

# MATERIALS SELECTION FOR SEAWATER PUMPS

by

**Stephen J. Morrow**

**Chief Metallurgist & Global Manager of Materials Technology**

**ITT Corporation, Industrial Process**

**Lancaster, Pennsylvania**



*Stephen Morrow is the Chief Metallurgist and Principal Materials Advisor for the ITT Corporation Industrial Process Groups in Lancaster Pennsylvania, providing metallurgical and other materials related technology support for the Fluid Technology Business interests of ITT. He has more than 30 years of broad-based pump manufacturing experience, which includes high alloy steel foundry casting production,*

*metallurgical and corrosion engineering expertise that includes alloy production, technical support, failure analysis, materials research, product development, and materials advisory. Mr. Morrow has been an active member of both ASM for more than 28 years, and NACE for the last 21 years and plays an active role in providing technical support to ITT customers and product specialists.*

*Mr. Morrow received his Bachelor of Science degree (Metallurgical Engineering with Honors, 1987) from Lafayette College.*

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## ABSTRACT

Materials used in seawater pumps depend upon many factors that include seawater quality, materials limitations and processing characteristics, as well as materials cost and availability. Many newer high alloy stainless steels not widely used a few decades ago have now become standard alloy offerings for seawater pumps. The benefits and limitations associated with materials considerations commonly used for seawater pumps, along with a relative ranking associated with overall cost performance and various materials options, shall be reviewed.

## INTRODUCTION

Pumps handling seawater are used in many industries ranging from power generation to desalination plants, as well as offshore oil and gas production. In addition many other industrial processes utilize seawater cooling. The location of coastal process industrial and power generation plants, along with increased demands for desalination and offshore oil and gas production, has led to an increased number of centrifugal pumps handling seawater. These services mainly use seawater for cooling purposes, high pressure desalination, oil/gas field injection, or seawater lift and fire fighting applications where pump reliability is essential. The number of pumps handling seawater is expected to continue to rise as needs for these services increases.

Appropriate materials choice depends upon many factors, which include the pump operating conditions, pump design requirements, seawater quality, materials limitations and availability, as well as cost. Materials selection must be given full attention at every stage of the design, construction, and operation of pumps used for seawater service. Attention to seawater corrosion resistance along with equipment design requirements is fundamental. A better understanding of materials and the seawater environment, and detailed knowledge of the conditions under which seawater pumps operate, will help with the selection of suitable materials.

While corrosion can become a major issue encountered in pumps, damage from seawater can be minimized, and in many cases eliminated completely by proper materials selection. However, high initial cost often limits the use of those superior alloys that would eliminate most corrosion problems. Corrosive conditions presented while pumping seawater requires more consideration because initial low-cost materials are not likely to result in the lowest pump life cycle cost. For pumps in a critical seawater service, periodic shutdowns for parts replacement leads to lost production, which adds to the total equipment cost. In many seawater applications it is generally wise to select a more corrosion-resistant and higher performance material that provides greater reliability and extended pump life.

Selecting the correct pump materials depends upon the proper selection of alloys suitable for the application and service environment. Many newer high alloy stainless alloys not widely used a few decades ago have now become standard materials offerings for seawater service pumps. Whether corrosion comes from accelerated velocity erosion, galvanic effects or biological damage in seawater pumping operations, matching the proper materials for the service application is fundamental to good performance.

The choice of materials for seawater pumping systems depends upon many factors, which shall be discussed along with their particular manufacturing and foundry characteristics. Materials selection will often be affected by materials reliability requirements, manufacturing characteristics, availability and cost. Maintenance reliability, life expectancy and past performance experience in similar services may also influence the materials choice decision.

There are limited materials comparisons that cover the range of material options running from cast-iron and coated steel to titanium that also include the copper based aluminum bronzes, nickel-based alloys and the conventional high alloy austenitic and duplex stainless steels used in seawater. The purpose of this tutorial paper is to present a range of benefits and limitations

associated with the more common materials options for seawater pumps, and provide a relative ranking associated with overall cost performance options. There are a large number of pump materials selection options for seawater services, so recommendations on design options and materials selection will be provided in general terms.

