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# Materials for saline water, desalination and oilfield brine pumps

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# Materials for saline water, desalination and oilfield brine pumps

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## Introduction

Pumps are a critical component of the cooling water system for power plants, desalination plants, other industrial plants and commercial buildings. When the pump fails, the cooling water supply is interrupted unless a spare pump is available to take up the load. Many users install a spare pump to provide uninterrupted service. The spare pump is placed on standby which means that pump materials must be selected not only to meet operating conditions but also to resist standby conditions where under-deposit corrosion, crevice corrosion and microbiologically influenced corrosion (MIC) frequently occur.

Pumps are assemblies of components of different materials, all of which must work together in an electrolyte (water). It is essential that the various materials used in these components be compatible and that the galvanic interactions work towards long service life and low maintenance.

There are five principal considerations that influence alloy selection for cooling water pumps.

1. Corrosion resistance in fresh and saline waters;
2. Corrosion resistance in chlorinated, polluted and deaerated waters;
3. Corrosion resistance in stagnant waters encountered during standby;
4. Resistance to high velocity and turbulence;
5. Galvanic compatibility.

Throughout the text, alloy materials may be identified by Unified Numbering System (UNS) designations or other national designations or by trademarks or other traditional designations of various suppliers or industry associations. Appendix A contains a cross reference to these various designations as well as the nominal chemical compositions of the alloy materials.

The article expresses corrosion rates in both mils per year (mpy) and millimetres per year (mm/y).
One mil = 0.001 inch; one mpy = 0.025 mm/y.

## Saline Waters

The frame of reference for characterizing the behaviour of materials in saline waters is their behaviour in clean sea water. Saline waters are those waters with sufficient electrical conductivity to allow an appropriate pump case material to galvanically protect the internals of the pump when it is shut down or on standby. In this context, saline applies to waters that contain greater than 1000 parts per million (ppm) chlorides.

At many tidal river locations, chlorides are low during most of the year and only exceed 1000 ppm during one or more of the later summer months when river outflow drops well below average. Fresh water practice, rather than saline water practice is frequently followed at such locations. Ground waters from wells in some areas have greater than 1000 ppm chlorides and are considered saline. However, ground waters are normally deaerated. The lack of oxygen modifies corrosion behaviour and greatly reduces galvanic effects. Geothermal waters are also saline with varying amounts of $H_2S$, $CO_2$, and such a variety of other species that pump materials are usually evaluated separately for each geothermal water. The sea water and saline ground water feed to desalination plants are other examples.

Saline waters then include: sea water, coastal and estuarine waters, high chloride ground waters, geothermal waters, desalination feed, oil-field brines and other brines. Saline waters may be either aerated or deaerated.

## Corrosion and Velocity Behaviour

### Saline Water

The corrosion rate of carbon steel increases rapidly from 3 mils per year (mpy)[1] in quiet water to 78 mpy in the same water flowing at 8.2 metres per second (mps) and to 177 mpy at 35-42 mps, as is shown in *Table I.* While the 35-42 mps range considerably exceeds the peripheral speed of pump impellers, which is normally in the 11-22 mps range, the higher velocities are believed to occur at some points in the vortex of turbulent eddies. These data in *Table I* show that carbon steel would have a very short life as an impeller. It is possible to design the case so that a relatively slow moving stream of water protects the

**Table I** Behaviour of common pump materials in quiet and flowing sea water(2)

| | Quiet seawater 0-0.6m/s (0-2 ft/s) | | | | 8.2m/s (26.9 ft/s) | | 35-42m/s (115-138 ft/s) | |
|---|---|---|---|---|---|---|---|---|
| | Average Corrosion Rate | | Maximum Pitting Depth | | Average Corrosion Rate | | Average Corrosion Rate | |
| **Alloy** | **mm/yr** | **(mpy)** | **mm** | **(mils)** | **mm/yr** | **(mpy)** | **mm/yr** | **(mpy)** |
| Carbon steel | 0.075 | (3) * | 2.0 | (78) | - | - | 4.5 | (177) |
| Grey cast iron (graphitized) | 0.55 | (22)* | 4.9 | (193) | 4.4 | (173) | 13.2 | (520) |
| C44300 & C52400 | 0.027 | (1 )+ | 0.25 | (9.8) | 0.9 | (3.5) | 1.07 | (42) |
| C83600 | 0.017 | (0.8)~ | .032 | (12.6) | 1.8 | (71) | 1.32 | (52) |
| C95500 | 0.055 | (2) | 1.12 | (44) | 0.22 | (8.7) | 0.97 | (38) |
| F47001 (austenitic nickel cast iron) (ANI) | 0.02 | (0.8)* | Nil | Nil | 0.2 | (8) | 0.97 | (38) |
| C71500 | <0.02 | <(0.8) | 0.25 | (9.8) | 0.12 | (4.7) | 1.47 | (58) |
| S31600 | 0.02 | (0.8) | 1.8 | (71) | <0.02 | (0.8) | <0.01 | (0.4) |
| N04400 | 0.02 | (0.8) | 1.3 | (51) | <0.01 | (0.8) | 0.01 | (0.4) |

*3-year test at Harbor Island, NC, U.S.A. + 42-month test at Freeport, TX, U.S.A.
~6-year test at Kure Beach, NC, U.S.A.
All of the above data are taken from actual test results and are thus not exactly reproducible. This is particularly true of the maximum depth of pitting which may vary widely from test to test.

surface from impingement of the more rapidly moving stream leaving the impeller. Even so, carbon steel, although low in cost, is only marginally useful as a case material.

Cast iron has about the same corrosion rate as carbon steel initially, but is subject to a special form of corrosion called graphitization. Graphitization is unique to cast iron and is characterized by preferential corrosion of the iron matrix leaving a residue of intact graphite and iron corrosion product having approximately the dimensions of the original cast material remaining in its place. The residue is usually black and soft and easily cut with a knife, sometimes to considerable depth. The rate of corrosion increases very rapidly during graphitization as the data in *Table I* show. Even worse, the graphitized surface acts as a strong cathode forcing both copper alloy and stainless steel internals to corrode at an accelerated rate.

The corrosion rates of the copper alloys also increase with velocity, but the corrosion rates are considerably lower than for steel and lie within a range that makes the copper alloys useful for pump impellers as well as for the case. C83600 alloy (85-5-5-5 or ounce metal) is widely used for small water pumps and for impellers in cast iron water pumps. The cast counterpart of C71500, C96400, is used in Navy centrifugal pumps.

Austenitic nickel cast iron (ANI), UNS designation F47001, has a low corrosion rate in quiet sea water and a useful but fairly high corrosion rate of 0.97 mm/y at 35-42 mps. ANI is widely used for the case, column pipe and transition piece but is unsuitable for impellers and wear rings.

The aluminum and nickel aluminum bronzes generally exhibit corrosion rates of about 0.03 mm/y or less.

Nickel-copper alloy N04400, N04020, and most stainless steels have very low corrosion rates that are not significantly affected by increasing velocities up to 42 mpy. Some stainless steels and N04020 are subject to pitting in quiet sea water and may require cathodic protection during down times or standby service. These alloys make excellent impeller materials because of their good corrosion and cavitation resistance in high-velocity saline water.

### Fresh Water

The corrosion rates of carbon steel, cast iron and copper alloys are somewhat lower in fresh water. The general pattern of corrosion behaviour is usually similar to that in sea water.

Fresh waters are usually aerated. Chlorides normally range from 10-150 ppm, but may range up to 1000 ppm, at which point it should be treated as saline water for materials selection. Corrosion rates for carbon steel and cast iron are controlled by the amount of oxygen reaching any point of the wetted surface, which, in turn, is controlled by the amount of oxygen dissolved in the water and the velocity. Both cast iron and carbon steel perform well in deaerated ground waters but corrode rapidly as aeration increases. The behaviour of copper alloys in fresh water is similar to their behaviour in saline waters although there seems to be a slightly greater tolerance for velocity effects in fresh as compared to saline water.

