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QUALIFICATION OF STAINLESS STEEL FOR OTEC HEAT EXCHANGER TUBING

F. L. LaQue

MASTER

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

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Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

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F. L. LaQue
Claridge Drive
Verona, New Jersey 07044

January 1979

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F. L. LaQue

ABSTRACT

This paper reviews the history of the AL-6X alloy and examines its credentials as a candidate for use as tubing in Ocean Thermal Energy Conversion Heat Exchangers. Qualification is based on results of accelerated tests using ferric chloride for resistance to crevice corrosion and pitting, long-time crevice corrosion and pitting tests in natural sea water and anticipated resistance to attack by ammonia and mixtures of ammonia and sea water.

Since the alloy has no natural resistance to fouling by marine organisms, it must be able to accommodate action to prevent fouling by chlorination or to remove it by mechanical cleaning techniques or appropriate chemical cleaning methods.

The satisfactory behavior indicated by the various accelerated and long-time corrosion tests has been confirmed by excellent performance of several million feet of tubing in condensers in coastal power plants.

Early evaluation tests demonstrated the need for proper heat treatment to avoid the presence of a sigma phase, which promoted severe pitting of some, but not all, specimens in tests in natural sea water.

The available data qualify the AL-6X alloy as being a satisfactory alternate to titanium for tubes in OTEC heat exchangers.

I. INTRODUCTION

The purpose of this paper is to examine the credentials of highly alloyed stainless steel materials as candidates for tubing in OTEC heat exchangers.

This class of material is represented primarily by the alloy known as AL-6X. AL-6X is the trade name of a product of the Allegheny Ludlum Steel Company. The nominal composition of AL-6X is 24% Ni, 20% Cr and 6% Mo.

Other alloys that appear to be worthy of consideration include one containing 26% chromium and 1% molybdenum, and others containing 25% or more chromium with various percentages of molybdenum and nickel. These other alloys have performed well in some screening tests and in exposure to natural sea water. Results of trial installations are not yet available.

At the present time, the AL-6X alloy has been qualified above the other alloys by reason of more extensive evaluation and, more importantly, by

successful large scale practical use in service pertinent to OTEC heat-exchanger applications. Consequently, this paper will concentrate on qualification of AL-6X as a representative of alloys of similar composition that may be offered by other suppliers for use as tubing in OTEC heat exchangers.

This effort is needed in view of questions that have been raised recently based on a few instances of poor performance of the alloy in evaluation tests and of a few tubes in a particular service installation.

As will be pointed out later in some detail, the poor performance in certain laboratory evaluation tests and in one test in natural sea water was due to an improper heat treatment used in the early stages of the alloy development. This has been corrected in recent and current production practice.

The service failure was associated with failure of another component, a steam baffle, which brought the outer surfaces of the tubes that failed in a power plant condenser into contact with steam at a very high temperature without adequate flow of cooling water inside the tubes. Other materials being considered for OTEC tubing, such as copper alloys, aluminum and titanium, would not have been able to survive the unusual conditions that caused failure of the AL-6X tubes in this instance.

The data to be obtained from accelerated screening tests, long-time tests in sea water, trial installations, service experience and supplementary pertinent information will provide additional evidence as to the potential utility of alloys with the AL-6X composition. These data will also support continued interest in future qualification of other highly alloyed stainless steels that have shown promise in exploratory tests. No consideration need be given the ordinary grades of stainless steel in the 300 and 400 series.

II. SERVICE REQUIREMENTS

The principal requirements for corrosion resistance of tubing for OTEC heat exchangers are as follows:

1. Resistance to general wastage, pitting and crevice corrosion in sea water in a temperature range from 5 to 38°C with oxygen concentrations from near zero to saturation at flow velocities ranging from stagnation to at least 8 feet (2.4 m) per second.
2. Resistance to sea water in the presence of concentrations of chlorine that may be used to control fouling.
3. Resistance to abrasion by devices that may be used to remove fouling.
4. Resistance to ammonia, alone or mixed with sea water, expected to be used as the fluid for power generation.

