or the U. S. Coast Guard.

ABSTRACT

This paper presents the results of research carried out by Rensslear Polytechnic Institute for the U. S. Coast Guard to identify abrasion-resistant, low-friction hull coatings for vessels that must transit or operate in ice-covered waters. Past efforts by RPI for the Coast Guard have identified two component solventless coatings as having both high bond strength and abrasion resistance. In this effort further tests were conducted to identify application and maintenance problems that could occur when using these coatings in a marine environment. An economic analysis of the coatings on four different Coast Guard vessels was conducted.

Laboratory and field tests were carried out to determine the antifouling properties and to reveal the actual environmental limits for successful application of the two most promising coatings. Results show that while the coatings do not inhibit fouling without a topcoat of antifoul marine growth is not able to penetrate the coating and the surface is relatively easy to clean. The economic analysis shows that the use of low-friction hull coatings can result in savings of up to 20 percent. The economic analysis considers coating costs, hull maintenance costs, and fuel savings.

Possible applications for abrasion-resistant coatings include offshore structures and vessels that must operate in the presence of ice or heavy silting. Other promising applications include piping systems that carry slurries or abrasive-laden fluids.

INTRODUCTION

Historically the hulls of Coast Guard icebreaking vessels have not been coated. Past decisions not to invest in a coating system have been based on the poor performance exhibited by conventional antifoul and corrosion preventive coatings when subjected to the extreme climate and the frequent contact with ice, and not from any lack of a need for such protection. A bare steel hull is constantly exposed to the abrasion of the ice, high levels of chemical pollution in many harbors and waterways, and the seasonal problem of marine fouling. The result of this abuse is hull deterioration in the form of plate pitting and weld erosion. Hull deterioration in turn results in a larger than necessary scantling design margin, more frequent hull repair, and increased frictional drag. The increased fuel consumption and additional hull maintenance represent increased costs for a vessel type that already incurs substantial fuel and maintenance costs due to its mission requirements.

Recognizing the potentially large benefits to be gained from reduced corrosion and lower fuel consumption, the Coast Guard in 1972 contracted with Rensslear Polytechnic Institute (RPI) to evaluate the new coating systems that are constantly appearing on the market and identify abrasion-resistant low-friction coatings for use on icebreakers and ice transiting vessels. In Phase I of this program, over 100 coatings were laboratory tested for abrasion and low-friction characteristics. Five feasible coatings were identified for testing.[1] In Phase II of the program, the most promising coating systems were applied to Coast Guard vessels for a field evaluation. This phase included theoretical and laboratory work on understanding the role of friction on icebreaking, and continued laboratory testing of new coatings.[2] The two most promising coatings were found to be a solventless polyurethane and a two-component filled epoxy system. Phase III of the program, which is the subject of this paper, is complete now. In this phase, the effects of environmental conditions on the success of coating applications were investigated. The antifouling properties of the two most promising coating systems were evaluated on various substrates. And an economic analysis of the hull-coating systems and their cost/benefits was conducted. This analysis included side-by-side tests of coated and uncoated

References and illustrations at end of paper.

vessels on icebreaking operations to determine the potential fuel savings that could be achieved with a coated hull.

SELECTION OF MATERIALS

In the initial effort, most of the major marine coating manufacturers were requested to suggest and supply test samples. Polymer manufactures and metal coating applicators were included also. The only criterion used for screening materials during the selection stage was, "could the material be applied to the hull of a ship in a dry dock environment?" In some cases, solids were evaluated, mindful that a coating could be developed at a later date if the material was successful during laboratory testing.

The testing program consisted of the following tasks: determine the surface damage during icebreaking, determine the various conditions that have an effect on the ice friction against steel, determine the friction coefficient of the candidate materials sliding against solid and particle ice under various conditions, determine the bond strength of the coating to a steel substrate, and determine the relative wear rate of the candidate coatings against ice.

The most important property required was the coating's ability to withstand icebreaking without significant damage. All coatings were applied by the respective manufacturer to eliminate the application variables.

LABORATORY TESTS

The icebreaking evaluation was run on a modified rock crusher that had been converted to accept ice chunks. A comparison of the surface roughness before and after exposure to breaking ice chunks was used to establish the coating's surface damage characteristics.

The frictional properties of the materials sliding against ice were studied on a test apparatus manufactured for this program. It consisted of a coated ring specimen sliding against ice. The resistance to sliding was measured by means of a strain gauged torque arm. The temperature, humidity, time in contact, load, and velocity were controlled during testing. In addition, the ice condition (solid, particle, etc.) and the surface roughness of the test specimen were controlled. Table A shows the parameters investigated and their effect on the frictional properties.

As a result of the laboratory investigation, six materials were selected for full-scale testing. They were (1) nonsolvented polyurethane, (2) nonsolvented epoxy, (3) polyurethane - solvented - elastomer, moisture cure, (4) polyurethane-solvented, rigid, chemical cure, (5) polyurethane - solvented, rigid, moisture cure, and (6) glass flake polyester.

All of the above materials were applied to icebreaker hulls. The nonsolvented polyurethane and the nonsolvented epoxy gave the most promising results.

FULL-SCALE TESTS

The nonsolvented polyurethane was applied to the Coast Guard cutter RARITAN during July 1974. After 1 year of icebreaking service (over 600 hours icebreaking), approximately 98 percent of the coati was still intact. Fig. 2 (upper) shows the total extent of the damage seen after 1 year of service. Fig. 2 (lower) shows the extent of the damage afte years service (over 2,000 hours icebreaking). Note that in Fig. 2 (upper) the coating (higher po n of the hull) only extended to the water line. e portion above the water line at the bow was no coated during the original application. After the first year of service, it was decided to extend th coating at the bow to the first bumper. As an expe ment, the polyurethane coating was applied by roll or brush rather than by spray, as was the original application. Most of the damage seen at the bow a in Fig. 2 (lower) is on the coating applied by bru The original line, cut in, during the spray applica tion is still visible. The interface between the spray application and the brushed-on coating is illustrated by a dotted line in Fig. 2 (lower).