This paper draws on decades of published materials and corrosion engineering literature, as well as more than 30 years materials and corrosion experience working within the pump industry. This paper examines some popular materials combinations used for seawater pumps, from lower-cost limited life, to higher-cost materials offering greater reliability and longer service life.

## SEAWATER COMPOSITION AND VARIABLES

From a corrosion point of view, Nickel Development Institute Reference Book Series No. 11003 (1987) shows seawater composition (Table 1, redrawn from NIDI Technical Series No. 11003, 1987), which may be considered as a neutral chloride solution that promotes both general and localized corrosion. Within localized regions in pumps the localized environment can become an acidic chloride environment promoting localized pitting and crevice corrosion in stainless steels and other alloys. Seawater environments are highly corrosive since they contain high concentration of salts (mainly sodium chloride), dissolved oxygen, carbon dioxide and biological marine life. Seawater can vary significantly in its corrosivity, which can be very different due to world location, temperature and biological activity. Under stagnant or polluted conditions, additional corrosive species such as ammonia or sulfide compounds, and/or reducing conditions due to presence of sulfate reducing bacteria (SRB) may affect some material's performance. Oxidizing biocides such as chlorine or ozone frequently are used to control microbiological and marine bio-fouling.

Table 1. The Major Constituents of Seawater.

Ion	Parts per million	Equivalents per million	Parts per million per unit Chlorinity
Chloride, (Cl <sup>-</sup> )	18,980.0	535.3	998.90
Sulfate, (SO <sub>4</sub> <sup>2-</sup> )	2,649.0	55.1	139.40
Bicarbonate, (HCO <sub>3</sub> <sup>-</sup> )	139.7	2.3	7.35
Bromine, (Br <sup>-</sup> )	64.6	0.8	3.40
Fluoride, (F <sup>-</sup> )	1.3	0.1	0.07
Boric acid, (H <sub>3</sub> BO <sub>3</sub> )	26.0	‡	1.37
Total		593.6	
Sodium, (Na <sup>+</sup> )	10,556.1	159.0	555.60
Magnesium, (Mg <sup>+2</sup> )	1,272.0	104.6	66.95
Calcium, (Ca <sup>+2</sup> )	400.1	20.0	21.06
Potassium, (K <sup>+2</sup> )	380.0	9.7	20.00
Strontium, (Sr <sup>+2</sup> )	13.3	0.3	0.70
Total		2593.6	

\* H.U. Sverdrup, M.W. Johnson, and R.H. Fleming, *The Oceans*, Prentice-Hall, Inc., New York, 1942. J. Lyman and R.H. Fleming, *J. Marine Research*, 3, 134-146, 1940.  
 † 0/00 is used to denote grams per kilogram or parts per thousand.  
 ‡ Undissociated at usual pH.

Dissolved chlorides and other salts contained in seawater increase localized corrosion of stainless steels and other active-passive metals. This corrosion can take the form of pitting, crevice or intergranular corrosion, and in high temperature seawater even stress corrosion cracking (SCC) may occur. Seawater solids and accelerated flow conditions promotes erosion-corrosion of certain alloys, particularly in the high flow-rate pump areas. The high electrical conductivity of seawater also promotes macro-cell corrosion and enhances such effects as galvanic corrosion and differential aeration-cell corrosion, including differential flow-rate-cell corrosion. Therefore, only materials that provide adequate corrosion resistance should be used for pumping seawater.

There are several seawater variables listed in Table 2 that can affect how materials perform in pump applications. Unfortunately more than just materials corrosion resistance must be considered

when selecting pump materials as other manufacturing and foundry processing factors can have a significant effect on materials performance, availability and costs.

Table 2. Seawater Variables Affecting Materials Selection.

