RESISTANCE OF STAINLESS STEEL TO CORROSION IN NATURALLY OCCURING WATERS

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS Nº 1262

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RESISTANCE OF STAINLESS STEELS TO CORROSION
IN NATURALLY OCCURRING WATERS

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Stainless steels are used in many applications that involve exposure to naturally occurring waters i.e. fresh waters such as river, lake, domestic and potable waters and marine waters e.g. estuarine and sea. In many fresh waters most types of stainless steel remain uncorroded but occasionally, incidents of corrosion occur that are unexpected. Frequently on examination it is found that, in the case of concern, the chloride content of the water has been the critical factor in causing corrosion.

The susceptibility of stainless steels to localised corrosion in chloride-containing solutions has been known from their inception. For this very reason it would not be expected that stainless steels could be used in marine environments. In fact, if care is taken in selecting and controlling the conditions of exposure it is possible to use stainless steels satisfactorily for a variety of marine applications[1]. It is the purpose of this paper to review behaviour of conventional stainless steels in fresh waters and to outline conditions for their satisfactory application in high chloride-containing waters.

ELECTROCHEMICAL MEASUREMENTS

Developments in electrochemical techniques for characterising stainless steel performance, particularly in the last decade, have permitted isolation and identification of those parameters, both alloy and environmental, that affect the occurrence of localised corrosion on stainless steels. Previously the effect of alloy composition, microstructure and environmental conditions were difficult to elucidate, partly because of the random character of localised attack, partly because of the variable time taken for corrosion to initiate and partly because of the interaction of the various parameters and the difficulty in isolating specific items for study.

Measurements of critical pitting potential (E_c) i.e. the potential at which a stainless steel in a near neutral chloride solution loses passivity and commences to corrode by pitting, and of protection potential (E_p) i.e. the potential at which existing pits will propagate but new ones will not initiate have permitted such isolation and study to be carried out. Measurements of the potential at which pits will repassivate has also been found significant. Whilst the exact values of E_c and E_p may vary according to the technique of measurement and the thermodynamic significance of the values may be in doubt, the change in value with change in parameter has mostly been found to be consistent and thus the significance of the parameter under study can be assessed with respect to pitting corrosion.

(a)   Environmental Conditions

Table I records the outcome of electrochemical measurements with respect to change in composition and temperature of the solution. The following deductions may be made:

1)   There is general consensus that increase in chloride content will increase probability of pit initiation — more particularly for ferritic than austenitic stainless steels. There is some indication that the likelihood of crevice corrosion is little affected by change in chloride concentration.

2)	In NaCl solutions variation in pH within the range 2-8 apparently has little effect but in $CaCl_2$ solution, increasing acidity increases probability of pit initiation — more particularly for ferritic than austenitic stainless steels. Addition of alkali is the most effective way of inhibiting pitting and as chloride content increases so a higher level of alkali is required for inhibition.

3)	Anions other than halide are non-aggressive and inhibit pitting corrosion. The order of effectiveness is $OH^- > NO_3^- > CH_3 COO^- > SO_4^{--} > ClO_4^-$. The observation that SO_4^{--} (and presumably other anions) decreases corrosion current in the passive condition is of significance in respect to the development of acidity in crevices and implies reduction in susceptibility to crevice corrosion with increasing content of unaggressive anion.

4)	The presence of sulphide ion increases susceptibility to crevice corrosion.

5)	Whilst there is some disagreement, oxygen has been found favourable in maintaining passivity, although in common with other oxidising ions Fe^{+++}, Cu^{++}, NO_3^{--}, it stimulates the cathodic reaction and shifts the open circuit potential to more noble values, possibly into a region where pitting can occur. Very low contents of oxygen and other oxidising species will reduce propagation of pits to negligible values.

6)	Increase in temperature above a certain critical value markedly increases pitting corrosion.

(b) Steel Composition

Table II records the outcome of electrochemical experiments with respect to the influence of alloying elements on susceptibility of stainless steels to pitting corrosion. The major factors in relation to the initiation of pitting corrosion are chromium and molybdenum contents and to much lesser degree the content of nickel in the steel. Minor beneficial influence has been shown for Si and N. Slightly adverse effects have been demonstrated for an austenite/ferrite structure and more pronounced adverse effects for an austenite/sigma structure. It may be that the beneficial effect of N is at least partly related to its ability to stabilise the austenite phase. The markedly adverse effects of sulphides in initiating pitting have been demonstrated (28, 29). Increase in manganese content appeared particularly detrimental in stainless steels containing Mo.