The nonsolvented epoxy was applied to the hul of the Coast Guard cutter OJIBWA on Oct. 10, 1976. The coating was applied under a polyethylene tent arrangement due to the low ambient temperature in Great Lakes area at that time of year. Essentially the entire bottom portion of the dry dock extendir from the ship deck down, was protected from the weather. During the coating application, the outs temperature was 30°F and it was snowing heavily. However, the area beneath the tent was heated with four large space heaters and the conditions during the coating were 60°F and 58-percent relative humidity. A similar arrangement used during the application of the nonsolvented epoxy to a large tanker is shown in Fig. 3. The poor weather conditions (heavy snow) would not allow satisfactory photographs to be taken from outside the tent i the hull coating of the OJIBWA.

After 358 hours of icebreaking, the ship was returned to the dry dock and the opportunity was taken to examine the hull. Fig. 4 shows the extent of the damage at the bow and on the keel near the stem where the ship had apparently grounded during service. The damage seen on the cutter OJIBWA after 358 hours of icebreaking service was slightl more than was seen on the cutter RARITAN after 60C hours of service. However, the nonsolvented epoxy performed very well since greater than 98 percent of the coating was still intact.

It should be noted that the cutters RARITAN a OJIBWA are sister ships, having the same hull configuration and both see icebreaking service in Great Lakes. The ship's specifications are as follows: 100 ft long, 27.3-ft beam, 12.25-ft draf and 384 tons maximum displacement.

ENVIRONMENTAL LIMITATION OF BOTH MATERIALS

Both materials gave encouraging results in full-scale tests. Both have advantages and limita tions. Since hull coating has to be done in a dry dock environment, the application is always at the mercy of the weather conditions. Most coating manufacturers specify that the material should not be applied at conditions below 60°F and above 10-percent relative humidity. In many cases, the coat can be held up for several days until favora weather conditions occur. There also are tim nc the coating is applied under marginal weather conditions or when a sudden change in weather will occur during or following the application. The immediate question is how will the change in weather affect the curing and the final properties of the coating. Therefore, a series of tests were established to determine the range of conditions that could be tolerated without seriously affecting the properties of both coatings. The coating was applied at various temperatures from room temperatures to 10°F and at relative humidities varying from 30 percent to 100 percent.

The results showed that the epoxy has a much more limited range of application conditions than the polyurethane. The epoxy would not set up completely at temperatures below 45°F. The polyurethane would set up at 25°F. Both materials could be frozen solid after application but before curing, but when the temperature was raised, the cure cycle would continue. After freezing and subsequent curing, the epoxy coating gave a slight decrease in bond strength. The polyurethane coating showed no change. At one point, moisture was allowed to condense on the uncured coating. The condensed moisture had no effect on either the epoxy or the polyurethane.

It should be noted that the nonsolvented polyurethane coating must be applied over a vinyl phenolic primer, while the nonsolvented epoxy is applied on the unprimed grit blasted steel. All of the above comments are pertinent to the vinyl phenolic primer coat except moisture contamination. If the vinyl phenolic primer is contaminated by moisture, the bond to the polyurethane topcoat will be marginal or poor. Therefore, the most critical step in coating with the polyurethane is the primer application and cure.

As a result of the above tests, it is evident that the application of the epoxy hull coating in the Great Lakes area is marginal between the months of October to April without the use of an environmental tent arrangement that was discussed earlier. The application of the polyurethane is less critical and unless the temperature drops to 25° or lower, the coating will cure uninterrupted. If the temperature does drop, curing will be inhibited but will accelerate again when the temperature increases with little or no sacrifice in properties.

MARINE FOULING EVALUATION

During the field tests, it was noticed that the vessel hulls could be cleaned after service without any apparent damage to the coating. However, since most of the field testing in Phase II was done on the Great Lakes with fresh-water ice, little information was available on the fouling tendencies of the solventless epoxy and polyurethane materials. Therefore, it was decided to evaluate test panels prepared with these two coatings. These materials applied to various substrates were tested at the Battelle Memorial Institute marine facility at Daytona Beach, Fla., and the Long Beach Naval Shipyard at Terminal Island, Calif. The Battelle facility was available through an on-going Coast Guard program to evaluate antifoul coatings for navigation aids. Long Beach was selected since this was the home port for two of the West Coast icebreakers.

Since no traditional antifoul chemical inhibitors were included in either coating formulation, an ability to prevent marine growth was not expected. However, since the coatings were known to be abrasion resistant, it was hoped that the marine growth would be unable to penetrate the coatings and would be relatively easy to remove and that the anticorrosion property of the coatings would remain intact. This would be a distinct advantage over conventional coating systems where the antifouling and anticorrosion performance are closely related.

The first set of test panels, consisting of ZEBRON polyurethane on substrates of steel, aluminum and plastic were placed in the water at Battelle in Nov. 1975. They were pulled for cleaning and inspection in Sept. 1976 and removed for shipping to RPI in March 1977. As predicted, the Zebron had fouled severely by September. The surfaces contained both hard- and soft-shelled organisms. There were some areas where the organisms had built up to the point where they could not support their own weight and eventually fell from the urethane surface. As expected, the unusual characteristic of the material was its ability to be cleaned without surface damage. Cleaning was accomplished with a wooden spatula and heavy wire brushes. Before placing the specimens back into the water, a scratch line was scribed to expose the substrate on the surface of all the metal substrate specimens to determine the resistance of the coating to lifting by fouling organisms. Fig. 5 shows the test specimens after cleaning. The scribe mark is clearly visible. When the test panels were removed in March, the fouling could still be removed manually, but it was slightly more difficult than the previous cleaning. The surfaces were somewhat scratched but no significant removal of coating material was noted. The scribe lines were still evident and very little, if any, corrosion had taken place beneath the surface adjacent to the lines. The fouling organisms did not appear to be able to lift the coating.

A rack of test panels coated with Inerta 160, Zebron, and Zebron with an antifoul topcoat on steel substrates was placed in the water off Pier 6 in Long Beach, Calif., during Nov. 1976. These specimens were pulled for inspection in late Feb. 1977. Fig. 6 shows the condition of the test panels. The amount of fouling was not significant and both specimens could be cleaned by hand brushing the surface. No damage could be seen on any of the surfaces. The Zebron panel with a topcoat of antifoul had only a scum on the surface, which was easily wiped off. Unfortunately, this test panel could not be relocated for removal in Nov. 1977. Because of this loss, it was decided to conduct another test series at Battelle.