III. HISTORY

The AL-6X alloy is related to an alloy originally identified as IN-748. The latter alloy, covered by U.S. Patent 3,547,625, was developed in the research laboratories of the International Nickel Company, Inc. The original objective was to provide a material for high strength wire rope that could be used in marine environments without failures from crevice corrosion encountered to an intolerable extent in wire rope made from the commercial 300 series grades of stainless steel.

Another objective was to provide an alloy substantially cheaper than such alloys as Inconel* 625 and Hastelloy** C that had the necessary strength and corrosion-resistant properties but were considered to be too expensive for most wire rope applications.

Coincidentally, manufacturers of welded, thin-wall Types 304 and 316 stainless steel tubes had found that, although these alloys were economically attractive and performed well in power plant condensers cooled with fresh water, they were not adequate for use in condensers cooled with salt water.¹⁻⁴ The principal cause of failure was corrosion in crevices formed by deposit of solids under conditions of interrupted flow without adequate cleaning.

The IN-748 alloy came to the attention of fabricators of stainless steels, including the Allegheny Ludlum Steel Company. They were interested in developing an alloy that would not be subject to corrosion in crevices under deposits on salt-water-cooled condenser tubes made of Types 304 and 316 stainless steel.

Using the composition of the IN-748 alloy as a guide, Allegheny Ludlum modified the alloy to suit their production practices while maintaining the required resistance to crevice corrosion and pitting. The nominal composition of the IN-748 alloy was 27% Ni, 20% Cr and 8.5% Mo. The resultant AL-6X alloy contains 24% Ni, 20% Cr and 6% Mo. Comparative tests of the two alloys have shown that the AL-6X modification of IN-748 retains the resistance to pitting and crevice corrosion in sea water that was the target for the development of the IN-748 alloy.

In the course of the alloy development program, it was found necessary to avoid the presence of an intermetallic sigma phase rich in chromium and molybdenum. This impaired resistance to corrosion in the alloy-depleted zones adjacent to the sigma.⁵

Poor performance attributed to sigma varied depending on the amount of sigma present and, particularly, on its most damaging location at grain boundaries. It also varied with the method of test. Sigma phase was responsible for poor performance in accelerated laboratory tests using ferric chloride. However, it was not found to be harmful in some early trial

*Trade Mark, International Nickel Co., Inc., New York, NY.

**Trade Mark, Cabot Corporation, Stellite Division, Kokomo, IN.

installations in which properly heat treated material performed satisfactorily despite the presence of a sigma phase.

An example of what has been described was provided by tests of the AL-6X alloy by the U.S. Naval Research Laboratory at Key West, Florida.⁶ Specimens exposed for 218 days under conditions of quiet immersion suffered crevice corrosion to a depth of about 0.01 inch (254 μ m).

Corrosion specimens were also exposed to sea water flowing at a rate of 180 ml/min in a test cell at Key West Laboratory. Under these conditions, an AL-6X specimen exposed for 218 days was perforated 0.065 in. (1651 μ m) while companion specimens exposed in a test cell for 552 days suffered practically no crevice corrosion.

It seems likely that the absence of crevice corrosion of the AL-6X alloy in the much longer test period was no more than an example of the statistical probability feature of the incidence of crevice corrosion of stainless steels. Such attack may not occur within all crevices of test specimens containing several crevices.

Incidentally, specimens of a 26% Cr 1% Mo alloy with a thickness of 0.06 in. (1524 μ m) suffered crevice corrosion to a depth of 0.05 in. (1270 μ m) in the quiet immersion test at Key West and perforated in the 552-day test in the flowing water cell.