• Salinity and Chlorinity
• Electrical Conductivity and Total Dissolved Solids (TDS)
• Oxygen and other Dissolved Gases (H <sub>2</sub> S, CO <sub>2</sub> )
• pH
• Temperature
• Biological Activity (Microbes & Bio-fouling)
• Pollutants & Turbidity (Suspended solids, Silt and Sediments)
• Scale Deposits and Hardness
• Velocity and Fluid Flow Rate
• Intermittent or continuous duty – Stagnant Conditions?
• Chlorination Practices

## GALVANIC CONSIDERATIONS

When dissimilar metals are coupled in pump construction, galvanic corrosion can occur. Accelerated attack usually occurs on the least noble material, which acts as the anode, while the more resistant noble material, acting as the cathode, is protected. As with all dissimilar metals, careful attention should be given to avoid unfavorable galvanic effects. Coupling to less noble alloys can be used effectively in pump design to provide cathodic protection to those alloys like stainless steels that may suffer localized damage under stagnant conditions without impressed current protection.

Since seawater is a highly conductive environment, galvanic considerations normally dictate material combinations. An understanding of the galvanic series of metals is essential to proper material selection. A few suggestions to combat galvanic corrosion in seawater pumps are:

- Select combinations of metals as close together as possible in the galvanic series unless the design utilizes galvanic cathodic protection. A potential difference of 0.25 volts indicates a galvanic couple exists. Metals closer to one another in the galvanic series should be selected, to minimize electrochemical differences. As a rule, the rate of attack is dependent upon the electrochemical reactions taking place on the materials surfaces forming the couple. Metals closer to the active end of the series will act as anodes and sacrificially corrode, while those closer to the noble end will act as cathodes and be protected.
- Avoid the combination of a small anode and a large cathode surfaces within pumps. Surface area ratio effect between dissimilar metals should avoid accelerate galvanic corrosion of the more active metal. The opposite ratio, large anode to cathode area ratio, is preferred, and produces very little galvanic activity effects. Proper area ratio effects must be carefully considered in pump designs.
- Use insulating materials on fasteners and insulating gaskets on mating flanges to isolate the materials coupled and break electrical contact.
- Use protective coatings on lower cost materials, and to reduce cathode surface areas.
- Locate sacrificial galvanic anodes on the pumps as close to the areas needing protection as possible. The greater the conductivity of the fluid, the greater the galvanic activity will travel. Provided stainless steels remain passive, they will generally be the more noble material in pump constructions, and thus act as cathodes in galvanic couples that become cathodically protected. (When less noble materials such as cast Ni-resist or bronzes are selected for use in combination with austenitic stainless steels in pump constructions, the galvanic effects will increase the corrosion rate of these less noble materials while protecting stainless components.)

Figure 1 shows a list of metals and alloys ranked in order of their electrical potential in flowing seawater. In a galvanic couple involving any two or more metals from the list, the one closer to the

more negative (anodic or active) potential end of the series will corrode faster, while the one toward the more positive (cathodic or noble) potential end will corrode slower or not at all. The galvanic series provides an indication of the potentials established when dissimilar metals are placed in contact with each other in seawater. What the series cannot predict is the rate at which the metals corrode. Figure 1 illustrates the corrosion potential of materials in flowing seawater.

