

CORROSION IN PUMPS

by

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ABSTRACT

Many of the corrosion-related problems encountered in pumps during their useful lives are reviewed. Seven forms of corrosion are discussed with guidelines given that could mitigate pump damage if proper consideration were taken when selecting materials. The seven forms of corrosion reviewed are: general, corrosion-erosion, crevice corrosion, stress corrosion cracking, intergranular corrosion, and cavitation.

INTRODUCTION

Pumps play a major role in today's modern industrial society. All types of industries use these fluid handling machines for a multitude of reasons. The corrosive nature of the fluid requiring transport or increase in pressure varies with each application. The useful service life of a pump is dependent upon a great number of variables, most of them pertaining to the corrosion or erosion resistance of the pump materials. If careful consideration in choosing the proper material is overlooked, damage from corrosion can render a pump useless in a very short period of time. A great deal of information concerning the behavior of material in a particular environment is available from the pump manufacturers. For many of the fluids pumped in the major industries, application experiences have been documented with successes and failures adding to the application data base. In addition, many professional societies have information concerning the proper material selection for a given environment. These organizations include NACE and API for fluids containing Hydrogen Sulfide (H_2S).

Ingersoll-Rand has been producing centrifugal pumps for more than 80 years in all markets around the globe. A few of the industries served by Ingersoll-Rand pumps include: the utility, pulp and paper, petroleum, municipal water services, agriculture, flood control, desalination, and chemical processing. The wide variety of fluids handled by these industries require a broad knowledge of material behavior for successful pump design.

This tutorial is intended to describe some of the corrosion problems that can occur in pumps, often the result of a service misunderstanding that could be avoided if the proper information is accurately determined in the initial stages of material selection. Some pump material selection guidelines developed by Ingersoll-Rand for major industrial markets are shared with the reader.

FLUIDS

Corrosion of pump components is caused by the pumpage reacting with the internal pump surfaces. Material damage can take many forms and is dependent upon the fluid corrosivity and on the pump user's operational practices. The forms of damage include general wastage of the material and very specific forms of local corrosion. The specific type of damage depends upon both the characteristic of fluid and the materials used in the pump. The aggressiveness of fluids and the corrosion behavior of material in these environments have been established in several manners. These include: 1) many years of pump application experience, 2) prudent laboratory material testing, and 3) exposure of samples to the actual fluid streams in which the pump will operate. Three key factors have been established, which directly impact upon a material's corrosion behavior in various services:

- Type of fluid
- Fluid temperature
- Oxygen level

The type of fluid is of particular importance. Fluid pumpages are categorized within a particular industry with respect to their corrosivity. For example, the primary fluid for the power-generation industry is water. Although, this is a common everyday liquid, it can vary greatly in chemical composition, which directly impacts upon the proper selection of pump material. The useful materials of construction for pumps in a given fluid associated with the utility industry are well documented. Both manufacturers of pumps and the utilities have years of application experience, which have led to the preferred materials. Such unique application information can be found in all major industries that use pumps. In addition to actual pump material performance in a particular fluid, the corrosive nature of many fluids has been determined by laboratory testing of coupons. These coupons are exposed to a particular fluid stream in a process of interest. For example, a large number of materials were tested in ultrapure waters by a major utility in the late 1940s using liquid diverted from the process. Today's understanding concerning the chromium content in carbon steel required to avoid corrosion-erosion is a direct result of these tests [1].

Corrosion of a metal surface is a chemical reaction. Therefore, the temperature of a fluid is important to consider for the proper material selection. The rate of a chemical reaction increases with increased temperature, thereby producing a more aggressive environment [2]. Therefore, a material that is perfectly adequate at room temperature may suffer severe corrosion when the fluid temperature is raised.

As mentioned previously, much valuable data concerning the corrosion resistance of a material is based on laboratory coupon exposure tests. Frequently, these tests are performed in a fluid that is stagnant. It should be fairly obvious that a pump is anything but a stagnant fluid containment vessel, and test results from a stagnant environment should be viewed with a degree of caution when selecting materials for a pump. Fluids within a pump are moving rapidly and in many locations, the local fluid velocities far exceed limits used in piping system design. It is also a fact that pumps are operated in such a manner that long periods of stagnation can occur, if more than one pump is used in a demand-type process. During idle operation, corrosion layers can form on wet metal surfaces. These operational modes often lead to more than one form of corrosion and can compound the corrosive effects resulting from intermittent operation.

Since these dynamic conditions exist in a pump environment, multiple forms of corrosion and pump damage can occur simultaneously. They include:

- General corrosion.
- Corrosion-erosion.
- Crevice corrosion.
- Stress corrosion cracking (SCC).
- Galvanic corrosion.
- Intergranular corrosion.
- Cavitation.

(In addition to corrosion by the fluid pumpage, damage to pump components can occur because of suspended solids in the fluid stream or as a result of contact between parts in relative motion within the pump. Solid-particle erosion and adhesive wear will not be addressed in this text.)