The effects of sigma phase and its elimination by proper heat treatment of the AL-6X alloy were demonstrated by crevice corrosion tests in hot sea water at Harbor Island, North Carolina. The test used was the multiple crevice technique developed by D. B. Anderson.⁷

In this test, 20 crevices are created on each side of a 4 x 6 in. (100 x 150 mm) flat specimen by pressing a serrated Delrin washer against the surface of the metal. The ratio of shielded-to-freely exposed area is 1 to 85.

After exposure, the depths of attack at any of the 40 crevices are measured and subjected to statistical analysis of the frequency and depths of attack.

This approach is responsive to observations that crevice corrosion of stainless steels in sea water is a matter of probability as well as intensity. The probability factor was illustrated dramatically in the tests at Key West by Lennox and Peterson,⁶ as described previously. Results of such tests showing the effects of annealing temperature are indicated in Table I.

Several types of accelerated screening tests have been used in the development of stainless steels that will resist pitting and crevice corrosion. Most important of these are tests using ferric chloride.

An early ferric chloride test was that used by H. Smith.⁸ The specimens used in this test did not include any crevices. Subsequent modifications using specimens with crevices have been found to be more discriminating in predicting resistance to pitting and crevice corrosion under conditions of long-time exposure to natural sea water.

In the course of the development of the IN-748 and AL-6X alloys, specimens have been subjected to ferric chloride tests to demonstrate their resistance to crevice corrosion and their superiority in this respect to such less resistant alloys as Types 304 and 316 stainless steel. Typical results* of such tests are shown in Table II.

Another ferric chloride test to measure resistance to crevice corrosion was developed by R. J. Brigham.^{9,10} This was based on running the test at a series of increasing temperatures and observing the highest temperature at which a significant increase in extent of crevice corrosion had occurred. Results, as reported by Bond et al.,¹¹ are shown in Table III.

This test showed the improved resistance to crevice corrosion of the AL-6X alloy and the other highly alloyed compositions over the Type 316 alloy.

Another approach to screening is an electrochemical test¹² in which current is applied to a specimen in a series of increasing potentials. Observations of the amount of current that is passed can define what is called a "breakthrough" or "rupture" potential coincident with a substantial increase in current. The higher this potential the greater the expected resistance to pitting and crevice corrosion. Representative results of such tests are shown in Table IV.¹³

IV. CREVICE CORROSION TESTS IN NATURAL SEA WATER

Although results of ferric chloride and other screening tests indicated that the AL-6X alloy would have a high level of resistance to crevice corrosion and pitting in natural sea water, it was necessary to confirm this expectation by long-time tests in the natural environment using the Anderson multiple crevice technique.

Specimens of the AL-6X alloy were exposed at Harbor Island, North Carolina for five years with results as shown in Table V.

The AL-6X specimens from this five-year test were found to be free of pitting as well as free of corrosion in the crevices. Also, no localized corrosion was found under the several varieties of fouling organisms that became attached to the alloy during the test period.

V. TRIAL INSTALLATIONS

Encouraged by the favorable results of accelerated laboratory screening tests and exposures to natural sea water, trial lots of welded AL-6X tubes and commercial Types 304, 316 and 216 stainless steel were placed in service in operating power plant condensers at New Haven, Connecticut and Oldsmar, Florida. The Connecticut location had been the site of failures of Type 316 stainless tubes by crevice corrosion under deposits.

In the Connecticut tests, some of the 216 and AL-6X tubes were installed with inlet end restrictions to reduce the flow velocity from the normal 8 feet

*Results of similar tests supporting the same conclusion can be found in appended supplementary references.

(2.4 m) per second to 0.1 foot (30 mm) per second. This was done to prevent deposition of solids, which had been found to have been the principal factor in the failure of Type 316 tubes in this service.

Withdrawals of test tubes after one and three years disclosed serious pitting in the Types 304 and 316 tubes but none in the 216 and AL-6X tubes in both the Connecticut and Florida tests.

After six years, the single remaining 304 tube in the Florida installation contained many small pits. The 316 tubes showed many smaller pits. Both the 216 and AL-6X tubes tested with unrestricted flow remained free from pits at the end of six years at both locations.