Nine test panels consisting of coatings of Inerta 160, with and without an antifoul topcoat, filled Zebron, unfilled Zebron, and unfilled Zebron with two different antifoul coatings on substrates of aluminum and steel recently were sent to the Daytona Beach facility. These panels will be evaluated over a 3-year period.

Underwater hull cleaning has not received wide industry acceptance, since with conventional coatings removal of the fouling caused damage to the coatings. Without any coating repair the vessels then experienced an increased fouling rate and hull corrosion. This would not be the case with either of the two solventless coatings. The unusual ability of these

Several points should be noted, when considering that the original coating was applied in 1974.

A. The ship had seen service in fresh water throughout most of the time in use. However, the last year it was in salt water.

B. There was no marine growth attached below the water line. In areas where algae or grass had attached itself (upper photos Figure 2), it was washed off with water.

C. In areas where the coating was still intact, there was no rust bleed through and no indication of corrosion beneath the coating.

D. Cavitation and erosion were evident on the rudder and stern portion of the bare steel hull. After the nonsolvented polyurethane was applied, that problem no longer exists. There was essentially no damage to the coating in areas where cavitation was a problem before the coating was applied.

E. There was no evidence of weld decay. Greater than 90% of the welds were still protected.

F. There was no need to replace any hull plating after 7 years of continuous service without hull maintenance, (except for the problem in 1976) and no evidence that hull plating would be needed in the near future.

G. Areas where the coating was still intact below the water line had coating thicknesses of between .025 and .030" as opposed to between .030" and .040" when the coating was first applied.

As a result of the overalll evaluation it can be concluded that the iceline coating had suffered severe damage while the coating below the ice line had continued to protect the hull for 7 years with no indication that it will break down in the near future.

Conclusion

It can be concluded that for this size ship, the nonsolvented polyurethane gave excellent hull protection below the ice line for a period of 7 years service with no indication that major maintenance would be required in the near future.

CHARLES L. SWEET, P.E.
Consultant - Civil
610 NEW MEXICO STREET • P. O. BOX 716
BOULDER CITY, NEVADA 89005
TELEPHONE 702 — 293-2521

COPY

31 August 1972

Attention:

Dear

In accordance with your request, I have reviewed the test data submitted to Lear Siegler, Inc by Testing Engineers, Inc, Santa Fe Springs, California on June 30th, 1971.

These data relate to results obtained using standard hydraulic stability or vapor test on six specimen samples of "Crandalon." This test was performed as an accelerated aging test to obtain a longevity rating on the coating system by the U. S. Navy. The maximum rating of 20 years life is assigned to any material retaining 50 percent of its initial Shore A Hardness at the end of 30 days.

Assuming a straight line relationship of 1 test day equals 0.645 years of service life above a 50 percent effectiveness, as shown on the accompaning graph, the half life of "Crandalon" is 37 years. This indicates the coating system will be half as effective at the end of 37 years as when applied and when subjected to normal atmospheric and weather conditions. The graph further indicates that an effectiveness of 30 percent will be achieved at the end of a 50 year period.

The data show an inconsistency for the 24 day readings which are higher than can be reasonably expected. This is not uncommon in laboratory testing and the readings for this data have been ignored in the above analysis.

Yours truly,

C. L. Sweet, P.E.

CLS/es

Enc

ZEBRUN T.M. *Formerly Known as* CRANDALON

LSI--CR171
May 24, 1971

TEST SPECIFICATION

CRANDALON HYDROLYTIC STABILITY

1. SCOPE: This specification covers a test procedure for measuring the hydrolytic stability of a polyurethane coating called Crandalon.

2. PROCEDURE:

   1. Prepare 6 die cut samples of Crandalon per ASTM D412.

   2. Place 150cc of water in a quart jar.

   3. Add sufficient Potassium Sulphate to maintain 90 - 95 percent relative humidity in the air space in the jar.

   4. Measure the Shore A hardness of the Crandalon samples.

   5. Suspend the 6 samples in the air space in the quart jar. The jar must be vented and additional water must be added periodically to maintain 150cc in the jar.