In regard to crevice corrosion the significant influence in chromium corrosion products in creating acidity within the crevice has been established. The beneficial effect of molybdenum, nickel and copper in improving resistance to crevice corrosion has been shown.

It may be deduced that with increasing aggressiveness of the water a steel is required of higher chromium, molybdenum and nickel content and particularly to higher molybdenum and, to some extent, nickel and copper contents, if crevice corrosion is of concern.

CORROSION IN FRESH WATERS

(a) Cold and Hot Waters, Storage and Transportation

(i) Conventional Steels

There are little published long-term data relating corrosion behaviour of stainless steels to the content of chloride, non-aggressive anions, oxygen level and other factors shown in the electrochemical tests to be of significance. The extensive spool corrosion tests undertaken by Inco Inc. provide some data which although incomplete, permit some practical indication of the range of usefulness of stainless steels. Some of these data have already been published (30) but a more complete survey is given in Table III in which the waters are listed in order of chloride content.

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The Inco corrosion test spool consists of an assembly of test discs mounted on a central rod and separated one from another by insulating spacers. Thus at the spacer a crevice is formed which permits some appreciation of susceptibility to crevice corrosion to be obtained.

The deductions that may be made from Table III are:

1) Type 304 stainless steel is satisfactory for the long term storage and transportation of cold and hot water with chloride contents less than about 200 ppm.

2) At levels of chloride between 200 and 1000 ppm, Type 304 is marginally satisfactory and its successful use would depend on other factors such as high content of other anions, moderate temperature, nature of crevices present etc.

3) Type 316 stainless steel would be preferred for critical application where the salt content exceeded 200 ppm and other adverse factors such as low sulphate content, tight crevices, high temperature were involved.

4) Type 410 steel is unsatisfactory for long term use with water unless the chloride content is exceptionally low e.g. 2 ppm.

(ii) Recently–developed Steels

There are no data comparable in duration and extent for the ferritic Cr/Mo steels. Figures from laboratory tests are given in Tables IV (31) and Table V (32) that compare performance of an 18Cr/2Mo/Ti steel with conventional stainless steels. It should be noted that the tests described in Table IV were intermittent in operation allowing intermediate periods of exposure to air and that those described in Table V were made on creviced specimens.

(b) Heat Exchanger Conditions

In those conditions where stainless steel is used to provide a heat exchanger surface austenitic stainless steels may fail by stress–corrosion cracking particularly if the temperature of the surface is high enough to permit incipient boiling. This arises because of the possibility of chloride concentration at air/water interfaces, in crevices or under deposits where evaporation can occur (33). Thus austenitic stainless steels are not recommended for boilers where incrustations or other deposits can form or which are incompletely filled. Provided care is taken in design and operation with regard to the above factors and also the avoidance of a high heat flux, Type 316 gives satisfactory performance.

(c) Resistance of Joints

(i) Welded Joints

The behaviour of stainless steel weldments in fresh waters is rarely different from that of the basis material but occasionally premature failure at a welded joint may occur. The failure may result from incorrect welding technique e.g. argon arc welding with inadequate argon backing, whereby a tarnish film is formed (34). The formation of chromium–rich, tarnish films or scales gives rise to adjacent zones locally denuded in chromium where corrosive attack can be initiated. Such films should be removed by abrasion or prevented from forming by use of correct welding technique.

The heat-affected zones of weldments in Type 304 stainless steel show no greater susceptibility to pitting corrosion in chloride-containing fresh waters than the annealed material. This may be deduced from Table VI which shows the results of long-term, spool corrosion tests on specimens that had been sensitised by heat treatment.

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In waters of high chloride content where Type 304 shows marginal behaviour, corrosive attack often occurs preferentially in the weld metal where the presence of microporosity provides a favourable site for initiation of attack.

Welded ferritic stainless steels unless stabilised with titanium or niobium suffer intergranular corrosion in the heat-affected zones of weldments when exposed to hot chloride–containing water.