TYPES OF CORROSION

General Corrosion

By far, general corrosion is the most common form of material degradation observed and frequently accepted. Examples of general corrosion are all around. From the corrosion of automobiles, to rusted nails on patios, to the brownish-red oxide formed on metal surfaces, it is an everyday occurrence to most people. In addition to corrosion of iron-based materials, corrosion of other materials frequently is seen in our everyday lives with little conscious thought about the chemical reaction that has taken place in nature. They include the formation of a green oxide on copper statues and roofs, which is artfully called patina. Another example is the tarnish of silverware, which requires laborious polishing to remove.

General corrosion is in fact an electrochemical reaction of a liquid with a metal that results in the formation of an oxide. This oxide usually has less strength than the base material from which it was formed. One exception is the austenitic stainless steels which have a tightly adhering oxide. Under stagnant conditions, the loose oxide layer can develop to a substantial thickness replacing the pure metal. If a sufficient amount of the metal is oxidized, the engineering component can be rendered useless. The useful life of a pump is designed on the normal wear and general corrosion expected for a particular fluid environment. Corrosion design limits of key pump components usually are based upon a rate of no more than 20 mils wastage per year.

A good example of general corrosion of a metal surface is shown in Figure 1. The microsection shown in Figure 1 was removed from a Ni-resist pump casing after approximately 10 years of service in seawater. Ni-resist is an austenitic cast iron developed by Inco for seawater services. As shown in Figure 1, Ni-resist forms a general

corrosion layer in seawater, thereby avoiding local corrosion pitting produced on other materials used in sea water. This corrosion layer is a uniformly oxidized surface over all wetted component surfaces. Also shown, is the influence of the environment beyond the uniform corrosion layer. This extension of the corrosion process can cause problems, since it would not be detected from the surface of the metal once the corrosion layer is removed. Although the surface can be cleaned to a bright metal finish, the preferential corrosion legs would cause problems in any weld repair attempted on these surfaces.

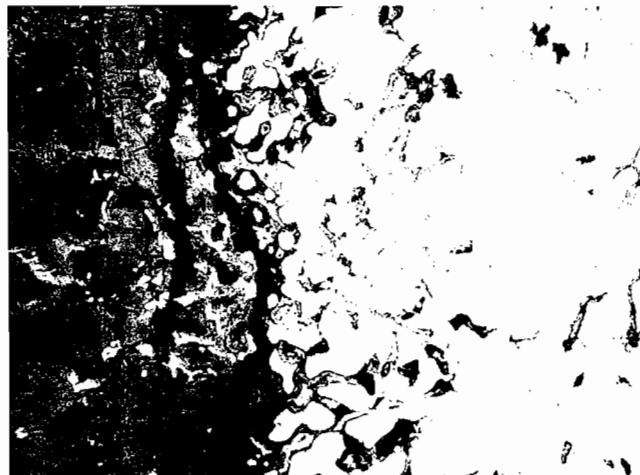


Figure 1. Magnification: 100 Corrosion of Ni-Resist by Seawater. General corrosion layer is shown to a depth of 0.016 in. with fingers of corrosion extending another 0.010 in. Etchant: Picric HCl.

Corrosion-erosion

The general corrosion layer formed on many metal surfaces due to reaction with an aggressive environment is expected as a naturally occurring phenomena. As mentioned previously, this oxidized layer is often friable and can be removed by the moving fluid. The shear forces generated by the movement of a liquid can wash away the oxide at specific locations on internal pump components. This oxide removal usually occurs at fluid impingement surfaces or regions of highest fluid velocity within the pump. The removal of these oxides produces local channels and flow paths on the component surface, which increase the turbulence of the fluid, producing additional fluid shear forces. This increases the rate of local oxide removal. The oxide removal mechanism is illustrated in Figure 2.

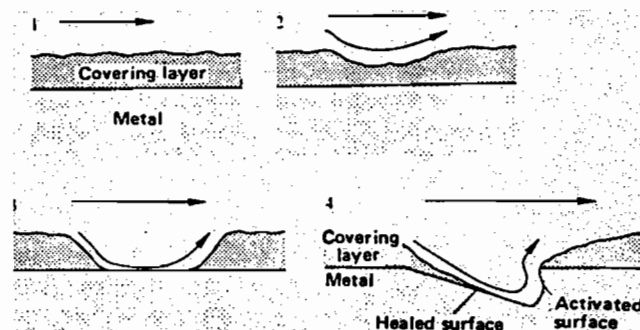


Figure 2. The Corrosion-Erosion Mechanism. This occurs when the local fluid velocity produces shear forces that remove the general corrosion layer [5].

The wastage of material as a result of this mechanism depends upon two primary factors. They are: (1) fluid velocity and (2) the relative strength or tenacity of the oxide formed on the metal surface. Inco has conducted tests to ascertain the relative velocity of a seawater needed to produce a rapid increase in the corrosion rate of a given material. A summary of Inco's test results is shown in a graph published for use as an application guideline for materials intended for flowing seawater. This chart is shown in Figure 3. From this chart, it is obvious that material behavior can vary widely, depending upon the nature of the oxide formed on the metal's surface.