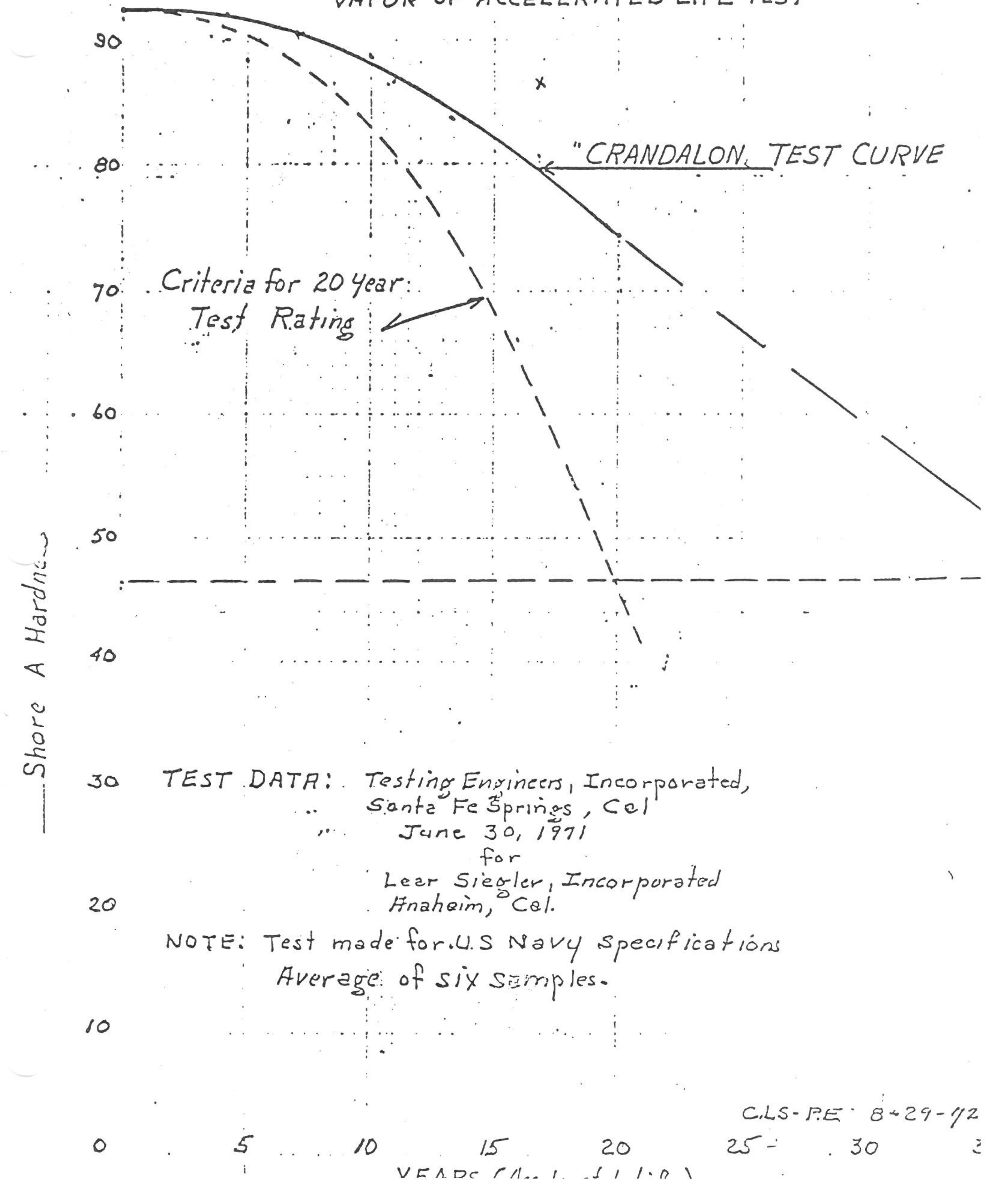
   6. Place the entire jar in a circulating air oven set at a temperature of 200-5^{o} F.

   7. Every 5 days (approximately) remove the samples, dry, and measure the Shore A hardness.

   8. Stop the test on the 30th day or when the Shore A hardness has decreased to less than half of the initial value.

3. REPORT. Report the Shore A hardness of the six samples as measured initially and at 5 day intervals for 30 days.

HYDRAULIC STABILITY TEST
VAPOR or ACCELERATED LIFE TEST



ADVANTAGES OF ZEBRON LOW FRICTION HULL COATINGS

1. LOW FRICTION :

The Zebron breakaway coefficient of friction is ¼ that of uncoated steel. It is unlikely a Zebron coated ship will become stuck in ice. Ref. No. 1 P.64 Fig 22.

The Zebron kinetic coefficient of friction is 1/3 that of uncoated steel and ½ that of conventional epoxy paints resulting in reduced hull resistance of 8.5% at 3 knots and 15% at 8 knots through slush ice. Average fuel savings of 15% have been documented by the U. S. Coast Guard for Zebron coated ships with savings as high as 20% in ice and 12% in open water. Ref. No.1. P.62, Table 12, P.64 fig.22, P.13 Fig 5, Pg.72 Table 15; Ref.No.3. P.1, P.7, P.8.

2. ULTRA HIGH ADHESION :

Adhesion of Zebron to steel is ten times greater then that of conventional coating systems resulting in excellent resistance to even the severest impacts. Ref.No.5 Fig.1, Fig.4.

3. EXCELLENT CORROSION PROTECTION :

Due to high bond strength, high film build, excellent abrasion and impact resistance, Zebron virtually eliminates weld decay and plate corrosion. Ref.No.1. Pg.34; Ref.No.6. P.3.

4. EXCELLENT ABRASION RESISTANCE :

Zebron has a wear rate in ice that is ten times better than that of mild steel and pure epoxy, epoxy having a similar wear rate as mild steel. Ref.No.1. P.55, Table 10; Ref.No.5 P.13, Fig.5.

5. LOW ICE ADHESION :

Maximum bond strength of ice to Zebron is 6 psi, which is 1/5 of the bond strength ice has to epoxy coatings. With low ice bond strength Zebron adds a measure of insurance to Zebron coated vessels operating in northern waters. Ref.No.5.P.16, Fig.5, Fig.6; Ref.No.4. P.43, Table 3.

6. SELF ANTIFOULING :

Marine organisms cannot penetrate the coating and are removed under their own weight or by water pressure equal to that that is experienced above 10 knots. Ref.No.1. P.37; Ref. No. 2. P.1.

7. EXCELLENT INTERCOAT ADHESION :

Zebron has excellent adhesion to itself, damaged areas can be repaired with hand applied Zebron #385 with excellent results at any time throughout the long life (37 ½ years) of the Zebron product. Ref.No.5. P.5, P.6.

8. APPLICATION FLEXIBILITY :

Because Zebron is a 100% solids material, it can be applied to film builds of 20-mil thickness to 250-mil thickness in a single application. Where more then 20-mils is required, Zebron can greatly reduce the application time of more conventional coating systems. Zebron has zero volatile organic compounds, so solvent entrapment is not a concern when building mil thickness.

Zebron will cure at temperatures just above freezing. Conventional epoxy systems require temperatures above 10 degrees C to cure thoroughly. Ref.No.2. P.940, P.941.

REFERENCES

1. "Low Friction Hull Coatings for Icebreakers, Phase III Technical Rreport No. CG-D-69-FB", S.J.Calabrese and F.F.Ling, Dept. of Mechanical Engineering, Rensselaer Polytechnic Institute, Troy, N.Y., 1978.

2. "The Operating and Maintenance Benefits of Abrasion Resistant Low Friction Hull Coatings", presented at the 10th annual Offshore Technology conference, Houston, Texas, 1978, by F.Marsh, R.Gulick, S.J.Calabrese.

3. "Recent Advances in Energy Savings Achieved in Icebreaker Operations", LCDR Dennis M. Egan, U.S.C.G., A.M. 1982.