The partially restricted 216 tubes in the New Haven test showed larger pits than the unrestricted Type 316. The partially restricted AL-6X tubes showed some light but insignificant attack. There was no attack in the crevice under the plug used to restrict flow.

The AL-6X tubes used in these trial installations had been made at a time when the annealing cycle did not avoid the presence of the sigma phase shown to be harmful in accelerated laboratory tests.

Samples from the tubes used in the trial installations were re-heat treated in accordance with the improved current production practice and subjected to the laboratory crevice corrosion screening test for comparison with samples of the test tubes in their original improperly heat treated condition. The properly heat treated material performed satisfactorily in the crevice corrosion test.

It would appear that the crevice corrosion screening test is much more drastic toward the AL-6X alloy than the restricted flow conditions established in the Connecticut trial installation designed to promote pitting under deposited solids.

VI. FULL-SCALE INSTALLATIONS

By the end of 1978, several million feet of AL-6X tubes had been installed in salt-water-cooled condensers in coastal power plants in the United States. These installations are shown in Table VI. In addition to these full-scale installations, thousands of AL-6X inserts are being used by several power companies to extend the life of brass tubes that have suffered inlet end erosion.

With the exception of one instance to be described in detail, no trouble has been encountered with the millions of feet of AL-6X tubes in the installations listed in Table VI. This one exception was the result of abnormal circumstances encountered early in 1977 at the United Illuminating Co. station in Bridgeport, Connecticut.

As a result of failure of a steam impingement baffle in front of six AL-6X tubes, 7/8 inch (21 mm) diameter, 0.028 inch (0.7 mm) wall, in an upper row of the condenser, high velocity steam bled from a heater drain vent or a

gland was dumped into the condenser through a 1-1/2 to 2-inch line in a temperature range of from 600 (316°C) to 1000°F (538°C). The steam ruptured the baffle and impinged directly on the tubes to cause the failure.

None of the other 7,556 AL-6X tubes that were installed in this condenser in 1975 failed at the time of the incident described, or since.

Any of the other materials being considered for OTEC heat exchangers would have been similarly damaged by the abnormal conditions that caused the failure of the AL-6X tubes.

The normal operating conditions in the condenser at the Bridgeport station are particularly severe, since they involve peaking service with daily shut down and start ups. The steam velocities are high but have not led to any failures from vibration. The steam contains some ammonia from the feed-water treatment.

VII. SUPPLEMENTARY INFORMATION

Qualification of a material for use in OTEC heat exchangers requires consideration of a number of other factors covered by the following discussions.

A. Galvanic Behavior

The AL-6X alloy occupies a position in a galvanic series in sea water shown by Table VII.

It can be expected that the AL-6X alloy will not be subject to acceleration of corrosion by galvanic contact with any of the materials with which it may become associated in OTEC systems.

The AL-6X alloy could accelerate corrosion of aluminum, steel or other less noble metals if coupled to them. The extent of this galvanic effect would be about the same as that expected from similar combinations involving titanium and copper-nickel alloys.

In new condensers, it would be desirable to use steel tube plates clad with a stainless steel of high molybdenum content such as Jessop* 700 containing 21% chromium, 25% nickel and 4.5% molybdenum if steel clad with the AL-6X composition should not be available. Second choices would be cladding with Incoloy** 825 or Carpenter 20 Cb.[†] The use of such alloy clad steel tube plates would facilitate seal welding of tubes, which would be desirable to prevent leakage of ammonia.

AL-6X tubes would be able to tolerate copper in corrosion products from copper alloys, such as the 90:10 copper-nickel alloy 706 that might be used upstream to take advantage of its antifouling properties, in screens or piping.

*Trade Mark, Jessop Steel Co., Washington, PA.

**Trade Mark, International Nickel Co., Inc., New York, NY.

[†]Trade Mark, Carpenter Technology Corp., Reading, PA.