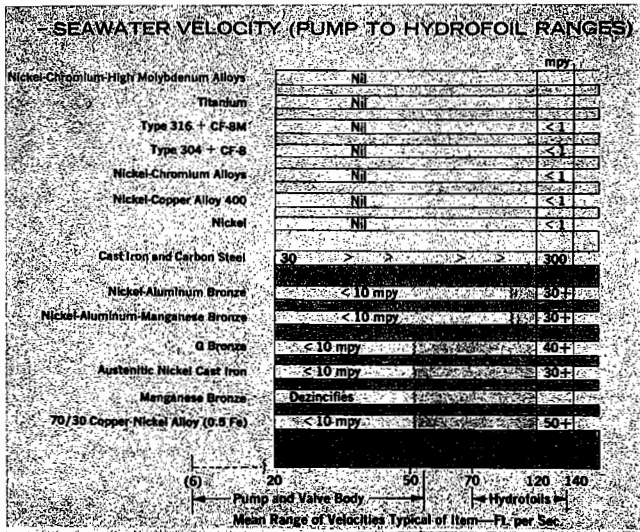


Figure 3. Velocity Limits of Various Materials Shown on the Chart Published by Inco.

Corrosion-erosion of carbon steel pump components has been observed in the utility industry in an apparent nonaggressive ultrapure water environment. It has been determined that in high temperature, low conductivity (less than 20 micromhos) boiler feedwater (BFW), carbon steel will suffer rapid damage in short periods of time. Conductivity relates to the total dissolved solids in the fluid. Low conductivity indicates the water is pure with a small number of dissolved solids. Conversely, the higher values of conductivity indicates a fluid with a high concentration of dissolved solids. The results shown in Figure 4 are of the damage produced on an AISI-1040 carbon steel exposed to a low conductivity BFW service after only six months of service. Note the channeling (worm-hole appearance) of the shaft's surface, which further aggravates the damage as a result of increased fluid turbu-



Figure 4. Corrosion-Erosion of an AISI-1040 Shaft Due to Attack by Ultrapure Water.

lence and increased velocity through the channels. Another example of corrosion-erosion is shown in Figure 5. In this case, a carbon steel casing (ASTM-A216 grade WCB) experienced channeling between stages at wear-ring fit locations.

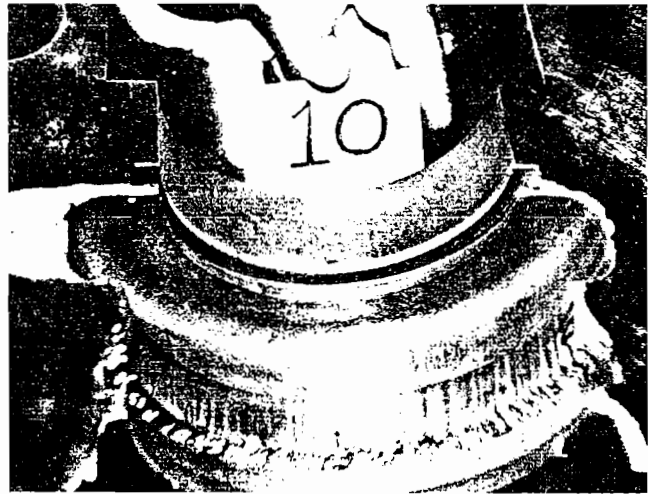


Figure 5. Corrosion-Erosion of a Carbon Steel Casing in a High Temperature, Low Conductivity BFW Service. Damage occurs at high velocity areas.

The corrosion-erosion of carbon steel in high temperature ultrapure waters was studied extensively by Detroit Edison in the late 1940s. A summary of this testing was published in the May 1947 issue of the Transactions of the ASME. This study shows that a material's chromium content is the primary alloying element that controls its resistance to corrosion-erosion in high temperature BFW. The study shows that a carbon steel with only three percent chromium rendered the alloy immune to the accelerated corrosion damage. Most pump manufacturers have standardized on the use of martensitic stainless steels (12 percent chromium) for resistance to the corrosion-erosion and other corrosion problems associated with BFW services.

Local Corrosion

Local corrosion is a term used to describe special forms of corrosion usually associated with alloys that have good general corrosion resistance in a particular service. Two of the common forms of local corrosion are pitting and crevice corrosion. These local corrosion forms will be discussed in detail as related to pump applications.

Oxygen Pitting

Oxygen pitting is a form of local corrosion that can occur in aerated high temperature waters found in the utility industry. This form of damage has been observed on all carbon steels and up to the five percent chromium steels. The five percent chromium alloys were used to resist the corrosion-erosion damage mentioned previously. It is the author's company's experience for BFW pumps that if a service has an oxygen content greater than 40 parts per billion (ppb), carbon steels will be susceptible to oxygen pitting. Oxygen pitting is characterized by random broad shallow pitting of the metal surface. The damage due to oxygen pitting of a cast iron diffuser is shown in Figures 6 and 7. In this case, the pitting is not concentrated in any one particular location, but rather over the component's entire wetted surface. Oxygen pitting of a carbon steel impeller is shown in Figures 8 and 9.