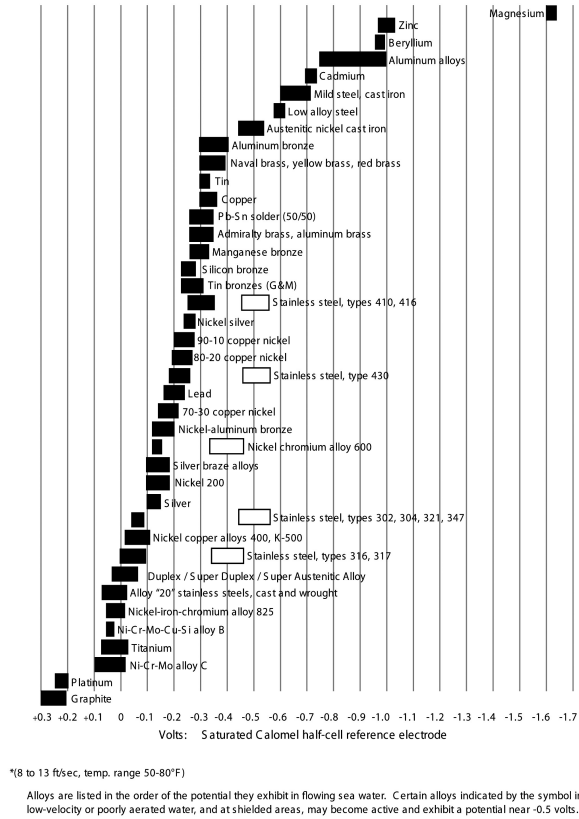


Figure 1. Galvanic Series in Flowing Seawater.

The potential of a metal or alloy is affected by other environmental factors. There is no absolute value of electropotential for a metal independent of the variables that influence the corrosive characteristics of the solution (i.e., electrolyte) in which that potential is measured. Values of potential can change from one solution to another or in any solution when influenced by variables such as pH, temperature, aeration, conductivity, polarization, and flow velocity effects such as degree of agitation or movement. Thus, corrosion product films and other changes in surface composition can occur in some environments and therefore, no one value can be given for a particular material. Consequently, there is no way, other than by direct potential measurements in each environment of interest, to determine potentials of metals and the subsequent direction of any galvanic effects.

Under some conditions the cathodic hydrogen-reduction is important as it may be adsorbed on cathodic surfaces. When high-strength materials are used such as fasteners or shafting in assemblies, or cathodic protection systems are employed, the amount of hydrogen adsorbed can result in hydrogen embrittlement and cracking failures in certain alloys.

Selecting cathodic materials for fasteners, weld filler metals, and critical components such as pump shafts, wear rings, and other internals, can take advantage of the galvanic effect, making these assemblies more durable. In fact seawater pump designs often incorporate dissimilar metals to provide a protective galvanic sacrificial anode effect to critical components such as internals and fasteners in assemblies. Large anodic metals are often furnished in

thick-walled components like casing, bowls and suction bells to provide large sacrificial surface areas with low current densities. The general uniform corrosion attack of the wetted surfaces is hardly noticeable while critical components are significantly protected.

For example, large vertical pumps used in seawater are often constructed with type 316 stainless or cast CF8M internals (shaft, wear rings, impellers, etc.), connected to massive thick-walled aluminum bronze or austenitic Ni-resist iron columns, casings and suction bells. By design, the more noble austenitic stainless internals are cathodically protected from localized (pitting and crevice) corrosion by the galvanic effects provided from contact with these more active metals. Alternative designs incorporate attachment of sacrificial anodes strategically placed within the equipment to provide galvanic cathodic protection in place of a more expensive impressed current cathodic protection system.

A note of caution: Graphite-filled packing and gaskets and other carbon containing materials are highly noble nonmetallic conductors that can lead to severe galvanic corrosion of copper-based alloys, stainless steels, and other metals due to significant potential differences when coupled together. These combinations are not recommended and are best avoided if possible.

VELOCITY EFFECTS AND MATERIALS LIMITATIONS

As seawater flow velocity increases, corrosion remains low until some critical velocity is reached that results in the accelerated loss of protective surface films. The surface shear stress associated with the higher velocity causes accelerated flow erosion that strip off the materials protective barrier films. The flow conditions within pumps can be high enough that some critical threshold value for materials velocity limitations is reached. Materials should be selected with operating speed and flow velocity damage in mind.

The corrosion and erosion resistance of many materials is often limited by the stability of the protective passive surface oxide layers that form, and the related fluid pump velocity as well as its aggressiveness. Figure 2 shows the behavior of many materials in ambient seawater and shows their related velocity sensitivity limitations in flowing seawater. As shown, the Ni-resist austenitic cast-irons, aluminum bronzes and the nickel-aluminum bronzes, are much more velocity sensitive while the stainless alloys show little to no accelerated seawater flow effects.