(ii) Soft Soldered Joints

Stainless steel joints made with conventional lead-tin solders or with silver-tin alloys are satisfactory where strength is not a major consideration. Early failures in domestic water installations were found due to the use of chloride–containing fluxes which had not been effectively removed after the soldering operation. Failure then occurred by pitting corrosion (most frequently when ineffectively cleaned, soldered tubes had not been used until some months after installation) or occasionally by stress corrosion — the latter on hot water tubing some time after the installation had been in use. In this connection, zinc chloride, the chloride most commonly used in conventional soldering fluxes, has been shown to be exceptionally deleterious (35). Use of fluxes based on phosphoric acid are recommended for the soft soldering of joints in stainless steel tubing (36).

(iii) Brazed Joints

Joints made in ferritic and austenitic stainless steels using a zinc–containing brazing alloy are subject to interfacial corrosion when exposed to water (37, 31) due to preferential dissolution of an Fe–Zn–Cu phase present at the interface. The problem is overcome by using a Ag–Cu–In–Ni brazing alloy. Preferential corrosion at the junction of braze metal and ferritic stainless steels may still occur unless a gold or palladium based solder is used (31).

(d) Service Experience

Type 304 stainless steel has been used extensively for domestic hot and cold water tubing in the UK over the previous 8 years with little complaint other than those in the initial period related to inadequate removal of zinc chloride fluxes after soldering.

Type 316 stainless steel has been used extensively in Germany and Switzerland for the manufacture of a special type of hot water boiler and storage tank. It is reported (34) that of 225,000 boilers that went into service since 1964 less than 200 were made unserviceable due to corrosion.

Type 304 stainless steel condenser tubes have been used for a high proportion of power stations in the USA located at inland sites. Whilst some failures have been reported these have been associated with high–chloride river waters coupled with discontinuous deposits of calcium carbonate or porous precipitates of iron and manganese (38).

CORROSION IN SEA WATERS

All stainless steels, with the possible exception of those of unusually high molybdenum content, are susceptible to localised corrosion in sea water, particularly at crevices. Typical values for the severe attack that can develop are given in Table VII. The extent of corrosion as measured by weight loss is usually quite small and often the strength of the stainless steel component is scarcely affected. Thus in some applications corrosion may be tolerated. However this may not always be the case and steps must then be taken to prevent or mitigate the corrosion. It may be sufficient to control or modify the conditions under which the stainless steel is used to ensure that corrosion is reduced to tolerably low levels. The following factors are of importance:

(i) Cathodic Protection

In many cases where stainless steel is used successfully in sea water it is used for a component that forms part of a total assembly that is receiving cathodic protection. Thus the stainless steel receives part of the protection that is provided to the system as a whole. An example would be a stainless steel ship's propeller that receives cathodic protection from zinc anodes used to protect the ship's hull.

More often the stainless steel component receives protection from adventitious contact with nearby mild steel structures. An example has been given where a smaller area of mild steel was sufficient to protect Type 316 marine gates from attack (39). Whilst coupling to mild steel is sufficient to give Type 316 stainless steel complete protection from attack, even in crevices, it may not be adequate to protect Type 304 completely from attack (40). Nevertheless even in the case of Type 304, corrosion is reduced to negligible or at least tolerable proportions. Coupling the stainless steel to zinc anodes or application of cathodic protection will provide complete protection.

(ii) Effect of Velocity

If sufficiently high velocity can be maintained in sea water flowing over a stainless steel surface passivity can be maintained and the steel will remain uncorroded. This characteristic is illustrated in Table VIII. It is advantageous if the sea water is flowing at velocities high enough to prevent attachment of deposits or settlement of suspended matter. Velocities greater than about 1 m/sec are generally necessary for this purpose.

Thus stainless steels are excellent materials for marine propellers and impellers for pumps used in sea water.