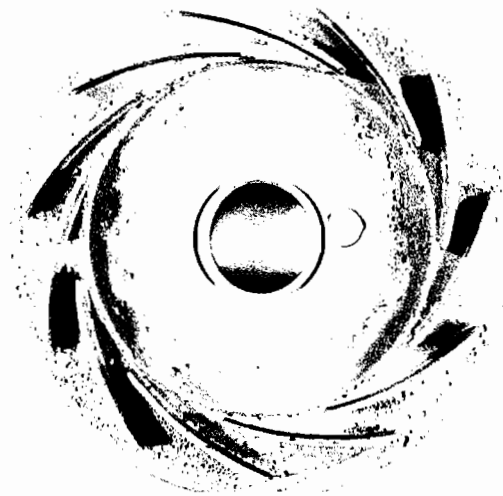


Figure 6. Oxygen Pitting of a Cast Iron Diffuser. Note random broad, shallow pitting.



Figure 7. Closer View of Oxygen Pitting of the Cast Iron Diffuser Shown in Figure 6.



Figure 8. Oxygen Pitting of a Carbon Steel Impeller.



Figure 9. Closer View of Oxygen Pitting of the Carbon Steel Impeller Shown in Figure 8.

If the oxygen level in a pure water system is in excess of the 40 ppb, the material needed to avoid oxygen pitting is one of the martensitic stainless steels. Oxygen pitting is shown in Figure 10 over the entire surface of a five percent chromium steel impeller, except for a region of the impeller that had been weld repaired with a 12 percent chromium martensitic stainless steel weld wire.

Corrosion Pitting

There are several factors which can cause a material to experience corrosion pitting. One variable is the solution's pH. In general, acidic conditions will cause corrosion pitting of carbon steels. However, this is not the sole reason for this form of damage in carbon steel. The pH value is only one of the limiting criteria to consider for proper material selection in water solutions. The author's company guideline for selection of materials based upon pH value is shown in Figure 11.



Figure 10. Twelve Percent Chromium Stainless Steel Repair in Five Percent Chromium Stainless Steel Impeller. Note the lack of oxygen pitting in the weld metal.

The austenitic stainless steels used in aggressive environments are susceptible to local corrosion in solutions such as seawater.

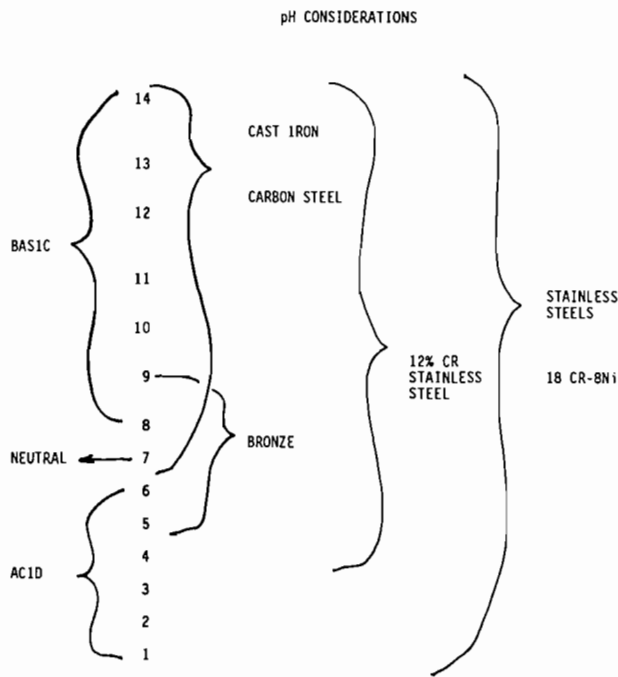


Figure 11. Guideline for Material Selection—Based on pH Value.

The local pitting is due to the chloride ion in the solution attacking the chromium oxide film formed on the surfaces of the stainless steel. This thin protective oxide film provides the material with its normally excellent corrosion resistance. However, once this film is breached and the unprotected material begins to corrode locally, several things take place. First, the pH of the solution at the actively corroding site decreases, making the local environment more aggressive. Second, the region of material which is not corroding because the chromium oxide film remains intact, acts as a cathode to the anodic corroding pit. This produces an unfavorable galvanic relationship between the small area of active corrosion and the large area of protected surface. These conditions produce local corrosion sites which can perforate tubular sections or produce notches on the surface of components that often initiate fatigue cracks.

A stainless steel's resistance to chloride attack is dependent upon the alloy's chemical makeup and the fluid environment. It has been found that chromium, molybdenum and nitrogen increase the local corrosion resistance of the stainless steels to chloride attack. That is, an AISI type 316 stainless steel containing approximately 2.5 percent molybdenum can be used in more corrosive services than AISI type 304 stainless steel that has no intentional addition of molybdenum. The maintenance of a stainless steel's protective film depends upon the quantity of oxygen in the fluid. During idle pump operational periods, the oxygen in the contained stagnant fluid is depleted for various reasons. When there is no longer sufficient oxygen in the fluid to rebuild the chromium oxide film on the stainless steel components, local corrosion will occur.