Crevice corrosion is less of a problem for stainless steel and N04400 in fresh water. Stainless steel cast alloys, CF8 and CF3, and their wrought equivalents, Types 304 and 304L, are resistant to crevice corrosion in waters containing up to about 200 ppm chlorides. Molybdenum-bearing cast stainless alloys, CF8M and CF3M, and their wrought equivalents, Types 316 and 316L, are resistant up to about 1000 ppm.(3)

There is no general consensus as to where fresh water pump materials selection criteria may be used and where saline water materials selection criteria are required. The author suggests that when one or more of the following conditions exist, use saline water materials selection criteria for pumps:

- Coastal waters – greater than 20% of the chloride concentration of full strength sea water;
- Estuarine waters – greater than 4000 ppm chlorides for 4 months or more per year;
- Recirculated cooling tower water – greater than 20% of the chloride concentration of full strength sea water;
- Waters with lower chloride content when pump materials with maximum durability are desired.

## Deaeration,Acidification, and Chlorination

Pumps frequently handle saline waters that are deaerated, acidified and chlorinated. These alterations to natural waters affect material performance.

### Deaeration

Deaeration is beneficial. Performance of both copper-base and stainless steel alloys is enhanced by deaeration. Crevice corrosion of stainless steels is much reduced. Brines for oil field injection are normally treated and deaerated. Deep well, ground waters such as those fed to reverse osmosis (RO) desalination plants are naturally deaerated. Stainless steels have much improved resistance to crevice attack in deaerated brines and deep well waters.

Microbiologically influenced corrosion (MIC) is rare in pumps. When the case materials are less noble than the internals as the author advocates, the internals are protected from corrosion, including MIC, that might otherwise occur. MIC is a potential problem in pumps where components are all stainless steel and to a lesser extent in pumps where components are all copper alloys.

## Acidification

Natural saline waters are generally above pH 6, sea water being above 8. Acidification, as sometimes practiced in desalination, can reduce the solution pH below 6. As pH drops below 6, copper alloys have increasing difficulty in forming good protective films in aerated waters. The aluminum and nickel-aluminum bronzes are somewhat more tolerant and appear to form good films down to pH 5 in aerated waters. In deaerated waters, corrosion resistance of copper-base alloys is outstanding at even lower pH levels.

In a few waters, such as acid mine waters, even lower pH levels of 3 or 4 are encountered. At these pH levels, CF8M becomes increasingly susceptible to localized corrosion, and more highly alloyed stainless steels are preferred. For the low pH, high chloride, high $H_2S$ waters stripped from sour crudes, only the more highly alloyed stainless steels containing 5 to 7% Mo appear to have adequate resistance.

## Chlorination

Chlorination at normal levels of up to 2 ppm residual does not appear to be detrimental to alloys commonly used in saline water pumps, provided injection is made far enough upstream of the pump intake so that dilution occurs in the line ahead of the pump. This is essential. When injection is made at the pump intake, copper alloys, stainless steels and austenitic nickel cast irons may suffer accelerated corrosion. There also have been a few reports of prolonged and excessive chlorination damaging pumps; however, these appear to be gross departures from good practice unlikely to be encountered in most plants.

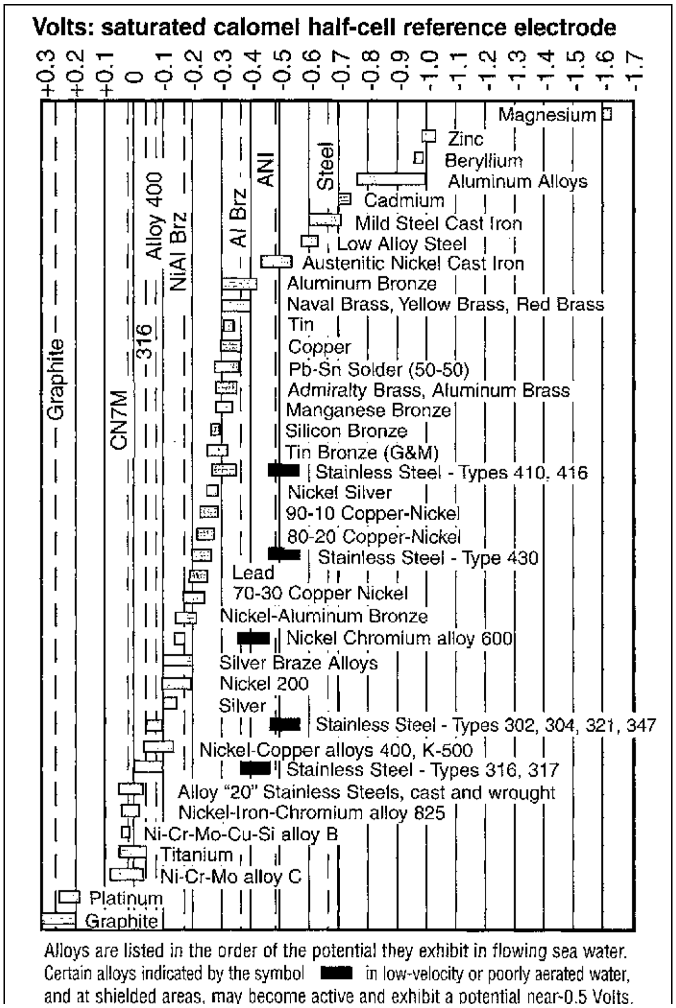
# Galvanic Considerations

For marine service, G and M tin-bronze pumps are fitted with nickel-copper Alloy 400 (N04400) impellers because of the higher erosion-corrosion resistance of alloy 400 as compared to the tin bronzes. Alloy 400 impellers are also galvanically protected by tin-bronze cases. It was not fully appreciated how beneficial the galvanic protection was until nickel copper alloy 400 impellers were tried in some stainless steel (CN7M) cases in which the Alloy 400 was deprived of the galvanic protection it had been receiving from the tin-bronze cases. Service life of Alloy 400 impellers in these CN7M cases proved to be quite short and this combination was abandoned.

The conventional galvanic series is shown in *Figure 1.* Lines have been added at:

| | |
|---|---|
| -0.65V | Mild steel and cast iron |
| -0.5V | Austenitic nickel cast iron (ANI) |
| -0.36V | Aluminum bronze (most anodic Cu alloy) |
| -0.18V | Nickel aluminum bronze (most cathodic Cu alloy) |
| -0.08V | Nickel copper alloy N04400 |
| -0.05V | Type 316/CF8M stainless steel |
| 0.0 | Alloy 20 (CN7M) |
| +0.25V | Graphite |

These are the potentials of most interest in selecting combinations of galvanically compatible materials for pumps.


Volts: saturated calomel half-cell reference electrode

Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol ▬ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near-0.5 Volts.

**Figure 1** Galvanic series

Carbon steel and ANI are about 0.45V to 0.60V more anodic than CF8M and are very effective in preventing crevice corrosion, under-deposit corrosion, and MIC in stainless steel. The area of stainless steel fully protected is ten times that of carbon steel or ANI in sea water at normal temperatures and considerably greater in cold sea water.(4)

The common ANI case-stainless steel impeller combination used in vertical turbine type intake pumps is a classic example of ensuring that the galvanic effect is favourable. The ANI case corrodes preferentially to, and protects the stainless steel internals from under-deposit and MIC corrosion during standby periods. This combination has been in service for at least 50 years, and there have been very few documented cases of impeller corrosion reported in such pumps despite exposure to stagnant waters during extended standby service.