4. "Evaluation of Two Icebreaker Hull coatings for Arctic Petro Carrier Project", S.J.Calabrese.

5. "Evaluation of the Physical Properties of Zebron ™ Nonsolvented Polyurethane Coating on Steel", S.J.Calabrese, 1983.

6. "Examination of the U.S.C.G. Cutter Raritan After Several Years of Icebreaking service", S.J.Calabrese.

VESSEL : CANADIAN PIONEER

OWNER : UPPER LAKES SHIPPING COMPANY LTD.

SHIPYARD : PORT WELLER DRYDOCKS LTD.

CASE HISTORY : No. 13.

1.

One year service

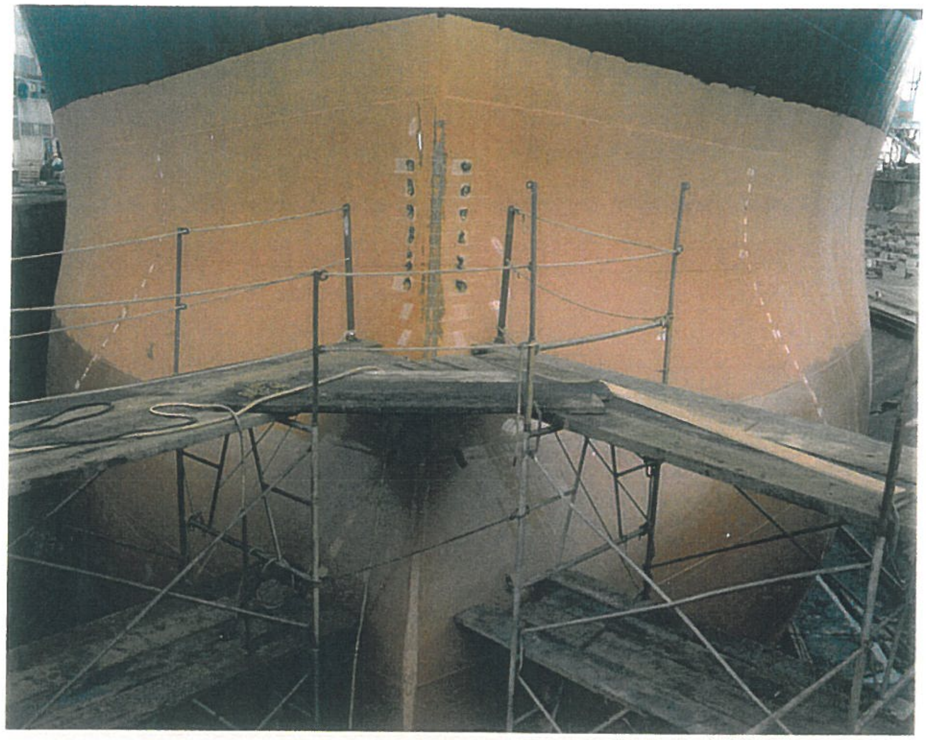
Zebron Bow -
Excellent condition.

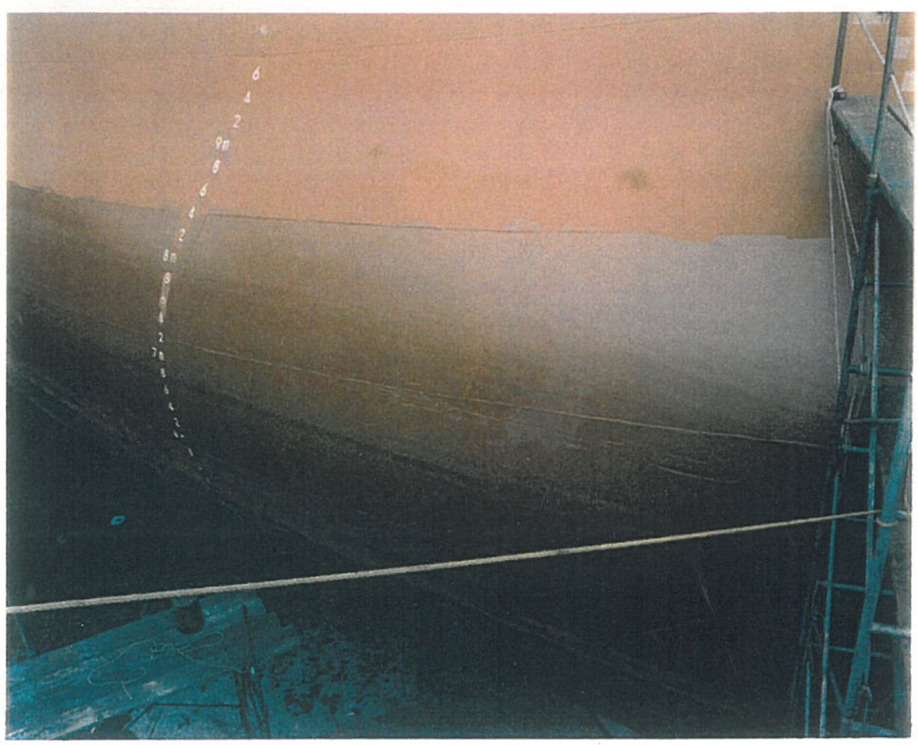
Five Coat Epoxy System -
Completely removed.

2. & 3.

Two years service.