Crevice Corrosion

Crevice corrosion is a special case of pitting and is associated with the active/passive alloys such as the austenitic stainless steels. In this case, a natural or man made crevice is formed on a metal's surface. These crevices impede the transport of oxygen to the surface of the stainless steel component. If insufficient oxygen is available to maintain or reform the chromium oxide film, as mentioned above, the stainless steel surface will be prone to local corrosion. Crevices in pumps can be found under o-rings, fasten-

ers, or marine organisms that grow on surfaces of a pump component. The outline shown in Figures 12 and 13 is of diffuser vanes that were in intimate contact with a channel ring during a pump's operation in a high-chloride-brine injection service.

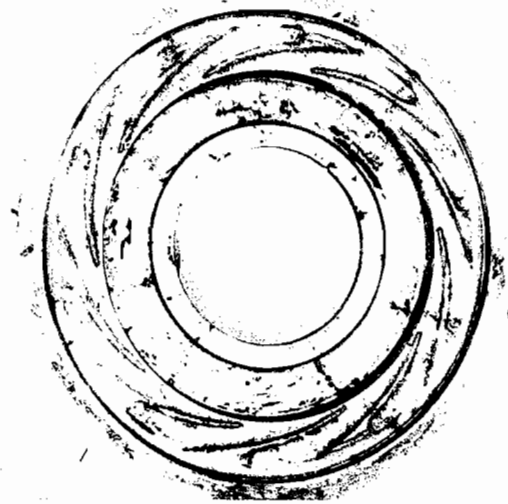


Figure 12. Crevice Corrosion Outlines Location of Diffuser Vanes in this Channel Ring.



Figure 13. Higher Magnification of the Crevice Corrosion Shown in Figure 12. Also shown are several sites of stress corrosion cracking.

Crevice corrosion resistance of austenitic stainless steels have been studied for many years using two standard test solutions. The two primary fluids used for these studies have been either seawater or a laboratory-produced aggressive corrosive solution of ferric chloride. Laboratory testing in ferric chloride is intended to simulate, in an accelerated fashion, the local corrosion of materials by seawater. Since the pH of the ferric-chloride solution is approximately one to two, it resembles the pH values that have been measured in actively corroding pits in a seawater environment. Initial testing was performed by placing an O-ring over the surface of a round specimen with the tight crevice formed at the O-ring/metal interface. Later, a more sophisticated test was designed that gave a quantitative number with respect to the degree of crevice corrosion produced on the test sample. This test employs a

multiple-crevice forming device tightened against a test coupon of material to a specified torque. This ensures a repeatable crevice geometry and crevice tightness from test to test. After exposing the test samples to one of the environment for a certain length of time, the crevice test assembly is disassembled, and the number of crevice corrosion sites formed on the coupon's surface is counted. This number determines a material's relative resistance to crevice corrosion. The test results are shown in Figure 14 of a series of samples exposed to the ferric chloride solution. In this figure, it is fairly obvious that the materials that have fewer crevice sites are more highly alloyed stainless steels. The alloying elements found to be most beneficial for crevice corrosion resistance are chromium, molybdenum and nitrogen.

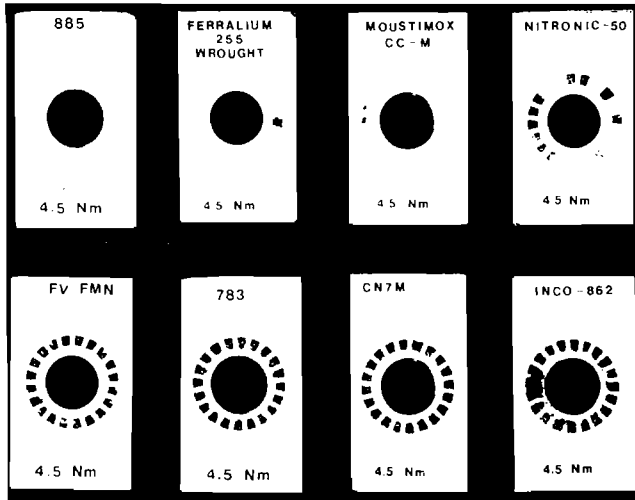


Figure 14. Crevice Corrosion Test Results of Several Alloys, Including IR 885.

Later, researchers found that a more quantitative test could be performed. A critical crevice temperature test (CCT) was devised, which involved increasing the fluid temperature until the first signs of crevice corrosion are observed. This point is referred to as the material's critical crevice temperature (CCT). Because the solution temperature is increased in small increments, this test is able to distinguish between samples that have similar crevice corrosion resistance based on the exposure test mentioned previously. Test results of samples evaluated by Ingersoll-Rand are shown in Table 1.

Stress Corrosion Cracking

Stress corrosion cracking (SCC) can occur in many of the alloys used in the construction of pumps. SCC requires four very specific conditions to occur simultaneously before it is a threat to a pump component. These conditions are:

- A corrosive environment that will produce SCC.
- A susceptible material.
- A threshold temperature.
- A tensile stress, either applied or residual.