There are generally three sections to the case of these pumps: the inlet or suction bell section, the bowl opposite the impeller, and the diffuser section. In most designs, the bowl opposite the impeller, is upgraded to stainless steel to resist erosion/corrosion in the turbulence at the periphery of the impeller itself. In some designs the diffuser section is also upgraded to welded Type 316L stainless steel. No impeller corrosion problems have been reported in such pumps so long as the inlet or suction bell section is ANI. The cathodic protection afforded by the inlet bell section appears to be adequate for protection of the impeller. In a few instances, the inlet or suction bell, as well as the diffuser and the bowl opposite the impeller, were upgraded to stainless steel. In some of these all-stainless-steel pumps, crevice corrosion was severe enough to require welded repairs and replacement within the first year of operation. Remedial measures included installation of carbon steel anodes in the inlet or suction bell section.

It is the cathodic protection of stainless steel afforded by the ANI case that makes this combination so effective in preventing localized corrosion of stainless steel and in promoting longer service life and lower maintenance. The use of the ANI-stainless steel combination in large sea water intake pumps has proven highly successful with little or no deterioration of the stainless steel impeller and service life of 20+ years reported in numerous coastal installations. Although the ANI case suffers some additional corrosion due to coupling with stainless, the added corrosion has not measurably reduced wall thickness nor decreased service life of the ANI case. When the construction is such that all components are stainless steel except the ANI suction bell, the protection afforded the impeller, shaft and other stainless steel components from corrosion in stagnant water during standby may increase the corrosion of ANI substantially. In such cases it would be well to add a corrosion allowance to the normal wall thickness of the ANI suction bell.

A primary caution about inadvertent galvanic couples with carbon is necessary. Contact with carbon in gaskets, packing, and greases can lead to serious galvanic corrosion of shafting and gasketed surfaces. Gaskets and packing that contain graphite must be rigorously banned from saline water pumps. They are easily identified; they are black. White gaskets and white packing are preferred, in fact, required.

In fresh waters, the galvanic effects are less because of the greater electrical resistance of fresh water. However, accelerated corrosion of impellers due to graphitization of cast iron cases, as previously discussed, can occur in fresh water as well as saline waters.

# Pump Component Materials

## Vertical Turbine Pumps

Ferrous materials combinations that are compatible and have proven to be effective and efficient in saline waters are shown in *Table II.* This is followed by a short discussion of each component, after which *Table III* shows the less expensive materials commonly used in fresh water.

**Table II** Ferrous materials for vertical turbine pumps for saline water service

| Part | Reference | Alternatives |
|---|---|---|
| Transition Section | CF3M, 316L(W) | ANI-D2W/D2 (FSR)<br>Epoxy coated steel |
| Column Pipe | ANI-D2W, D2, 316L(W) | Epoxy coated steel |
| Diffuser | ANI-D2W/D2-(FSR) | 316L (W) |
| Bowl | ANI-D2W/D2 (1) with 316 shroud | CF8M |
| Inlet Bell | ANI-D2W/D2(1)(2) | ANI-D2W/D2(1) |
| Impeller | CF3M CF8M, CD4MCu | Austenitic and duplex stainless steels with Mo |
| Shaft | N04400,316 | N50,2205 |
| Shaft Sleeve | N04400 & 316L $CrO_2$ coated | N04400,316 |
| Wear Rings & Bolting | Discussed under field experience | |

FSR= Furnace stress relieved W= Welded

(1) FSR is recommended for these components as multiple cases of SCC have been reported for unstress-relieved ANI in these components.

(2) When fabricated 316L is used for the diffuser section, it is necessary to increase the wall thickness of the inlet or suction bell in order to compensate for the increase in galvanic corrosion of the ANI inlet or suction bell that will result from a change to stainless steel or copper alloy for the diffuser section.

Austenitic nickel iron (ANI) refers to austenitic grey iron – ASTM A436 grades 1, 1b and 2; to austenitic ductile iron – ASTM A439 grade D2; and to a niobium-containing variant of D2, referred to as D2W, which is popular in Europe, but not covered in ASTM A439. Currently the preferred grades are D2 or D2W. The older grades of ANI–A436, 1, 1b and 2 have built up an excellent service record over the last 50 years except in the diffuser section where all grades are subject to stress-corrosion cracking unless furnace stress relieved. Experience has shown very little difference in the corrosion and velocity resistance of the four grades of austenitic iron.

Stress-corrosion cracking of ANI can occur in warm deaerated brines as well as in saline cooling waters. Producers and users have been reluctant to specify furnace stress relieving because of the extra cost. However, experience has shown furnace stress relieving is essential for the diffuser section and most advisable for the other sections, especially the transition section.

Reference materials have given outstanding service. These and alternative materials are discussed under each section.

**Transition Section –** This is usually a large casting with an elbow and an external platform to support the motor and shaft. The principal problems reported relate to casting quality and repair, shrinkage cracks, incompletely fused chaplets etc. CF3M is preferred over CF8M and ANI-D2W (FSR) over ANI-D2 (FSR) for the transition section to facilitate weld repairs of defects at the foundry. Epoxy coated steel is a lower cost alternative material but is subject to serious corrosion at those points where abrasive wear and turbulence lead to local breakdown of the coating.

**Column Pipe –** The column pipe is either ANI-D2, ANI-D2W or weld fabricated Type 316L designated Type 316L(W) in Table I. Epoxy coated steel performs somewhat better in the straight sections of the column pipe but is still subject to early failure in the section just above the diffuser where impingement and turbulence are greatest.

**Diffuser Section –** ANI vanes in the inlet section of the diffuser are subject to slow erosion-corrosion on the leading edge. Metal loss is usually low enough for a service life of more than 20 years to be achieved. Un-stress-relieved ANI diffuser sections tend to crack in the area where the thin vanes meet the heavier wall of the shell. The cracks, which propagate slowly, are usually visible within 1-to-3 years if they are going to occur at all. Furnace stress relieved (FSR) austenitic iron diffuser sections have an excellent track record with service life of more than 15 years without cracking. FSR is preferred to stress relief in the mold by slow cooling unless the mold is made with a collapsible core. Even with a collapsible core the user receives no documentation of the stress relief cycle as he does with a furnace chart.

Some diffuser sections have been redesigned for welded fabrication in Type 316L and C61400.

**Bowl –** The bowl section opposite the impeller may be ANI-D2 or D2W with a Type 316 internal sleeve, or a stainless steel casting – CF3M or CF8M. ANI is subject to erosion-corrosion rates as high as 100 mpy when the high velocity stream from the impeller is allowed to impinge directly upon an ANI wall. The stainless steels, CF3M and CF8M, are not subject to the same erosion-corrosion, and the high-velocity surface scouring may actually enhance the performance of CF3M or CF8M.

**Inlet Bell –** The inlet bell is a relatively simple casting. As more pump cases are converted to stainless steel and more diffuser sections are fabricated from stainless steel or copper alloys, the role of the ANI inlet bell in providing galvanic protection to the stainless steel internals becomes increasingly critical. The author considers it essential that the inlet bell be ANI to prevent under-deposit and microbiological influenced corrosion of the stainless steel components of the pump assembly–especially the impeller and shaft during inevitable standby service.

**Impeller –** The principal impeller material continues to be CF8M. Although repair of stainless steel impellers during service is rare, CF3M is sometimes preferred to assure freedom from sensitization during foundry weld repair. CD4MCu, a cast duplex alloy, has been increasingly and successfully used as an alternative to CF8M impellers. There are also numerous proprietary modifications of CF8M offered by foundries for impellers. These cannot be reviewed in detail, but as long as Cr and Mo exceed that of CF3M, they would be expected to offer good performance. More detailed information on the duplex alloys that are performing so well is given later in the section reporting on alloy experience.

**Shafting –** The principal shafting materials have been N04400 and Type 316. The higher strength of N04400 offsets some of its higher cost, but Type 316 stainless steel remains the principal shafting material. The duplex stainless steel, 2205, and a high manganese proprietary alloy, N50, have also been used for shafting. In terms of corrosion resistance, these two high strength shafting materials would be expected to perform as well or better than Type 316. Pump manufacturers using 2205 or other alloy shafting should ensure that there will be no more distortion during machining than with the more traditional N04400 or Type 316.

Wear rings and bolting materials are reviewed in the later section on field experience.