B. Resistance to Ammonia

Since AL-6X is a ferrous alloy, it can be expected to be free of corrosion by ammonia. Leakage of ammonia into sea water, or vice versa, would not be expected to impair resistance to attack by either. AL-6X has been reported to be resistant to ammonia.¹⁴

Less highly alloyed stainless steels have been used successfully as tubes in heat exchangers involving exposure to ammonia.

C. Resistance to Chlorine

There have been no reported problems attributable to the use of chlorine for controlling fouling in heat exchangers in which stainless steels less highly alloyed than AL-6X have been used. Because of its higher molybdenum content, the AL-6X alloy would be expected to have superior resistance to chlorinated sea water. This was confirmed also by results of a laboratory screening test in which the AL-6X composition was found not to be affected by exposure to a 5% solution of sodium hypochlorite at 50°C.¹⁵

VIII. BIOLOGICAL AND INORGANIC FOULING

Since the AL-6X alloy is inert in sea water, it does not resist fouling by macroorganisms or bacterial slimes. It would be necessary to remove such fouling from heat exchanger tubes by mechanical or chemical cleaning or prevent fouling by chlorination or other treatment of the water.

Mechanical cleaning of stainless steel heat exchanger tubes, e.g., by the Amertap system, has been employed without damage to the tubes.⁴ There is no record of the use of the Amertap system with AL-6X tubes, but no damage to such tubes need be anticipated.

The absence of corrosion products and maintenance of a smooth surface on AL-6X tubes should contribute to heat transfer and facilitate mechanical cleaning.

The resistance of the AL-6X alloy to a broad range of chemicals should broaden the choice of chemical cleaning agents, if this approach to maintenance of heat transfer should be adopted.

Since the AL-6X alloy will not corrode, there will be no electrical currents from local corrosion action that might trigger deposition of calcium and so forth from supersaturated water. This would give the AL-6X alloy an additional advantage over materials such as aluminum which is less resistant to corrosion.

IX. EFFECTS OF VELOCITY OF WATER FLOW

AL-6X tubes are being used successfully in power plant condensers with a design water velocity of 8 feet (2.4 m) per second. This also was the velocity encountered in the successful trial installations previously

described. Although the alloy could withstand higher flow velocities, these are not likely to be used in OTEC heat exchangers.

In the evaluation of the alloy for other possible applications in sea water, specimens were exposed to sea water flowing at velocities up to 140 feet (43 m) per second. The results are shown in Table VIII.

Resistance to deterioration from impingement of high velocity sea water would be an advantage for the AL-6X alloy, if sea water jets were to be used for cleaning OTEC heat transfer surfaces.

As noted previously, the AL-6X alloy will tolerate the even more dangerous conditions of exposure to slowly moving sea water in partially obstructed tubes, under deposits in tubes, and under attached marine organisms.

X. STRESS-CORROSION CRACKING

The temperatures to be encountered in OTEC heat exchangers are well below those at which chloride stress-corrosion cracking of austenitic stainless steels has been observed [above 140°F (60°C)].

The AL-6X alloy was found to be susceptible to stress-corrosion cracking in boiling concentrated magnesium chloride, which is considered to be the most aggressive medium for promoting stress-corrosion cracking of austenitic stainless steels. Other chlorides, including sea water, are much less aggressive.

The relatively high nickel content of the AL-6X composition improves resistance to chloride stress-corrosion cracking.¹⁶ This improvement was demonstrated by freedom from cracking in boiling 20% sodium chloride.¹⁴

XI. INTERGRANULAR CORROSION

The AL-6X alloy is made with a sufficiently low carbon content (less than 0.03%) to avoid sensitization to intergranular corrosion that results from precipitation of chromium carbides in austenitic stainless steels.

Another form of sensitization caused by formation of a sigma phase, discussed previously, is avoided by appropriate heat treatment used in the production of the alloy.