If any of these four variables is missing, SCC will not occur. The corrosive environment depends upon the material category. For example, bronze materials are susceptible to SCC in ammonia environments. This form of SCC was dubbed season cracking because it was observed only during warm moist seasons of the year when agriculture products begin to decay, producing ammonium. A susceptible material goes along with the first condition

Table 1. Critical Crevice Temperatures (CCT).

Alloy	Structure	CCT	Reference
Cast IR 885	85% Austenite 15% Ferrite	35°C (95°F)	Ingersoll-Rand
Wrought Al 6X	Austenitic	33°C (90°F)	(1)
Wrought Ferralium 255	Duplex	31.3°C (33.3°F)	Avg. of 2 Samples (2)
Cast Kubota KCR-D283	Duplex	29°C (85°F)	Ingersoll-Rand
Cast Kubota KCR-D183	Duplex	27°C (80°F)	Ingersoll-Rand
Cast Maustinox CCM	Duplex	27°C (80°F)	Ingersoll-Rand
Wrought Ferralium 255	Duplex	27°C (80°F)	Ingersoll-Rand
Cast FV-FMN	Duplex	24°C (75°F)	Ingersoll-Rand
Cast Zeron 25	Duplex	21°C (70°F)	Ingersoll-Rand
Wrought AL 2205	Duplex	20°C (68°F)	(1)
Cast Ferralium 255	Duplex	12.5°C (55°F)	(3)
Wrought 317L	Austenitic	2°C (35°F)	(1)
Cast CF-3M	90% Austenite 10% Ferrite	2°C (35°F)	Ingersoll-Rand
Cast CN7M	Austenitic	1.1°C (30°F)	Ingersoll-Rand
Cast CF-8M	90% Austenite 10% Ferrite	-2.5°C (28°F)	(3)
Wrought 316L	Austenitic	-2.5°C (28°F)	(2)
Wrought 316	Austenitic	-3°C (27°F)	(1)

- (1) J.R. Maurer and J.R. Kearns, "Enhancing the properties of a 6% Molybdenum Austenitic Alloy with Nitrogen", NACE, Corrosion 85, Paper No. 172.
- (2) A.P. Bond and H.J. Dundas, "Resistance of Stainless Steels to Crevice Corrosion in Seawater", NACE, Corrosion 84, Paper No. 26.
- (3) A. Poznansky and P.J. Grobner, "Highly Alloyed Duplex Stainless Steels", 1984 International Conference on New Developments in Stainless Steel Technology, Detroit, Michigan, Sept., 1984, Paper No. 8410-026.

mentioned. Chloride environments can cause SCC in austenitic stainless steels. In most cases a critical temperature at which SCC will occur is needed. The SCC of 300 series austenitic stainless steel in a chloride environment is between 140°F to 160°F, depending upon the alloying of the material. In all cases of SCC, a tensile stress acting on the material is necessary. This stress can be the result of a load action on the engineered component or a residual tensile stress resulting from a process such as welding or heat treatment of a component.

SCC can cause catastrophic failure of a component and can be dangerous because it almost always occurs without any outward signs or warning. An example of SCC of an austenitic impeller in seawater service is shown in Figure 15. SCC is identifiable by the branching cracking appearance unique to this form of material embrittlement. Note the many branching cracks in this figure. This is in contrast to the relatively straight cracking associated with a fatigue cracking mode of component fracture. SCC is shown in Figure 13, along with the crevice corrosion experienced by the channel ring in this brine service. The appearance of a SCC surface is often described as mud cracking. The metal's surface looks very much like a dried-up lake bed. A Nitronic-60 pump impeller is featured in Figures 16, 17, and 18, exhibiting the characteristic features of stress corrosion cracking. This ring was in a multistage brine injection pump handling a high chloride water solution at



Figure 15. Stress Corrosion Cracking of an Impeller Operating in Seawater.



Figure 16. Stress Corrosion Cracking of Nitronic-60 Impeller Wear Rings.



Figure 17. Higher Magnification View of Nitronic-60 Impeller Wear Ring Surface Shown in Figure 16. Note mud cracking appearance due to SCC.

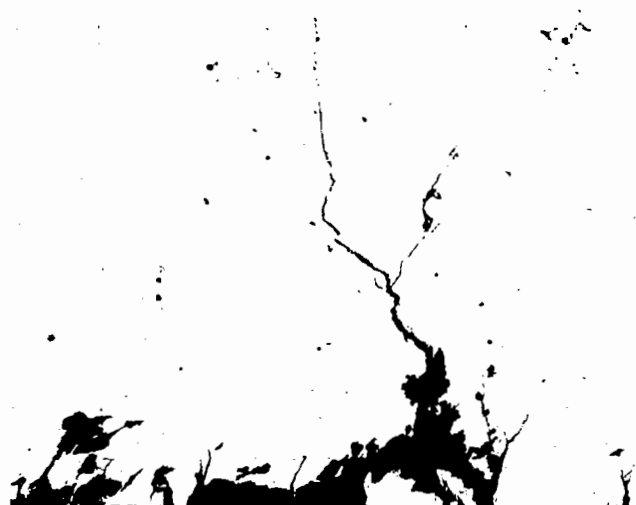


Figure 18. Microsection through Nitronic-60 Ring Showing Branching Cracking Indicative of SCC.