**Table III** Ferrous materials for vertical turbine pumps for fresh and mildly brackish waters

| Part | Reference | Alternatives |
|---|---|---|
| Column pipe | Epoxy coated steel | |
| Diffuser | ANI-D2W/D2 (FSR) | 316L (W) |
| Bowl | 2% Ni Cast Iron<br>with 316 shroud | CF8M |
| Inlet Bell | 2% Ni Cast iron | |
| Impeller | CF3M, CF8M,<br>CD4MCu, CF3, CF8 | Austenitic and duplex stainless steels |
| Shaft | S31600 | N50, 2205 S30400 |
| Shaft sleeve | S31603 $CrO_2$ | S31600 |

FSR= Furnace stress relieved W= Welded

The impeller and shaft are normally stainless steel as shown in *Table III.* These components have little tolerance for corrosion. The impeller and shaft are sometimes downgraded to the molybdenum free grades when there is an appreciable cost saving. Two-percent Ni cast iron is frequently used for the inlet bell and those portions of the case protected from velocity and impingement. Two-percent Ni cast iron is preferred to grey iron for the better distribution of graphite which enhances resistance to graphitization. Ductile iron is sometimes used as an alternative to 2% Ni cast iron for the same reason. It should be stated clearly that 2% Ni cast iron is not an austenitic cast iron and does not exhibit the low and uniform corrosion rates of the ANI in natural waters. Two-percent Ni cast iron is a less expensive alternative case material of limited usefulness in fresh water and may be subject to early failure in saline water.

### Copper Alloy Vertical Turbine Intake Pumps

*Table IV* shows the principal copper alloys used in large vertical turbine intake pumps. The copper alloy construction is used as an alternative to ferrous alloy construction. While good performance has been reported in inland and recirculated waters with chlorides as high as 12,000 ppm, there have been multiple erosion type failures of nickel aluminum bronze impellers and wrought aluminum bronze diffuser sections in sea water. These are discussed in the section on alloy experience.

**Table IV** Copper alloys for vertical turbine pumps for brackish and recirculated waters with up to 12,000 ppm chlorides

| Part | Reference |
|---|---|
| Column pipe | C61300(W), C61400(W) |
| Diffuser | Modified C95500*,<br>C61300(W), C63000(W) |
| Bowl | C95400, C61400(W) |
| Inlet bell | C95400, ANI-D2W/D2 |
| Impeller | Modified C95500* |
| Shaft | C63000 |

(W)=Welded

*C95800 HT has been used for impellers and diffusers but has suffered erosion-corrosion failures in sea water service. Refer to section on alloy experience. Modified C95500 is discussed later under “Copper Alloys”.

## Centrifugal Pumps

Centrifugal pumps are generally smaller with less components and are positioned in a manner that provides better access for maintenance than vertical turbine pumps. Centrifugal pumps are not routinely placed on standby service as are vertical turbine intake pumps. Materials used in centrifugal pumps by the US Navy are shown in *Table V.*

**Table V** Some materials used in Naval centrifugal pumps

| Part | Stainless Steel | Weldable Nonferrous Alloys | | WWII |
|---|---|---|---|---|
| Case | CN7M | C96400 | IN768 CrCuNi | C90300, C92200 |
| Impeller | CN7M | N04400 | C95800 HT | N04400 |
| Shaft | 20Cb3 | N04400 | N04400 | N04400 |
| | N05500 | N05500 | N05500 | |

Naval pumps must withstand rigorous operation. Again, the case of the pump should be anodic to the impeller and shaft and should be selected from materials that will corrode preferentially to, and cathodically protect the impeller and shaft during standby periods. The IN768 CrCuNi has somewhat higher strength than C96400, 70-30 CuNi, and is used by the British Admiralty.

CN7M is used in high pressure, continuous duty pumps which operate in port and at sea. The carbon content (0.07%) precludes weld repair of crevice corrosion defects without sensitizing the alloy and, therefore, limits its usefulness. ASTM has been requested to include an 0.03% C max grade in applicable specifications to overcome this limitation.

Commercial practice usually differs from naval practice. For copper alloy pumps, C83600 (Ounce metal, 85-5-5-5) is standard for most small and many large centrifugal pumps handling saline waters. Ferrous practice for saline water is normally CF3M for case and impeller and Type 316 for the shaft, an all stainless steel centrifugal pump without built-in cathodic protection. Centrifugal pumps tend to operate continuously rather than intermittently which makes them less prone to under-deposit and MIC type corrosion. Maintenance usually consists of C83600 alloy impeller replacement in copper alloy pumps and weld repairs of pitted areas in CF3M cases in stainless steel pumps. CF3M should be specified for the cases.

### High Pressure Oil Field Water Injection, and Reverse Osmosis Pumps

These multistage centrifugal pumps have evolved considerably over the years. The early pumps injecting water into oil producing strata were either stainless steel or nickel aluminum bronze. Although the waters are normally saline up to and including sea water, corrosion is not a significant problem as it is necessary to deaerate, and treat the water for it to be effective in displacing oil from the older fields. Some fatigue failures occurred, which were subsequently prevented by redesign. These early pump materials have been augmented with nickel alloys and duplex stainless steels.

*Table VI* gives the corrosion fatigue strength of some of these materials. One of the most commonly used shaft materials is Type 316 stainless steel. The data on cast Type 304 stainless steel are included to show the pronounced beneficial effects of cathodic protection on corrosion fatigue strength; in this case more than doubling the unprotected value.

With the development of nitrogen additions to the cast duplex stainless steels resulting in higher strength and good corrosion resistance there is widespread use of duplex stainless steels in these and similar high pressure pumps, as shown in *Table VII*. Duplex stainless steels are discussed in the section titled "Alloy Experience", which follows.

**Table VI** Rotating cantilever beam tests in natural seawater 1450 rpm. All values in Mpa at 100 megacycles (48 days)[2]

| Alloy | Ultimate Tensile Strength | Corrosion Fatigue Limit |
|---|---|---|
| Alloy 625 (N06625) | 1028 | 345 |
| Alloy 400 (N04400) | 1214 | 179 |
| CF-4 | | 62 |
| CF-4 (with cathodic protection) | | 138 |
| Nickel aluminum bronze (cast) | 600 | 86 |
| Type 316 stainless steel | 586 | 96 |

**Table VII** Materials for high pressure oil field brine and reverse osmosis pumps

| Part | Duplex | Austenitic | Copper Alloy |
|---|---|---|---|
| Case | Duplex | CF8M | C95400 |
| Impeller | Duplex | CF8M | C95800 HT |
| Shaft | Duplex | 316 | C63000 |

Fatigue and strength are paramount in selection of materials for high pressure pumps. Nickel aluminum bronze was preferred over CF8M for the earlier oil field brine injection pumps because of its higher corrosion fatigue strength. In deaerated brines, stainless steel is quite resistant to crevice corrosion allowing CF8M oil field pumps to perform for up to 20 years with little or no corrosion problems. The higher strength and good corrosion resistance of some of the newer duplex stainless steels is making them the material of choice for these pumps today.

## Alloy Experience

Pumps are multicomponent systems operating in an environment where galvanic corrosion occurs. For intake pumps, the austenitic iron – stainless steel system has proven very effective in preventing localized corrosion of stainless steel components that, in the absence of galvanic protection, would occur. For shipboard centrifugal pumps, the copper alloy case with nickel copper alloy internals have also given very good service for the same reason – the case galvanically protects the internals.

## CF3M, CF3MN, CF8M and Related Proprietary Grades

The Mo-containing grades, especially CF3M and CF8M, are the principal alloys used in industrial seawater pumps. When galvanically protected by an ANI case, service life of upwards of 20 years is reported with little or no metal loss in saline .waters. There are a variety of low Mo content proprietary cast stainless steel alloys that perform in much the same manner as CF8M. One Gulf Coast plant reports 20 plus years service with Mo-free CF3 impellers in large sea water intake pumps when fitted with sacrificial anodes.