1984 Docking.



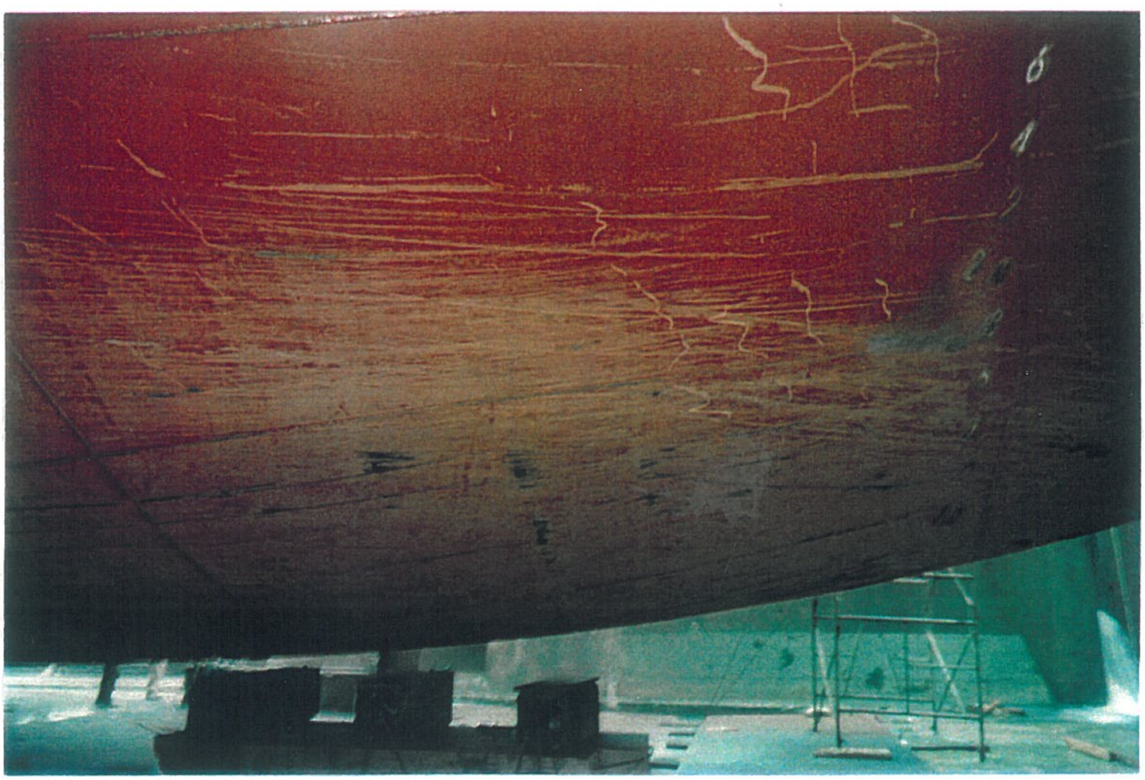


4. & 5.

Two years service.

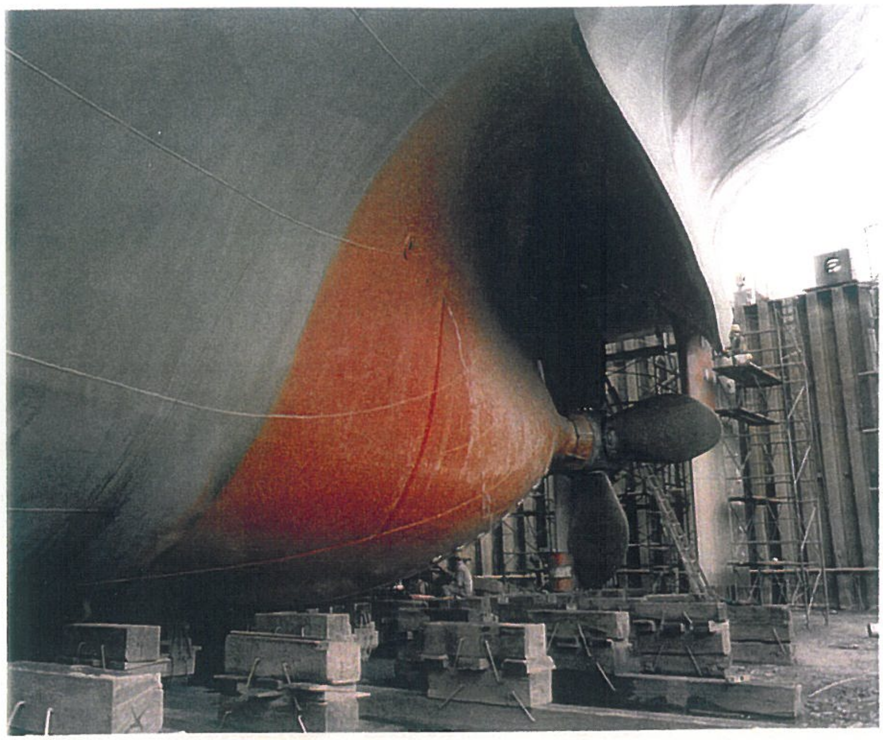
1984 Docking.

Limited damage to coating where ship touched bottom. Coating did not peel and resisted the extreme abrasion.



6. & 7.

Two years service
1984 Docking.
Stern coating undamaged.



VESSEL : DES GROSEILLIERS, Class III Icebreaker.

OWNER : CANADIAN COAST GUARD

SHIPYARD : PORT WELLER DRYDOCKS LTD.

CASE HISTORY : No. 6.

8.

Ship originally coated 1982.

1985 Docking.

9. & 10.

3 years service breaking up to 5 meter thick ice.