180°F. The tensile stress was due to the shrink-fit of the ring onto the impeller hub.

Galvanic Corrosion

When two dissimilar materials are used in a corrosive environment, caution must be taken to avoid unfavorable area ratios with respect to any galvanic corrosion. Corrosion is an electrochemical process and is influenced by the electric potential that can be generated due to the active corrosion of a material. The relative electric potentials associated with a variety of elements are summarized in the electromotive series. The standard electrode potential (volts) is listed in this table and can be used to determine the likelihood of dissimilar metal corrosion. A variety of tables and charts are available to determine the propensity for galvanic corrosion of electrically connected dissimilar metals in an electrolyte.

A chart often used for this purpose is shown in Figure 19. This Galvanic Series of Metals in Seawater published by F. L. LaQue, shows graphically the differences in electropotential of metals between very resistant graphite to least resistant magnesium. It is a good practice to use materials with similar potentials in aggressive environments if at all possible, especially if the area ratios of the two metals are equal. Another beneficial use of this chart is in the development of sacrificial anodes to protect structures in corrosive environments. In this case a more anodic material, which is easily replaceable, can be attached to another more cathodic material for preserving the latter from corrosion damage. This requires careful consideration of surface area ratios. For example, wasting zinc anodes (very anodic) are frequently used for protection of carbon steel in corrosive environments. A misunderstanding of dissimilar metal corrosion can cause rapid corrosion of the more anodic materials.

Intergranular Corrosion

Usually, this form of corrosion is associated with the austenitic stainless steels. Intergranular corrosion will occur when the material is in a condition that renders it susceptible to corrosion attack along the grain boundaries. If an austenitic stainless steel is exposed to a temperature range between 1150° to 1250°F, the carbon in the material will diffuse toward the grain boundaries. The high concentration of carbon now at the grain boundaries ties up the chromium by forming chromium carbides at this location. This leaves a zone of chromium depletion in the immediate area around the grain boundary, making this area less corrosion resistant than the bulk material. It is not uncommon to find that the

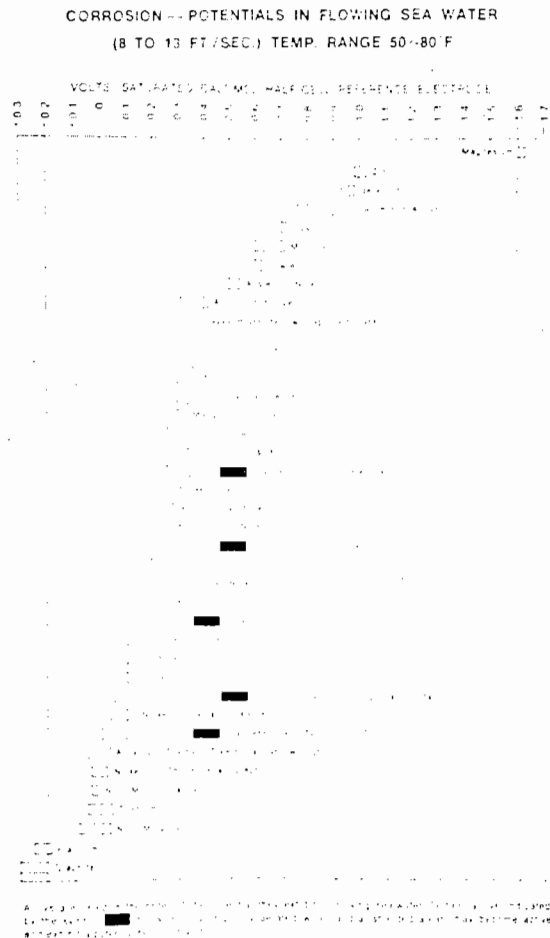


Figure 19. Galvanic Series of Metals in Seawater, Published by F. L. Laque.

depleted zone has less than 12 percent chromium content with the remainder of the material at 18 percent chromium. When this component is exposed to an aggressive environment, selective corrosion along the grain boundaries will occur rapidly.

The Nitronic-60 bushing shown in Figure 20 experienced selective attack along its grain boundaries because the material was sensitized. A higher magnification view, shown in Figure 21, demonstrates that the corrosion attack is limited to the grain boundaries. This amount of corrosion was observed after only nine months of pump service in a sulfuric acid and copper-sulfate solution. Laboratory evaluation of this component and field exposure testing of test coupons identified that the intergranular attack was due to sensitization of the Nitronic-60. This was due to insufficient solution annealing of the material.