The low-carbon CF3M grade is preferred, especially for larger pumps where post-weld heat treatments after all weld repairs is not always practical. Since the lower carbon content is accompanied by lower mechanical properties, some manufacturers use the higher-strength nitrogen-containing variation, CF3MN, to restore mechanical properties and avoid sensitization during weld repairs.

## CN7M

More highly alloyed stainless steels began to be used in selected naval service in the 1950s. Worthite, a proprietary alloy, was the first stainless approved for naval pumps. In the 1960s, CN7M replaced bronze for the arduous-duty fire-fighting pumps on US Navy vessels. Water for fire fighting is taken from the service water system, and these pumps operate continuously in port as well as at sea. The CN7M alloy has shown excellent resistance to erosion from the silt and sand ingested during operation in shallow water. Some crevice corrosion occurs under the stationary O-rings used in some designs and under gaskets. Corroded areas can be ground out and rewelded with Alloy 625 filler metal without post-weld heat treatment provided the carbon content is kept below 0.03% instead of the 0.07% allowed in ASTM A743/A743M and A744/A744M.

Severe crevice attack as been reported on some CN7M/20Cb3 vertical turbine intake pumps at a Mid-East desalination plant during an extended 9 month standby period in saline waters. Pitting attack required replacement of the 20Cb3 shafting and repair of the CN7M impellers. The inlet bells were fitted with sacrificial steel anodes on these pumps, to prevent a recurrence of corrosion.

## 5-7% Mo Alloys

A need arose during the 1970s for a multistage high pressure pump to inject a low pH, high chloride, high $H_2S$ brine stripped from sour crudes into deep disposal wells in Saudi Arabia. Materials considerably more resistant than CF8M, Worthite, and CN7M were needed. A new 5% Mo composition, IN 862, was selected for this aggressive service. There were 48 pumps in paired sets, with 24 operating and 24 on standby at all times. Inspection after 6 years revealed little or no corrosion of the IN 862 case and impeller. The Nitronic 50 (N50) shafts were severely corroded and were replaced with Alloy 625. Extensive testing shows the IN 862 and other 5-7% Mo-containing stainless steels to be resistant to crevice corrosion in sea water. Several foundries in the United States and Europe have introduced a cast 5-7% Mo alloy for valves and fittings for offshore oil sea water piping and for reverse osmosis-type desalination plants. This cast alloy, CK-3MCuN, is similar to S31254 and is intended for use with S31254 piping. More recently, CN3MN, a cast counterpart to N08367, another 6% Mo alloy, has been introduced for valves and pumps for nuclear power plant raw water cooling systems which are beginning to use N08367 piping. In these high Mo compositions, a nitrogen addition and close control of ferrite are necessary for weldability and corrosion resistance.

## Duplex Stainless Steels

While the older CD4MCu duplex stainless steel was very useful as an impeller in saline water pumps, it was the ability to add nitrogen to the cast duplex compositions that made these alloys increasingly useful in pumps. Nitrogen, in addition to improving the ductility and the weld-reparability of duplex stainless steels, also reduced the partitioning of chromium between the ferrite and austenite. The reduction in partitioning of chromium improved the pitting resistance and contributes to the improved corrosion resistance of this family of materials.

The cast duplex stainless steels used in high pressure pumps are primarily proprietary alloys containing about 25Cr, 5-6Ni, 2-3Mo with N and sometimes Cu (see *Appendix A).* The Nitrogen addition is particularly helpful in improving corrosion resistance. As cast, these duplex stainless steels contain about 80% ferrite. After heat treatment, the alloys exhibit approximately a 50% austenite, 50% ferrite composition. Producers' recommendations should be followed carefully.

One of the earlier uses of these nitrogen-enhanced duplex stainless steels was in oilfield seawater injection pumps, especially on offshore oil platforms where the weight saving due to their higher strength resulted in cost savings in support structure.

A typical large injection pump would have 20,000 hp and deliver 9000 US gallons per minute at 2800 psi. Materials are generally as follows:

| | |
|---|---|
| Case | Duplex |
| Impellers | Duplex |
| Shaft | N04400, Alloy 625, Nitronic 50, Duplex |
| Wear rings | Duplex, Waukesha 88, Stellite |
| O rings | Alloy 625 overlay in seal areas when standby periods are anticipated. |

Proprietary cast duplex stainless steels have been employed in more than 50 water-flood-type installations injecting deaerated sea water into oilfield formations in the North Sea and in the Mideast.(2) Generally good performance was reported with up to 11 years service. So few problems have been reported that time between overhauls is being extended from 20,000 to 40,000 hours.

The success achieved with duplex stainless steels in high pressure oilfield injection pumps has led to increased use in both vertical turbine and centrifugal pump saline water applications. Where best resistance to pitting and crevice corrosion are required the more highly-alloyed grades are used. Even the lower-alloyed grades have been used with appropriate precautions of either flushing with fresh water and draining, or circulating an hour a day, if pumps must be left full while on standby. In some North Sea offshore oil platforms entire sea water systems, pumps, piping, and valves have been fitted in the higher-alloyed duplexes based on weight reduction and attendant cost savings.

### Austenitic Cast Iron (ANI) ASTM A436/A439

ANI cases have proven very effective in protecting stainless steel impellers and shafting from localized corrosion that otherwise would occur during standby periods. The older, widely used, Type 1b high-chromium austenitic grey iron, the copper-free Type 2, the higher-strength Type D-2 and, in Europe, the more weldable version of D-2, Type D-2W, have all been used successfully as case materials. Despite the fact that early tests indicated that high chromium content (Type 1b) might have somewhat better erosion resistance, little practical difference in the erosion-corrosion resistance of these grades under actual operating conditions has been found. Since the higher-chromium content increases machining costs and has higher shrink, chromium is now kept to the low side of the range.

Although ANI has performed exceptionally well as the inlet bell, it can suffer erosion-corrosion at rates up to 2.5 mm py (0.1 ipy) when used for the bowl. Some owners are satisfied with the resulting 5-10 year life and replacement of the bowl section. Others utilize a Type 316 protective liner or make the bowl of CF8M or CF3M. The stainless components are galvanically protected by the ANI above and below the bowl and have given up to 20+ years service.

It is in the diffuser section that ANI has limitations. The principal problem is delayed cracking, usually where the thin vane joins the heavy wall of the case. Controlling chromium content to reduce shrink and providing generous vane-to-wall fillets can greatly reduce the incidence of cracking. Carefully controlled foundry practices are essential.

Stress corrosion cracking (SCC) has also occurred in other ANI pump components. Stress relief in a properly equipped furnace at 620-675°C (1150-1250°F) for 1 hour per inch of thickness after shaking out of the mold and cleaning up has proven to be very effective in preventing SCC. A survey of ANI pumps in Mideast desalination plants found that ANI diffuser sections that had been furnace-stress-relieved were virtually free of cracking. However, there was a significant incidence of SCC of ANI pump components that had not been furnace-stress-relieved.$^{(2)}$

One large inland power plant experienced multiple instances of cracking in the vane to wall area of A436 Type 1 austenitic iron diffusers that had not been stress relieved. During the replacement period, an A439 Type D2 diffuser, furnace-stress-relieved at 650°C, was purchased and placed in service. One of the original non-stress-relieved diffusers with the least cracking was furnace-stress-relieved at 650°C, and returned to service. Both of these stress relieved diffusers were carefully inspected after one year in service. There was no progression of the minor cracking in the original diffuser, and no cracking at all in the newly purchased furnace stress-relieved one.

Slow cooling in the mold has proven to be less effective than furnace stress relief for two reasons: there is usually a need to take a large casting out of the mold early so that it will cool faster to make room for other work, and it has been found that mold cooling does not insure full stress relief unless the core is collapsible.

The ASTM specifications treat stress relief as optional. Users must request furnace-stress-relief in the procurement documents.