(iii) Intermittent Exposure

The depth of localised attack on stainless steels is much reduced if exposure to salt water is not continuous but occasional periods occur when the steel is exposed to a non-aggressive environment. For example the stainless steel may be allowed to dry or at least be exposed to air for a sufficient length of time to permit corrosion products to oxidise and precipitate within pits that may have formed during exposure to the salt solution. This point is demonstrated in Table IX (41) where comparison is made of the corrosion of stainless steel when (a) fully submerged in sea water and (b) exposed in the tidal zone. A further example can occur when stainless steel is subjected to alternate stagnant and moving sea water under conditions where attack would be inevitable if the steel were continuously exposed to the stagnant water (42). Another example occurs when exposure to salt solution is alternated with exposure to a chloride-free solution. Freedom from corrosion by these means is particularly applicable to those steels that have a high resistance to initiation of pitting corrosion.

(iv) Avoidance of Crevices

The solution within a crevice rapidly becomes diminished in oxygen and then progressively more acidic than the bulk solution with the passage of time (43). Thus localised attack is most likely to be initiated at a crevice region. There are a number of factors of importance involved in crevice corrosion including crevice geometry, composition of alloy and environmental conditions such that the likelihood of attack in a specific environment can only be assessed on a statistical basis (44). Among the measures that can be taken to minimise crevice corrosion are:

     (a) design to avoid formation of a crevice or at least to keep it as open as possible
     (b) overlaying susceptible areas with a more corrosion resistant alloy
     (c) paint surrounding surfaces if cathodic
     (d) use inhibiting paste
     (e) avoid metallic/non-metallic joints

(v) Low Oxygen Level

Although passivity of stainless steel is promoted by the presence of oxygen it is also true that oxygen or other cathodic reactant is necessary for the propagation of pitting and attack at crevices. Hence in sea water low in oxygen, pitting and attack at crevices may be initiated but such attack can only proceed at a slow rate. An example is given in Table X (45) which records some results from a deep sea water test where the oxygen concentration was less than 1/10th the saturation value. The results should be compared with those in Table VII.

CONCLUSIONS

Stainless steels can often be used satisfactorily in sea water despite their tendency to suffer localised corrosion in chloride-containing solutions provided attention is paid to the conditions of use. Factors of significance are:

1) to prevent formation of crevices or if crevices are inevitable to keep them as open and as shallow as possible
2) to provide cathodic protection either as such or by connecting to adjacent mild steel structures
3) to maintain high velocity of movement preferably sufficient to keep entrained solids in suspension
4) to allow periodic renewal of the protective film by intermittent exposure to air or to non-aggressive solution
5) to minimise access to oxygen if it is accepted that some corrosion is inevitable.

ACKNOWLEDGMENTS

TABLE I

Effect of Environmental Conditions on Susceptibility of
Stainless Steels to Localised Corrosion in Naturally
Occurring Waters as Deduced from Electrochemical Measurements

Conditions	Comment and References
Cl⁻	E_c shifts in negative direction with increase in chloride concentration (2). According to (4) a logarithmic relationship is obeyed $E_c = -0.088 \log$ (Cl⁻) + 0.168. Whereas (5) found E_c independent of NaCl concentration in range 0.1N to 5N for 18Cr/8Ni stainless steel but for 18Cr/1Mo steel a logarithmic relationship was established. Reference (6) showed increase in chloride to have a marked effect in negative direction on potential for formation of stable pits but slight effect on potential at which pits could repassivate.
pH	E_c for 18Cr/8Ni steels in NaCl appears to be independent of pH in range 2–8 (4, 5, 7). At a higher pH value, dependent on chloride concentration, E_c shifts sharply in positive direction. In $CaCl_2$ solutions pH has a significant effect (5) particularly on a 18Cr/1Mo steel in 0.1N solution.