Sensitization can result from various manufacturing processes involving heating of austenitic materials. One of the most common sources of sensitization of austenitic stainless steels is welding. During this process, material is heated well above the melting range and cooled from this temperature through the sensitization temperature range. One common practice used to avoid sensitization is the use of low-carbon stainless steels and low-carbon electrodes when welding. The formation of carbides at the grain boundaries depends on the solid-state diffusion of carbon in the material. Therefore, if there is less carbon available, which is the case for low carbon stainless steel (0.03 percent max carbon in AISI-316L stainless steel), carbide formation will be more diffi-

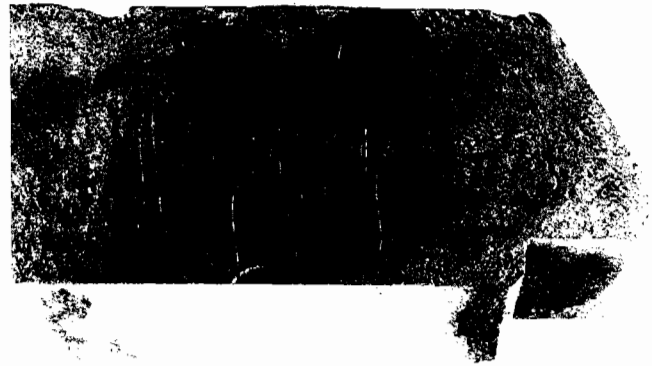


Figure 20. Cross-Section through a Nitronic-60 Center Bushing Showing Gross Areas of Intergranular Attack.

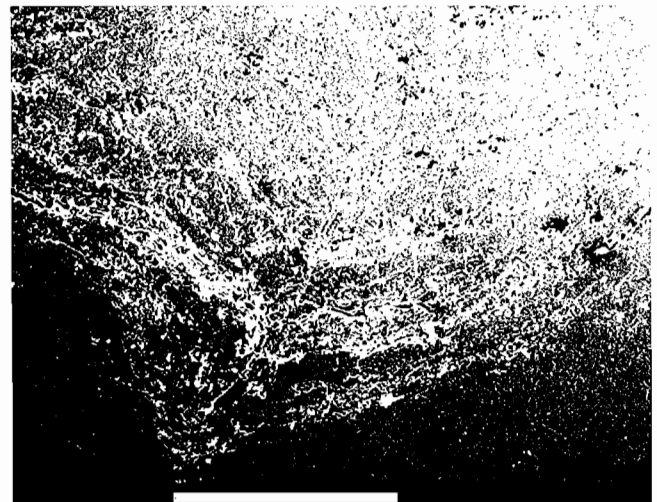


Figure 21. Higher Magnification of Intergranular Attack Due to Sensitization.

cult and take longer to occur. This is in contrast to the standard austenitic stainless steels which can have as much as 0.08 percent carbon. It is also beneficial to employ a low interpass temperature control to the welding process. This control will prevent exposure of the metal to long intervals in the sensitization temperature range.

In all cases, if a material is suspected of being sensitized, a complete solution anneal will remove the threat of intergranular corrosion attack. Solution annealing requires heating the material into a region where the carbon will diffuse back into the matrix of the material. This temperature is typically above 1950°F, followed by a rapid water quench to trap the carbon in the metal's matrix, thereby eliminating chromium carbide formation.

Cavitation

While cavitation often is categorized as a form of corrosion, in fact it is not. Cavitation results when vapor bubbles form in a liquid and implode next to a material's surface. This implosion energy is strong enough to fatigue the material on the surface and mechanically damage this site. Repeated implosions result in local material removal of the component. Often, cavitation is observed on impellers where changes in fluid velocity and fluid pressures may vary significantly along the vanes. Cavitation damage is shown in Figure 22 along the inlet vanes of a high-energy boiler feedwater



Figure 22. Cavitation Damage along Inlet Vane of a 12 Percent CR Boiler Feedwater Pump.

impeller. This damage is located along each of the vanes usually a few inches back from the leading edge. This highly local damage is characteristic of cavitation found on pump components. An unusual case of cavitation at the exit vane tips of a closed-shroud impeller is shown in Figure 23. This was produced when an obstruction in the pump's casing volute caused unusual pressure pulsations at this location.



Figure 23. Cavitation Damage at Exit Vane Tips of an Impeller.

Cavitation can be reduced or eliminated through the utilization of a proper hydraulic design. Research has led to the understanding of vapor bubble formation in impellers and resulted in design criteria for its elimination. In addition to studying the mechanism of cavitation bubble impedance, the research material group has studied cavitation with respect to a material's resistance to this form of damage. These studies were performed using a vibratory cavitation tester built to the requirements of ASTM-G32. In these tests, samples of material were subjected to a controlled cavitation environment. After testing many materials, a relative cavitation resistance database was developed. More significantly, these results determined which material properties were important in resisting cavitation damage. The testing ultimately led to the development of a patented material for improving the life of a component in a cavitating environment such as high-energy boiler feedwater services.

CONCLUSION

Corrosion problems encountered in industrial pumps can vary widely. In fact, several types of corrosion and wear can occur simultaneously, which can mask the symptoms of one or more forms of material damage. The best prevention of corrosion often encountered in pumps is a full understanding of the fluid environment prior to deciding on the materials of construction. Pumps are highly engineered machines which require close tolerances for proper performance. Therefore, the compatibility of a material with the pumpage is essential to the overall satisfaction of the pump user. A complete understanding of corrosion as it relates to the various pump components is vital in achieving the reliability expected today.

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