## Copper Alloys

The tin bronzes, G (C90300) and M (C92200), aluminum bronze (C95400), and nickel-aluminum bronze (C95800HT) as well as the more common 85-5-5-5 (C83600), sometimes termed *Ounce metal,* and sometimes *leaded red brass,* are popular materials for saline water pumps. Wide availability and ease of replacement make C83600 useful for small centrifugal pumps where low first cost rather than durability is the primary consideration. C90300 and C92200 cases with N04400 impellers were standard for WWII naval vessels and are still widely used in commercial ships and in less-demanding naval services.

After WWII, the US Navy adopted C96400 (70-30 CuNi) for the case to provide better weldability from battle damage and routine overhaul. In England, a 1.7% chromium version of C96400 alloy, BS 1400 CN1, has been used successfully as a case material. N04400 was the principal impeller material for copper alloy pumps until the US Navy approved C95800-HT (nickel-aluminum bronze) as an alternative for use in C96400 cases. A key consideration is to select material combinations so that the impeller is noble to, and will be cathodically protected by, a less noble case material.

The principal aluminum bronze and nickel aluminum bronze alloys used in pumps include C61300/C61400 aluminum bronzes, cast C95400 aluminum bronze, and cast C95800-HT nickel aluminum bronze. The C61300/C61400 aluminum bronzes are used primarily for weld-fabricated components such as the column pipe and diffuser section. The C95800 (HT) alloy is heat treated at 650°C (1200°F) to prevent dealuminification.

Although some erosion/corrosion failures of C95800-HT impellers in sea water have been reported, excellent performance has also been reported in inland waters with chlorides up to 12,000 ppm. It has been suggested that the heat treatment required to prevent dealuminification in the C95800 alloy also reduces resistance to erosion/corrosion in sea water, but this has not been confirmed in laboratory testing. However, for this reason, a modified C95500 composition is suggested for impellers in *Table IV.*

Weill-Couly recommends a modified C95500 alloy containing a maximum of 5% Ni and a balanced aluminum-nickel ratio within the C95500 composition limits. Aluminum is controlled to 8.2% plus 0.5x%Ni to a maximum of 10.7% aluminum. Iron content is kept below the nickel content to a maximum of about 4%. A slow cool is recommended to avoid dealuminification. The Weill-Couly modified composition falls within the rather broad ranges of C95500 and is the basis for the “modified C95500 alloy” in this report.

Although there has been no specific experience with this modification of the C95500 alloy as pump impellers, the alloy is certainly within the composition range for C95500 ship propellers, which have given excellent performance on naval and merchant ships without the heat treatment required to prevent dealuminification. Ship propellers receive cathodic protection from the hull cathodic protection system. Weill-Couly suggests that the modified alloy, slow cooled, should be resistant to dealuminification without heat treatment or cathodic protection.

Future service experience will establish the merits of the modified C95500 alloy for pump impellers.

Aluminum bronze C95400 is suggested for the inlet or suction bell as it is anodic to, and will provide some protection for, the modified C95500 nickel aluminum bronze impeller during standby periods. If more protection than C95400 can provide is desired, ANI-D2 or D2W could be used for the inlet bell.

## Nickel-Copper Alloys (N04400 and N04020)

Nickel-copper-alloy impellers have been standard for copper alloy saline water pumps for so long that the weldable, cast nickel-copper alloy normally used has had a variety of designations: EMonel, Monel 411, QQ-N-228 composition A and E and M-35-1 or M-30C in ASTM A494. In this report the UNS designation N04400 is used for the more common grade and N04020 is used for the weldable cast alloy. M-35-1 limits Si to 1.25% and M-30C limits Si to 2.0% to improve weldability. As a rule, nickel-copper-alloy components should not be used in stainless steel cases because of the unfavourable galvanic relationship between the two materials.

## Other Constructions

Cast iron and 2% nickel cast iron are frequently used as case materials in lower salinity waters with copper alloy, N04400 or stainless steel impellers in low speed pumps to reduce cost. The corrosion rate for cast iron and nickel cast iron in sea water increases with velocity. The use of these alloys is limited to low-speed pumps. While initially cast iron and nickel cast iron afford protection to the impellers, after a year or so in service a more or less continuous film of graphite can form. When this happens the galvanic relationship reverses and the graphite accelerates impeller corrosion. This has frequently been reported when copper alloy impellers are used in cast iron pumps. Replacement copper alloy impellers seldom last as long as the copper alloy impeller fitted in the original (new) cast iron case.

## Wear Rings

Wear rings are essentially seal rings separating the low- and high-pressure sides of the pump. As rings wear, clearance increases and pump efficiency falls off. Low wear rates under high turbulence are a major requirement for wear rings. Because wear rings rotate in close proximity, resistance to galling is also a requirement. A third requirement is that the wear ring must be at least as noble as the case or impeller to which it is attached. These three requirements have led to a variety of alloys being used for wear rings. Since efficiency falls off as clearance between wear rings increases, pump maintenance personnel seem always to be changing wear ring materials to obtain a longer life between shutdowns. There is little site-to-site agreement on the relative effectiveness of various alloys used for wear rings. The following experience with wear ring materials is offered to assist in wearring alloy selection. These are only guidelines, not final answers.

In vertical turbine pumps, resistance to erosion-corrosion tends to outweigh resistance to galling since the wear rings are not loaded as they are in pumps with horizontal shafts. Many plants have found that with attention to bearing alignment, Type 316 and other austenitic stainless steels can be used for wear rings despite their tendency to gall. The austenitic stainless steels have excellent resistance to erosion-corrosion.

Many experts advocate the use of different alloys for the case and the impeller wear ring. The problem here is to be sure that both alloys have adequate resistance to sea water. Ferritic stainless steels have better resistance to galling but corrode readily in saline waters. The precipitation-hardening stainless steels have better resistance to galling but, lacking molybdenum, also corrode readily in sea water. Despite their better resistance to galling, the ferritic and precipitation hardening stainless steels are not good candidates for wear rings.

Two case/wear-ring combinations are being tried and evaluated currently.

1) Type 316 / Nitronic 60 – A proprietary alloy designed to have good galling resistance but lacking Mo needed for corrosion resistance in saline water.
2) Type 316 / Duplex – The duplex stainless steels, being half austenitic and half ferritic seem to have somewhat better resistance to galling than fully austenitic materials and have good corrosion resistance in saline water.

Many other combinations are in use with varying results. The following comments provide some useful information on wear ring materials.

- Many tables ranking wear resistance have been published. That published by the American Iron and Steel Institute, *"Review of the wear and galling characteristics of stainless steel," is* one of the better ones.(6)

- Type 316 has been used successfully in vertical turbine pumps where there is minimal contact of the case and impeller wear ring.
- Nitronic 60, a high-Si high-Mn 18Cr 8Ni stainless steel, is reported to show excellent resistance to galling against itself and most austenitic stainless steels. It is being tried as wear rings in saline water pumps but has not yet established a track record. The lack of molybdenum in the composition suggests that it is likely to be susceptible to crevice attack in saline waters when pumps are idle on standby.
- Waukesha 88 has good resistance to corrosion and erosion-corrosion, and outstanding resistance to galling when running against stainless steels.
- M-25 high-silicon nickel-copper alloy, has an excellent performance record in service as wear rings. Limited ductility and the need to finish by grinding, rather than machining are principal factors limiting its use.
- The tin bronzes, C51000, C52100 and C52400, the aluminum bronzes C61300/C61400 and C95400, and the nickel aluminum bronzes, C95500 and C95800-HT all have outstanding resistance to galling. These alloys are used as wear rings in copper alloy pumps. The C95500 -Type 316 stainless steel combination is popular for wear rings in large fresh and saline water pumps. C95500 is resistant to galling in contact with stainless steel and has the best resistance to the high turbulence in the vicinity of wear rings. Although some metal loss of C95500 due to turbulence does occur, it is usually low enough so that performance is not significantly impaired before the pump is removed for overhaul for other reasons. Since erosion-corrosion of wear rings results in increased clearance and a gradual decrease in pump performance, it is important to select wear ring materials with the greatest resistance to erosion-corrosion in saline waters. It is also important to select wear ring materials that are compatible galvanically with the impeller and the case of the pump
- ANI has outstanding resistance to galling when running against stainless steel, but it is not resistant to erosion-corrosion. It is also anodic to copper alloys and to stainless steel. ANI is not a good choice for wear rings.
- Stellite and Colmonoy hard facing materials have outstanding resistance to galling but are limited in saline-water pumps by galvanic corrosion effects. The galvanic relationship is such that either the hard facing or the substrate suffers accelerated attack. Service life is limited either way. Nevertheless, both Stellite and Colmonoy are used where wear rate, rather than corrosion resistance, controls the selection.