XII. CORROSION FATIGUE

No data are available on the corrosion fatigue properties of the AL-6X alloy. However, its high resistance to pitting, which otherwise could serve to create local stress-raising notches, can be expected to give the alloy an advantage over metals less resistant to local attack.

XIII. VIBRATION

There have been no instances of failure of AL-6X tubes that replace copper alloys. In these cases, the spacing of the tube supports had been designed for thicker-walled tubes of copper alloys. In new installations of AL-6X tubes, the spacing of the tube supports will, presumably, be related properly to the properties of the AL-6X alloy and the dimensions of the tubes.

Choice of the AL-6X alloy in preference to titanium to replace copper alloys in condensers with tube supports designed for the copper alloys has been reported¹⁴ to have been based on vibration-related failures of thin-wall titanium tubes in such installations.

The higher modulus of elasticity of the AL-6X alloy (29×10^6), as compared with titanium (15×10^6), should be advantageous with respect to vibration.

XIV. CONCLUSION

The evidence compiled in this review supports continuing consideration of the AL-6X alloy as a desirable material for tubing in OTEC heat exchangers.

The high-purity high chromium alloys containing from 1 to 4% molybdenum have performed well enough in evaluation tests to warrant further attention. To date, the number of trial or full-scale installations has not been adequate to provide a record of condenser service experience for the chromium alloys that is comparable to that of the AL-6X alloy.

As noted in its history, the AL-6X alloy is a modification of the INCO IN-748 alloy. Other alloy producers may, in the future, offer either the original IN-748 composition or a modification (containing at least 6% molybdenum) that could be expected to perform well in OTEC heat exchangers.

In a more general way, it has been found that alloys likely to demonstrate adequate resistance to pitting and crevice corrosion have chromium and molybdenum contents to the right of the line in Figure 1.¹⁷ The alloy in this figure, identified as Sea-Cure,* has a nominal composition of 26% Cr, 3% Mo and 2.5% Ni.

None of the commercial stainless steels in the 300 or 400 series have the level of resistance to pitting and crevice corrosion required for use in OTEC heat exchangers.

*Trade Mark, Colt Industries, Inc., Crucible Materials Research Center, Pittsburgh, PA.

TABLE I. Effect of Heat Treatment on Resistance of AL-6X
to Crevice Corrosion in Sea Water at Harbor Island,
North Carolina for 30 Days at 50°C^a

Annealing Temperature	Attack Initiated, %	Attack Propagating to 0.25 mm, %	Maximum Depth of Attack, mm
2200°F (1204°C)	0	0	0
1600°F (871°C) ^b	17.5	0	0.02

^aPrivate communication, International Nickel Co., Inc.

^bTo promote presence of sigma phase.

TABLE II. Results of Exposure to 10% FeCl₃ for 72 Hours
at Room Temperature

Alloy	Weight Loss, %	Crevice Attack	Pitting
304	2.5 to 5.1	Severe	Severe
316	2.5 to 5.1	Severe	Severe
317	0.8 to 1.1	-	-
29% Cr 4% Mo	0	0	0
26% Cr 1% Mo	0	0	0
Al-6X	0	0	0
Titanium	0	0	0

TABLE III. Critical Crevice Corrosion Temperatures
in 10% FeCl₃ pH 1

Alloy	Temperature of No Crevice Corrosion, °C	Temperature of Slight Crevice Corrosion, °C
304	-	-2.5
316L (17% Cr 12% Ni 2.5% Mo)	-	0
27% Cr 1.5% Mo 4% Ni	5	7.5
25% Cr 3.5% Mo	47.5	50
26% Cr 1% Mn	20-22.5	22.5-25
AL-6X	17.5-20	20-22.5

TABLE IV. Breakthrough Potential Tests of Stainless
Steels in Chloride Solutions

Alloy	Minimum Breakthrough Potential, mV	
	1000 ppm Chloride	10,000 ppm Chloride
304	220	180
316	330	250
AL-6X	1000+ ^a	940

^aBeyond range of test.