TABLE I cont'd

Conditions	Comment and References
SO_4^{--}	In common with many other anions, sulphate has inhibitive effect on pitting by chloride ions (2, 3, 4, 6, 8) and shifts E_c to more noble values. According to (4) the relationship $\log (Cl^-) = 0.85 \log (SO_4^{--}) - 0.05$ applies for 18Cr/9Ni in regard to minimum anion activity to inhibit pitting. A significant observation by (11) shows that SO_4^{--} decreases corrosion current steels in the passive condition.
NO_3^-, CrO_4^{--}	These anions are effective inhibitors (2, 4, 9) but if present in insufficient amounts will increase corrosion by cathodic stimulation.
$CH_3 COO^-$ and ClO_4^-	These anions act as inhibitors although less effectively than the nitrate ion (3, 4, 9).
O_2	Results reported in literature are not in agreement e.g. (10) shows E_c for 17Cr and 18Cr/9Ni steels to be significantly more noble in oxygenated solutions than in nitrogenated solutions; (11) shows E_c to become slightly less noble with increase in oxygen.
Ca^{++}	The replacement of Na^+ by Ca^{++} shifts E_c in noble direction — slightly in case of 18Cr/8Ni, appreciably in case of 17Cr/1Mo.
Other cations	Other cations are without effect (3) although of course oxidising cations e.g. Fe^{+++}, Cu^{++} will shift the open circuit potential to more noble values into a region where pitting can occur.
S^{--}	Addition of S^{--} widens the active potential range (12) and thus makes repassivation of pits more difficult.
Temperature	Increase in temperature shifts E_c in a negative direction (3, 4, 13). A narrow range of temperature exists in which E_c changes rapidly and is preceded and followed by regions in which little sensitivity to temperature is shown. The critical range of temperature increases with Mo content of the stainless steel (14). Protection potentials E_p are influenced in the same manner indicating decisive influence of temperature on crevice corrosion (15).

TABLE II

Effect of Alloy Composition on Susceptibility of

Stainless Steels to Localised Corrosion in Naturally Occurring

Waters as Deduced from Electrochemical Measurements

Alloy Constituent	Comment and References
Cr	Increase in content has major effect in shifting E_c in positive direction (2,3). This is particularly marked for Cr contents greater than 25% (11, 16). Chromium corrosion products are largely responsible for the development of acidity in crevices (17, 18). Thus increase in Cr may not necessarily improve resistance to crevice corrosion.
Mo	Increase in content has major effect in shifting E_c in positive direction (2, 3, 11, 16). The effect of Mo is temperature dependent (14) and at 0°C the presence of Mo is deleterious (16, 19). Mo is more efficacious than Cr in improving resistance to crevice corrosion (20, 21).
Ni	Large increase in content has moderately beneficial effect (2, 3, 11, 16) in shifting E_c in positive direction but small variations have insignificant effect. High nickel contents give improved resistance to crevice corrosion (22).
Cu	Cu additions whilst having no effect on E_c (21, 14) do reduce rate of propagation of pits (21) and improve resistance to crevice corrosion (23).
Si	High levels of Si, say 4%, give improved resistance to pitting corrosion (3). Variation in silicon at lower levels appears to have negligible effect, unless Mo is also present (14, 23).
Mn	Reduction of manganese content to, say 0.2% from 1.8%, shifts E_c in a positive direction (24); significant benefit was found by reducing Mn from about 1.5 to 0.5% when Mo was present (14).
N	The balance of evidence indicates that high nitrogen level has a favourable effect on E_c and resistance to pitting corrosion (25, 14).
Microstructure	Duplex structures e.g. ferrite/austenite or austenite/sigma have adverse influence on E_c (26, 27) and resistance to pitting corrosion.

TABLE III : Results of Spool Corrosion Tests

WATER							Test Duration days	Steel AISI Type	Max. Depth of Pit or Crevice Attack mm
Type	Chloride ppm	Sulphate ppm	Others ppm	pH	Oxygen ppm	Temp. °C			
Mains Soft	–	–	–	–	–	66	1448	304	0.025 in crevice
water	–	–	–	–	–	66	1448	304	0.075 " "
supply	–	–	–	–	–	66	1448	304	0.075 " "
Corrosive	–	–	free CO_2	–	low	71	1555	304	0.025 " "
soft well	–	–	free CO_2	–	low	71	1555	304	0.025 " "
water	–	–	free CO_2	–	low	71	1555	304	nil
	–	–	free CO_2	–	low	71	1555	304	0.15 " "
River	2	5		6.7	low	27	349	430	0.05 " "
								304	nil
City water supply	2	10		6.7	present	8	367	304	nil
Product water from desalination plant	24	–	total dissolved solids 66	8.8-9.9	no aeration	23	1313	304	nil pitting incipient crevice corrosion
								410	0.35 pitting 0.63 in crevice
Well	40	2	CO_2 30	7.5	absent	22	63	302	nil
								304	nil
								316	nil
Product water from desalination plant	51	–	total dissolved solids 268	10.0	moderate aeration	23	1258	304	nil
								410	nil pitting 0.25 in crevice
Product water from desalination plant	52	–	total dissolved solids 112	8.4-8.7	movement 2m/sec for 89 days remainder stagnant	23	573	410	0.18, 0.25
								304	incipient in crevice
								316	incipient in crevice

TABLE III cont'd.