### Bolting

N04400 (Alloy 400) is still the leading material for casing bolts in saline water pumps. N05500 (Alloy K500) is used where higher strength is needed.

Type 316 stainless steel bolting does well where one flange is ANI, but it is subject to crevice attack when both flanges are stainless steel. The precipitation-hardening stainless steel, 17-4PH, has higher strength but requires more corrosion protection than Type 316. Care should be taken to avoid any use of Type 303 free-machining stainless steel. Type 303 experiences rapid corrosion in sea water, which does not seem to be appreciably reduced by cathodic protection from less noble materials.

Aluminum bronze is a good bolting material for copper alloy cases. Silicon bronze bolting can suffer high corrosion rates in saline waters and is best restricted to short term applications or as a temporary expedient.

## Heat Treatment

The stainless steels and aluminum bronzes generally require post-weld heat treatment after weld repairs to restore full corrosion resistance in the heat-affected zone of the weld.

For stainless steels the intent is to prevent intergranular attack in the heat-affected zone and to homogenize molybdenum in the cast structure of the weld. The temperature to insure homogenization of molybdenum requires furnaces capable of reaching temperatures greater than 1066°C (1950°F).

For cast C95800 nickel-aluminum bronze alloy, the intent is to prevent dealuminification corrosion. The alloy is usually heat treated at 650°C (1200°F) for 6 hours and air cooled. *Table VIII* provides guidelines for post-weld heat treatment. Aluminum bronze and nickel-aluminum bronze castings may be weld repaired without post-weld heat treatment if the interpass temperature of the heat affected zone does not exceed 316°C (600°F) for an extended time.

**Table VIII** Guidelines for post weld heat treatment

| Alloy | Temperature °C (°F) | Quench |
|---|---|---|
| CF3M | 1120 (2050) | Water |
| CF8M | 1120 (2050) | Water |
| CN7M | 1120 (2050) | Water |
| CN7MS | 1160 (2125) | Water |
| 5-7% Mo | 1175 (2150) | Water |
| Duplex | Follow Producer Recommendations | |
| C95800 | 675±10(1250±50) | Air |
| C61300 (W) | 621 (1150) | Air |

W= Welded

Stainless steel castings may be procured to ASTM A743/A743M, or to ASTM A744/A744M for severe service. The latter requires post-weld heat treatment after all weld repairs; ASTM A743/A743M does not. ASTM A743 is the reference specification suggested for saline water pumps. Provided carbon is no more than 0.03%, the molybdenum-containing grades of stainless steel can be successfully weld-repaired.

Although ASTM A743/A743M and A744/A744M allow CF3M and CF8M to be annealed at 1040°C (1900°F), the temperature for annealing the molybdenum-free grades, the higher 1120°C (2050°F) solution-annealing temperature suggested in *Table VIII* greatly improves the corrosion resistance by reducing molybdenum gradients. The higher annealing temperature must be specifically stipulated in procurement documents.

As molybdenum content increases; higher solution-annealing temperatures are required to homogenize the alloy. A temperature of 1175°C (2150°F) is appropriate for the 5-7% molybdenum alloys.

The addition of nitrogen to the higher molybdenum-containing grades retards sigma and chi formation, improves corrosion resistance and is generally beneficial. Nitrogen-containing duplex and austenitic stainless steels can be welded readily with appropriate fillers, and cast-and-welded fabrication of these alloys is often used to produce complex shapes, for example, in barrel-type water-injection pumps.

Weld repairs on cast duplex stainless steel components are preferably carried out before final heat treatment. Also, the heat treatment applied must follow manufacturers recommendations to ensure the correct microstructure and dimensional accuracy and to avoid 475°C (885°F) embrittlement. Welding after heat treatment is allowable provided the resulting internal stress and distortion are acceptable. However, extremely careful welding technique is essential to avoid high ferrite content of welds and/or heat affected zones, which increases the susceptibility of the casting to hydrogen embrittlement and cracking when exposed to corrosion.

## Stress Relief

Stress-relief, treatments are conducted at much lower temperatures than the post-weld and solution-annealing temperatures just described. Stress-relief treatments are undertaken when the manufacturer finds it necessary to reduce distortion during machining operations. In the case of austenitic iron diffuser sections, furnace stress relief is essential to prevent stress corrosion cracking at the vane to wall junction.

There are two stress relief treatments for stainless steel. The 400°C (750°F) 8-10 hour stress-relief treatment is below the temperature-time spectrum at which sensitization is likely to occur. This treatment is usually adequate to maintain dimensional stability during machining. If this stress-relief treatment does not maintain dimensional stability within the limits imposed, stress relief at higher temperatures within the sensitization range may be necessary. Such treatments can be designed with full knowledge of the actual carbon content, temperature, and time, but they must be designed specifically for each case.

**Table IX** Guidelines for stress relief

| Alloy | Temperature °C (°F) | Comment |
|---|---|---|
| Austenitic stainless steel | 400 (750) 8-10 hours | This stress relief treatment is designed to stay below temperatures at which sensitization may occur. |
| Duplex stainless steel | Follow producer recommendation | Duplex is subject to 475°C (885°F) embrittlement. |
| ANI | 621-650 (1150-1200) | Furnace stress relief required. Mold cooling of large castings may take several days and does not result in full stress relief unless the core is collapsible. |

## Summary

- In selecting materials for saline water pumps, the galvanic relationship can be made to work towards longer life and improved performance when the case is less noble than, and galvanically protects, the impeller, shaft, wear rings and bolting. When the galvanic relationship is misunderstood, overlooked or ignored, increased maintenance and more frequent replacement can be expected.
- While it is important to select alloys that have adequate resistance to the velocities anticipated in each design, it is equally important to select alloys and alloy combinations that will have adequate resistance to stagnant conditions encountered during standby service and to crevice conditions that occur under O-rings and gaskets.
- The ANI case/stainless steel internals and the copper-alloy case/nickel-copper-alloy internals are outstanding examples of materials combinations that provide galvanic protection for the internals, especially during standby service in saline waters.
- Furnace stress relief of ANI diffuser sections has proven to be effective in preventing SCC but must be specified in procurement documents. ASTM A436/A439 does not require stress relief unless the user specifies the stress-relief option.

- Packing, gaskets and lubricants containing graphite can lead to severe galvanic corrosion of copper alloys and stainless steels in saline waters and should be avoided in favour of carbon-free materials. The usefulness of cast iron is also limited by its tendency to form a graphitic surface layer as the matrix corrodes.
- The new high strength duplex stainless steels perform very well in deaerated brines used for water-flood service where the low oxygen content reduces the intensity of crevice corrosion. In aerated waters, the duplex stainless steels are also performing well.
- Nickel aluminum bronze impellers, C95800HT, heat-treated to prevent dealuminification, have suffered multiple erosion failures. A modification of the C95500 composition is suggested as a possible solution to this problem.