TABLE V. Results of Multiple Crevice Corrosion Test
in Flowing Sea Water in Ambient Temperatures at
Harbor Island, North Carolina for Five Years

Alloy	Average Weight Loss, g	Initiation	Probability, %		Max. Depth	
			10 mils (0.25 mm)	50 mils (1.25 mm)	mils	mm
316 ^a	0.14	6	6	0	38	0.95
AL-6X	0.01	0	0	0	0	0

^aTested for 126 days.

TABLE VI. AL-6X Installations

Company	Plant	Date
United Illuminating	Bridgeport Harbor No. 1	1973
	Bridgeport Harbor No. 2	1976
Tampa Electric	Big Bend No. 1	1976
	Hooker's Point No. 5	1976
	Gannon No. 6	1977
Public Service Elec. & Gas New Jersey	Linden	1977
	Sewaren	1978
New Orleans Public Service	Michoud No. 3	1977
	Michoud No. 2	1978
Long Island Lighting	Northport No. 1	1978
	Northport No. 2	1979
New England Electric	Brayton Point No. 1	1978
	Brayton Point No. 2	1978
Maine Yankee		1978

TABLE VII. Galvanic Series in Sea Water for
Alloys of Interest in OTEC Systems^a

Material	Range in Potential vs Sat. Calomel Half Cell, mV
Aluminum 5052 ^b	-880 to -1080
Steel	-600 to -700
Copper	-300 to -350
90:10 Cu-Ni (706)	-210 to -280
70:30 Cu-Ni (715)	-170 to 230
Stainless Steel (Type 316)	-350 to -450 (Active)
	-100 to 0 (Passive)
26% Cr 1% Mo ^c	-100 to +100
Titanium	-50 to +50
Al-6X ^c	-50 to +280

^aFrom Marine Corrosion, John Wiley and Sons, Inc., 1975, Fig. 6-1.

^bFrom T. J. Lennox, Jr., Naval Research Laboratory Report 3622, 1977.

^cFrom T. J. Lennox, Jr. and M. H. Peterson, NACE Corrosion/76, Houston, Texas, March 1976, paper 78.

TABLE VIII. Results of Tests in Sea Water Moving at High Velocity^a

TEST 1. Specimens on Rotation Disc^b at Tip Velocity of 27 ft/sec (8.2 msec) for 60 Days at 16°C (61°F). Exposed area 7.2 in.² (46 cm²).

Alloy	Weight Loss, g	Appearance
IN-748	0.004	No visible corrosion
316 Stainless Steel	0.004	No visible corrosion

TEST 2. Extreme Velocity Test^c Test Velocity 129 ft/sec^d (39 msec) for 30 Days at 9°C (48°F). Exposed area 3.5 in.² (22 cm²).

Alloy	Weight Loss, g	Cavitation Damage
IN-748	0.04	Trace
316 Stainless Steel	0.03	None

TEST 3X. Extreme Velocity Test^c Test Velocity 130-140 ft/sec (40 msec) for 30 Days at 15°C (59°F).

Alloy	Corrosion Rate	
	mils/yr	mm/yr
304 Stainless Steel	1	0.025
316 Stainless Steel	1	0.025
90:10 Cu-Ni (CA-706)	25	0.63
6061 Aluminum	65	1.6
Carbon Steel	150	3.8

^aInternational Nickel Co., Inc., private communication, 1977.

^bSee F. L. LaQue, Marine Corrosion, John Wiley and Sons, Inc., New York, Fig. 3.14, p. 59, 1957.

^cSee F. L. LaQue, Marine Corrosion, John Wiley and Sons, Inc., New York, Figs. 3.22 to 3.25, p. 64, 1957.

^dHole in specimen to induce cavitation.

Figure 1. Susceptibility of Alloys to Crevice Corrosion as a Function of Chromium and Molybdenum Content

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