1985 Docking:
 Versatile Vickers Shipyard, Montreal.

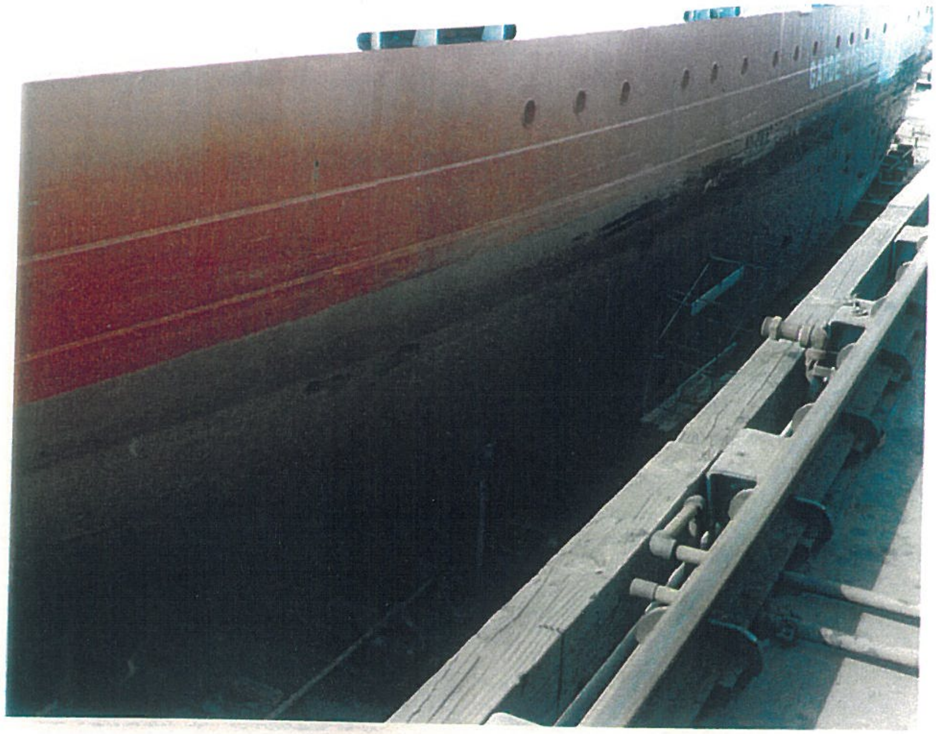
Port side:
 Max. loss due to ice damage - 10%

11. & 12.

Stern:
Coating virtually undamaged.

13. & 14.

Starboard side:
Max. loss due to ice
damage : 10%



VESSEL :	WESTWARD VENTURE
OWNER :	TOTEM OCEAN TRAILER EXPRESS
SHIPYARD :	VERSATILE PACIFIC SHIPYARDS LTD. Victoria Division.
SERVICE :	Weekly service from Tacoma to Anchorage 20 knot speed through brash ice.
CASE HISTORY :	No. 17.

15.

Coating trial:

Ship received a 50 sq.m. patch of Inerta 160 high solids epoxy to starboard bow and a 50 sq.m. patch of Zebron to port bow in Victoria during JAN.1982. The epoxy system required a heated environment during application and curing.

16. & 17.

After one year service the epoxy is worn through in several locations.

18.

One year service:

Weld corrosion evident on epoxy.

One year service:

Zebron in excellent condition.
Slight wear at raised weld only.

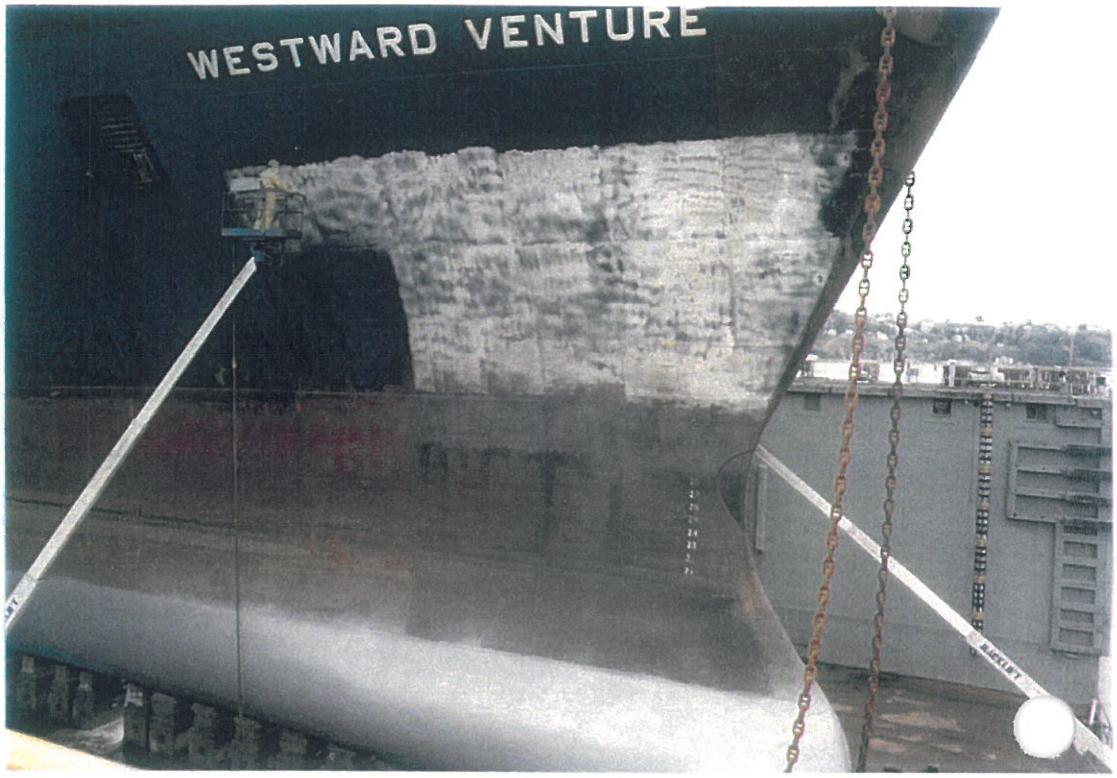
20.

Two year service:

1984 Docking:

Todd Shipyard,
Seattle, Wa.

Epoxy completely removed.



21. & 22.