WATER							Test Duration days	Steel AISI Type	Max. Depth of Pit or Crevice Attack mm
Type	Chloride ppm	Sulphate ppm	Others ppm	pH	Oxygen ppm	Temp. °C.			
Blend of river water and desalination plant product.	55	–	Total dissolved solids 350-400.	7.3-7.6	oxygen 7.5-8.5 : movement 1m/sec.	24	425	410 430 304 316	0.33 nil nil nil
River	81	292	bicarbonate 149	8.4	saturated	16	234	410 316	0.55 nil
Blended desalination product and well water	154	–	total dissolved solids 407	7.5	no aeration	23	571	304 410	incipient pitting 0.03 in crevice 0.1 pitting 1mm perforation in crevice
Water from flue gas scrubber	175	75	–	2.5	moderate aeration	60	75	316 310 304 410	0.25 0.38 0.38 0.51
Water from flue gas scrubber	175	75	–	2.5	moderate aeration considerable agitation	71	131	316 310 304 410	0.33 0.28 0.35 0.41
Blended desalination product and well water	212	–	total dissolved solids 268	7.7	no aeration	23	1426	304 410	0.05 pitting 0.15 crevice 1mm perforation in crevice and outside.
Mine water	445	50	39 CaO 17 MgO	8.5	Some aeration; slight movement	22	90	430 304	0.025 nil

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TABLE III cont'd

WATER							Test Duration days	Steel AISI Type	Max. Depth of Pit or Crevice Attack mm
Type	Chloride ppm	Sulphate ppm	Others ppm	pH	Oxygen ppm	Temp. °C			
Cooling Tower	414–460	1176–1613	240–320Ca 61–87 Mg	6.6–7.2	well aerated; 1.5m/sec flow	24	90	304 316	nil nil
Well (de-aerator unit)	450		bicarbonate	7	low	109	63	430 304 316 825	0.1 0.1 0.05 nil
Mine	600	700		1.5	low	7	60	302 304 316	0.43 perforated nil
Cooling water	834	160	bicarbonate 46	8.5	well aerated: some movement	15–90 fluct-uating	30	304	0.1 0.13
	834	160	bicarbonate 46	8.5	no aeration; slight agitation	18	30	304	nil
Cooling tower water	1204	about 3,500		7.8	high	27	270	304 316	nil nil
River	1300	225	sulphide 20	6.3	high	7–30	148	304 316	0.25 nil
River	3030	nil	chlorine	8.1	high	31	74	304 316 Alloy "20" Alloy 825 Worthite	perforated 0.15, 0.2 0.1, 0.2 0.05, 0.07 0.4

(3)

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TABLE III cont'd

WATER							Test Duration days	Steel AISI Type	Max. Depth of Pit or Crevice Attack mm
Type	Chloride ppm	Sulphate ppm	Others ppm	pH	Oxygen ppm	Temp. °C			
Harbour Water (Condenser Tube)	3500-5000				low	40	14	321	4
Mineral	8250	2800	CO_2 42 H_2S 274		low	about 85	138	304 304	perforated 0.27
Brackish river water (a) at mud line	13296-16725	1832-2275	total dissolved solids 30,000	7.2-7.8	oxygen 0-10.5 slight movement	ambient	372	304 316	1.0 0.025
(b) below low tide	"	"	"	"	tidal flow	"	"	304 316	0.01 0.025

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TABLE IV

Corrosion of Stainless Steel Tubing carrying Water Containing Chlorides at 95°C[+]

Chloride Content mg/1	Flow*	Performance of Tubing in Test Period Indicated			
		12Cr Ti 428 days	17Cr Ti 428 days	18Cr 2Mo Ti 102 days	18Cr 10Ni 231 days
75	Continuous	Weld seam corrosion and pitting	No corrosion	No corrosion	No corrosion
	Discontinuous	Slight weld seam corrosion	No corrosion	No corrosion	No corrosion
500	Continuous	Weld seam corrosion and pitting	Slight weld seam corrosion and pitting	No corrosion	No corrosion
	Discontinuous	Weld seam corrosion and pitting	Slight weld seam corrosion	No corrosion	No corrosion

+ Reference (31)

* Flow system was disconnected at week-ends and holidays.