## References

1. *Materials for saline water, desalination, and oilfield brine pumps, 1st ed.,* 1988. NiDI Reference Book No. 11 004.
2. Todd, B., *Materials choice and design of pumps and valves for sea water handling systems,* 1986.
3. *Guidelines for the selection of nickel stainless steels for marine environments, natural waters and brines,* 1987, NiDI Reference Book No. 11 003.
4. Lee, T S. and Tuthill, A. H., *Guidelines for the use of carbon steel to mitigate crevice corrosion of stainless steels in sea waters,* NACE Corrosion '82, Paper 63, 1982.
5. Weill-Couly, P., *Welding aluminum bronze castings,* Welding Conference, Bradford, England, 1975.
6. *A Review of the wear and galling characteristics of stainless steel,* AISI, NiDI No. 9006.
7. Moller, G. E., *The successful use of austenitic stainless steels in seawater,* 8th Offshore Technology Conference, Paper No. OTC 2699.
8. Glover, *T J., Recent developments in corrosion resistant metallic alloys for the construction of sea water pumps,* 10th International Conference for British Pump Manufacturers Association, Paper No. 16, BHRA, The Fluid Engineering Center, 1987.

# Appendix A

## Alloy Designations and Nominal Compositions (percent by weight)

| Traditional Designation | Proprietary Trademark | UNS or other National Designation | C (max) | Cr | Ni | Mo | N | Cu | Other | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Austenitic and Precipitation-Hardening Stainless Steels (Balance not shown is Fe)** | | | | | | | | | | |
| CF3 | | J92500 | 0.03 | 19 | 10 | | | | | |
| CF3M | | J92800 | 0.03 | 19 | 11 | 2.5 | | | | |
| CF3MN | | J92804 | 0.03 | 19 | 11 | 2.5 | 0.2 | | | |
| CF8M | | J92900 | 0.08 | 19 | 11 | 2.5 | | | | |
| CN7M | | J95150 | 0.07 | 20 | 29 | 2.5 | | 3.5 | | |
| CN7MS | | J94650 | 0.07 | 19 | 23 | 3 | | 1.75 | | |
| CK3MCuN | 254 SMO | J93254 | 0.025 | 20 | 18 | 6.5 | 0.2 | 0.75 | | |
| CN3MN | AL6XN | N08367 | 0.03 | 21 | 25 | 6-7 | 0.2 | | | |
| Type 316 | | S31600 | 0.08 | 17 | 12 | 2.5 | | | | |
| Type 316L | | S31603 | 0.03 | 17 | 12 | 2.5 | | | | |
| 17-4PH | 17-4PH | S17400 | 0.07 | 17 | 4 | | | -3-5 | Nb:0.2 | |
| 20Cb3 | | N08020 | 0.07 | 20 | 35 | 2.5 | | 3.5 | Nb 8xC-1.0 | |
| | Nitronic 50 | S20910 | 0.06 | 21 | 12 | 2 | 0.2 | | Mn:5 | Nb:0.2 |
| | Worthite | | 0.07 | 19 | 23.5 | 3 | | 2 | | |
| **Duplex Stainless Steels (Balance not shown is Fe)** | | | | | | | | | | |
| Type 329*(3A) | | S32900 | 0.02 | 26 | 4 | 1.5 | | | | |
| CD4MCu* | | J93370 | 0.04 | 25 | 5 | 2 | * | 3 | | |
| 2205 | | S31803 | 0.03 | 22 | 5 | 18 | 0.15 | | | |
| | Ferralium 225 | S32550 | 0.04 | 25 | 6 | 3 | 0.17 | 2 | | |
| | Noridur | DIN G-X3CrNiMoCu24 6 | 0.04 | 25 | 6 | 2.4 | 0.2 | 3.1 | | |
| | Norichlor | DIN G-X3CrNiMoCu24 6 5 | 0.04 | 24 | 6 | 5 | 0.2 | 2 | | |
| | Zeron 25 | S32760 | 0.03 | 25 | 6 | 2.5 | 0.15 | 0.5 | | |
| | Zeron 100 | S39276 | 0.03 | 25 | 7 | 3.5 | 0.25 | 0.75 | W: 0.75 | |
| | FMN | | | 25 | 5 | 2 | 0.2 | | | |
| | Uranus 50 | S32404 | 0.04 | 21 | 8 | 2.5 | 0.17 | 0.5 | | |
| **Nickel-base Alloys** | | | | | | | | | | |
| Alloy 625 | | N06625 | 0.10 | 22 | Bal | 9 | | | Fe: 3 | Nb+Ti: 3.5 |
| Alloy 400 | | ASTM A494 M-35-1 | 0.35 | | Bal | | | 30 | Si:1.25 | |
| Alloy 400 | | ASTM A4949 M-30C | | | Bal | | | 30 | Si: 1.5 | |
| Alloy 400S | | ASTM A494 M-25S | 0.25 | | Bal | | | 30 | Si: 4 | |
| Alloy 500K | | N05500 | 0.1 | | Bal | | | 30 | Al: 2.7 | Ti: 0.6 |
| ANI | | ASTM A436/A439 | | | | | | | | |
| ANI Type 1b | | F47001 | 3 | 3 | 15.5 | | | | | Bal: Fe |
| ANI Type 2 | | F47002 | 3 | 2 | 22 | | | | | Bal: Fe |
| ANI Type D2 | | F47006 | 3 | 2.25 | 20 | | | | | Bal: Fe |
| ANI D2W | | | 3 | 2.25 | 20 | | | | +Nb | Bal: Fe |

## Appendix A
## Alloy Designations and Nominal Compositions (cont'd)

| Traditional Designation | Proprietary Trademark | UNS or other National Designation | C (max) | Cr | Ni | Mo | N | Cu | Other | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Copper-base Alloys (Balance not shown is Cu)** | | | | | | | | | | |
| | | | Pb | Fe | Sn | Zn | Al | Mn | Ni | |
| Leaded Red Brass | | C83600 | 5.0 | 0.30 max | 5.0 | 5.0 | 0.005 max | | 1.0 max | |
| Tin Bronze “G” | | C90300 | 0.3 | 2 | 8.25 | 4 | | | 1 | |
| Tin Bronze “M” | | C92200 | 1.5 | 0.25 | 6 | 4 | | | | |
| Al Bronze | | C95200 | | 3 | | | 9 | | | |
| Al Bronze | | C95400 | | 4.0 | | | 11.0 | 0.50 max | 1.5 max | |
| NiAl Bronze | | C95500 | | 4 | | | 10.8 | | 4 | |
| NiAl Bronze | | C95500 Modified | | 4 | | | 8.2+Ni/2 | | 5.5 max | |
| Ni Al Bronze | | C95800 | | 4 | | | 9 | | 4.5 | |
| 70-30 Cu Ni | | C96400 | 0.03 | 1 | | | | 1 | 30 | |
| IN 768 | | | 0.03 | 0.6 | | | | 0.7 | 30 | Cr: 1.7<br>Zr: 0.10 |
| **Other** | | | | | | | | | | |
| | Waukesha 88 | 4Sn,1.1 Mn, 3Mo, 2Fe, 4Bi, 12Cr, Bal Ni | | | | | | | | |
| | Stellite | Family of Cobalt-base hard-facing alloys | | | | | | | | |
| | Colmonoy | Family of Ni-B hard-facing alloys | | | | | | | | |

UNS - Unified Numbering System.

* Although standard specifications do not require nitrogen, CD4M Cu is normally furnished with the nitrogen addition so benefical to the duplex alloys.

# Trademarks

| Alloy | Product of |
|---|---|
| Ferralium | Langley Alloys |
| Noridur | KSB |
| Norichlor | KSB |
| FMN | Firth Vickers Foundries |
| Uranus | Manoir Industrie |
| 17-4PH | Armco, Inc. |
| Nitronic 50 | Armco, Inc. |
| Worthite | Dresser Industries Inc. |
| Waukesha 88 | Abex Corporation |
| Stellite | Haynes International |
| Colmonoy | Wall Colmonoy Co. |
| 20CB3 | Carpenter Technology |
| Zeron | Weir Materials |
| 254SMO | Avesta Sheffield |
| AL6XN | Allegheny Ludlum |