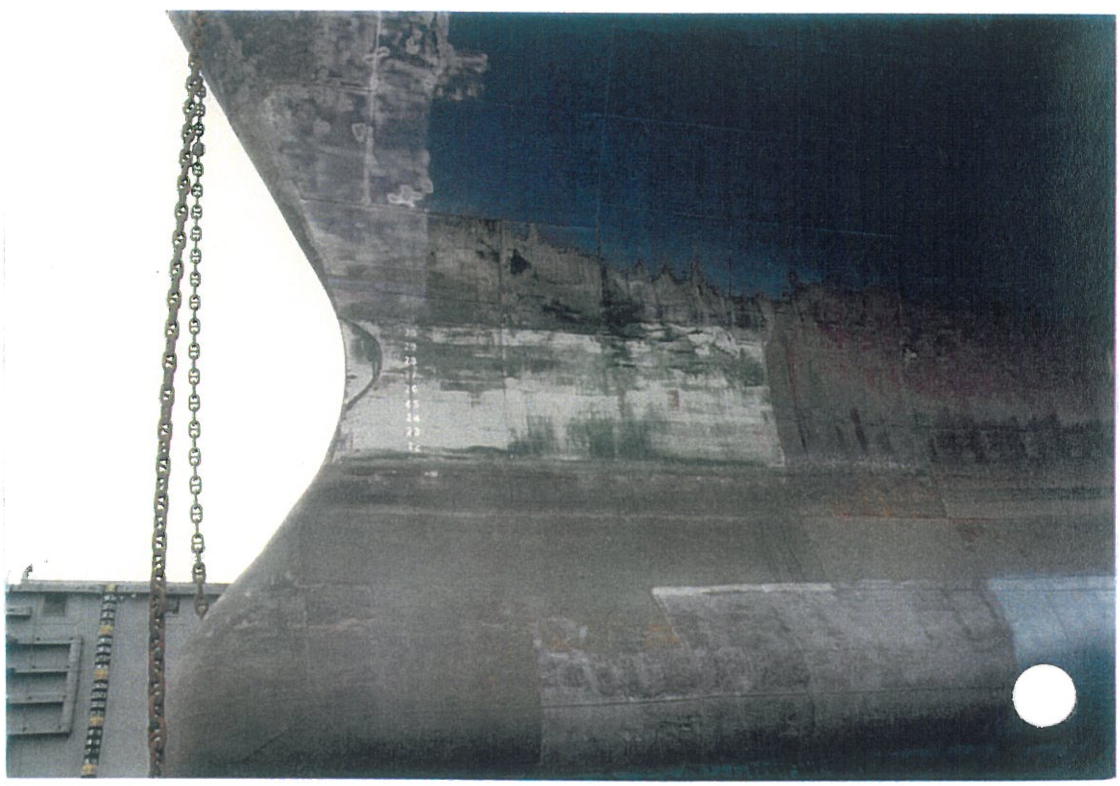
Two years service.

1984 Docking.

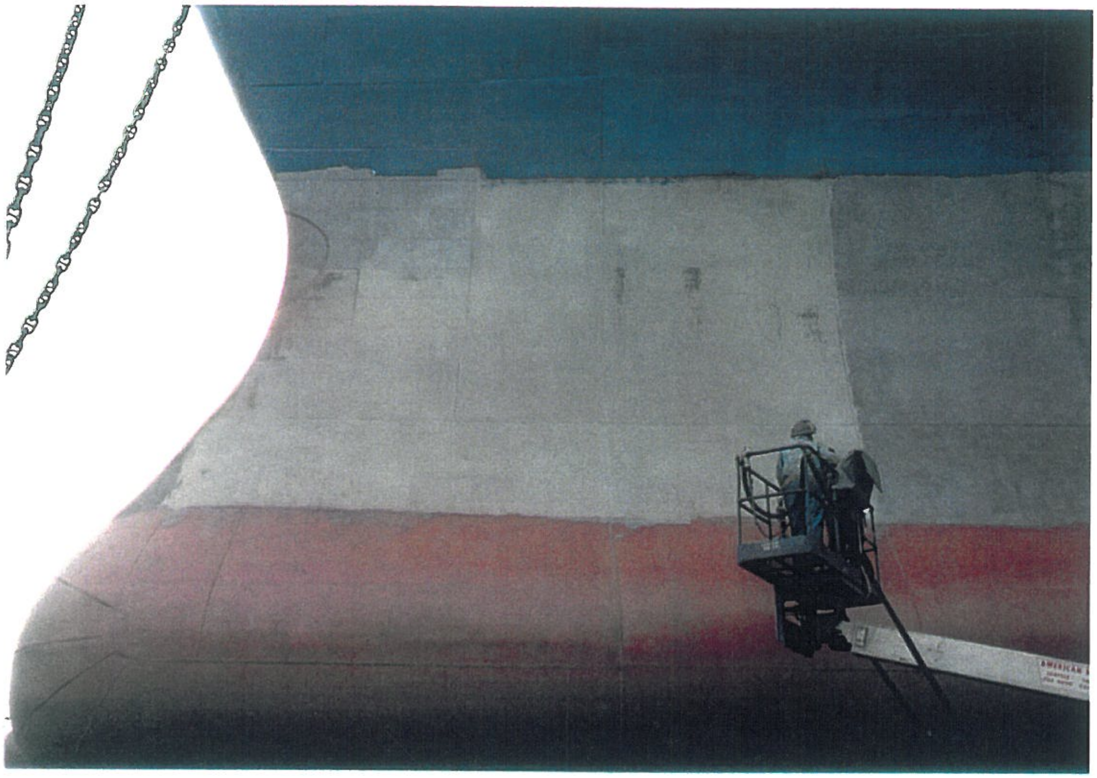
Zebron in excellent condition could not be grit blasted from surface without great difficulty.

21. NOTE:

Max. extent of fouling.



22.



23.

As a result of this trial Zebron has been applied to the ice belts of both of Tote's container vessels. A program is currently underway to extend the low friction coating over their underwater hulls.

VESSEL : KULLUK.

OWNER : GULF CANADA RESOURCES INC.

SHIPYARD : MITSUI MINING AND SMELTING,
TAMANO YARD, TAMANO, JAPAN.

SERVICE : ARCTIC DRILLING. BEAUFORT SEA.

CASE HISTORY : No. 7.

APPLICATION : Zebron applied to entire underwater hull including moon pools during 1982-1983.

24.

Fabricated boxes were shop coated up to 6 months prior to coating the erection welds and seams in the dock.

Resulting intercoat adhesion was excellent.

VESSEL: MOLIKPAQ.

OWNER : GULF CANADA RESOURCES INC.

SHIPYARD : I.H.I. CHITA WORKS.
CHITA CITY, JAPAN.

SERVICE : ARCTIC DRILLING. BEAUFORT SEA.

CASE HISTORY : No. 8.

APPLICATION : Zebron applied to ice belt during 1982/83.

26.

Zebron applied to box sections.

27.

Box sections then welded into erection panels.

28.

Erection panels were welded into place several months later with joint coating performed up to one year after shop coating of box sections.

29.

Coating performance in Beaufort Sea during second ice season.