TABLE V*

Resistance of 18Cr 2Mo Ti and Type 316 Stainless Steels
to Crevice Corrosion in Chloride-Containing Water[+]

Stainless Steel	Surface Condition	Number of Surfaces Attacked out of 8	Total Area Attacked mm^2	Total Weight Loss mg
18Cr/2Mo/Ti	Ground	2	7	7.0
Type 316	Ground	0	0	9.2
18Cr/2Mo/Ti	Pickled	0	0	5.7
Type 316	Pickled	0	0	3.7

* Reference 32

+ Solution conditions were 300ppm Cl^-, 80°C, 180 days.

TABLE VI

Effect of Sensitisation on Resistance of Type 304 Stainless Steel
to Corrosion by Chloride-Containing, Fresh Water

Water Type	Chloride Content ppm	Total Dissolved Solids ppm	pH	Aeration	Duration days	Max. Pit Depth mm		Max. Crevice Corrosion m	
						Annealed Steel	Sensitised Steel	Annealed Steel	Sensitised Steel
Blended desalination product and well water	212	510	7.7	None	1426	0.075	0.075	0.05	0.075
						0.23	0.13	0.18	0.13
						0.075	0.05	0.075	0.1
						0.05	incipient ·	0.15	0.15
	24	66	8.8	None	1313	nil	nil	nil	0.075

TABLE VII

Resistance of Stainless Steels to Corrosion by Sea Water

Condition of test: Fully immersed, tidal flow
severe fouling, ambient temperature.

Stainless Steel	Exposure Period (years)	Depth of Localised Attack (mm)	
		Maximum	Average
Type 304 (19Cr, 10Ni)	1	0.99	0.20
	3	3.15 (perforated)	
	7	3.15 (perforated)	
Type 316 (17Cr, 12Ni, 2.5Mo)	1	0.86	0.64
	3	1.51	1.07
	7	3.15 (perforated)	

TABLE VIII

Effect of Sea Water Velocity on Pitting of Welded Types 316 and 310 Stainless Steels

Material	Pitting Corrosion after 1,257 days Exposure					
	at 1.2m/sec			Quiet		
	No. of Pits	Max. Depth (mm)	Average Depth (mm)	No. of Pits	Max. Depth (mm)	Average Depth (mm)
Type 316 (17Cr, 12Ni, 2.5Mo)						
Plate	0	0	0	87	2.0	0.96
Weld	0	0	0	47	3.3	1.9
Type 310 (25Cr, 20Ni)						
Plate	0	0	0	19	2.8	0.96
Weld	0	0	0	23	Perforated > 6.35	3.04

TABLE IX

Resistance of Stainless Steels to Sea Water
(a) when Continuously Immersed, (b) when Exposed in Tidal Zone

Stainless Steel	Average of 20 deepest pits (mm)							
	1 Year		2 Years		4 Years		8 Years	
	Continuously Immersed	Mean Tide Zone	Continuously Immersed	Mean Tide Zone	Continuously Immersed	Mean Tide Zone	Continuously Immersed	Mean Tide Zone
Type 316 18/12/2.5 Mo	1.1	0.13	1.3	0	1.2	0.18	3.85	0.4
Type 321 18/10/Ti	1.6	0.2	3.0	0.58	4.38	0.93	4.83	1.4

TABLE X*

Results of Exposures in Deep Sea Water

Test Conditions: Duration of Test   197 days

                    Depth   715 metres

                    Sea Water Salinity 34.4 ppt, Oxygen 0.39 ppm

                                   pH 7.5   Temp. 4°C

Stainless Steel	Depth of Crevice Attack mm
Type 304	0.2 - 0.28
Type 316	0

*Reference 45

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