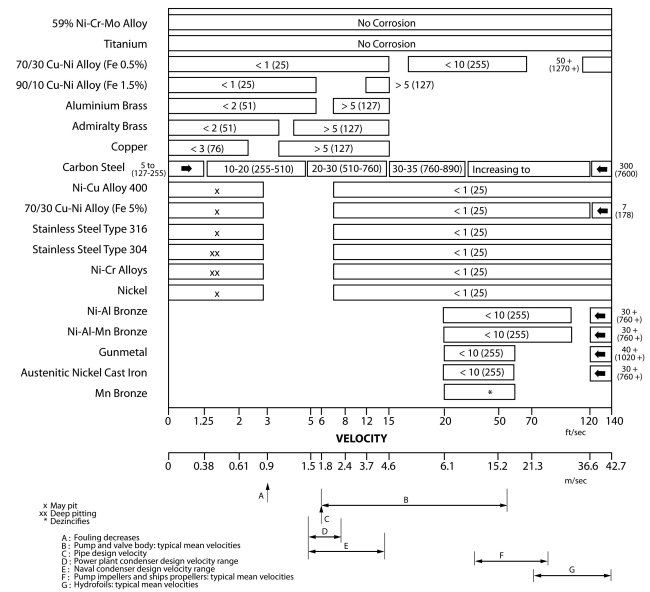


Figure 2. Materials Velocity Sensitivity in Flowing Seawater.



For an active-passive material like nickel, Monel® or stainless steels Figure 2 shows an initial higher corrosion rate at low flow velocities due to localized corrosion, often due to oxygen differential concentration cells and/or a build-up of aggressive ions such as chlorides. As the velocity increases to about 3 to 5 ft/sec (0.9 to 1.5 m/sec) for Monel® and stainless steels in seawater, the material passivates and the rate of corrosion decreases to a minimum level until very high velocity levels where flow erosion accelerates at some critical velocity.

The austenitic and duplex stainless steels exhibit excellent resistance to high velocity seawater. These materials perform well provided that stagnant conditions do not exist because this can result in localized corrosion attack. This can easily be prevented by ensuring a minimum flow of 3 to 5 ft/sec (0.9 to 1.5 m/sec) as indicated, or by periodically operating the pump on a regular basis; or by flushing the system with fresh water to eliminate the corrosive environment. Cathodic protection systems are often also used to provide localized corrosion protection when these conditions exist.

The chromium oxide film that forms on austenitic stainless steels, the nickel oxide film on nickel-based alloys, and the titanium oxide film that forms on titanium are very tenacious, and for the most part, eliminate velocity sensitivity in these alloy systems. The aluminum-bronze and nickel-aluminum bronzes are much more velocity sensitive, as well as the copper-nickels, which do not have as stable a film. As a result, bronzes exhibit a restrictive velocity limitation of about 60 to 80 ft/sec (18 to 24 m/sec) or less. The copper-nickels are also limited to about 40 to 50 ft/sec (12 to 15 m/sec) with limits on austenitic nickel cast-iron (Ni-resist) falling at similar flow rates.

Pump impeller peripheral velocity tip speed can be calculated from the following formulas:

$$\text{Velocity (feet/sec)} = [\text{Diameter in inches} \times \text{RPM}] / 229.2 \quad (1)$$

$$\text{Velocity (m/sec)} = [\text{Diameter in mm} \times \text{RPM}] / 19098.5 \quad (2)$$

In general, these velocity limits can be lower if solids are present in the system or the pH is lowered. This is particularly true in polluted seawater if hydrogen sulfide is present. Soluble sulfide films can replace the passive oxide layers resulting in an increased rate of attack.

Corrosion rates of carbon steel, iron, and bronzes in seawater are accelerated with increased flow rate. In addition, when there is a difference in flow rate as inside the casings of pumps, lower flow regions sometimes preferentially corrode at an accelerated rate due to differential-aeration-corrosion cells caused by differential oxygen levels and flow rates. Low flow regions can exhibit accelerated corrosion behavior attributed to the differential aeration cell in which the lower flow and low oxygen regions act as an active corroding anode and the higher flow more aerated regions are protected and act as cathode surfaces. Once again alloys should be selected with low velocity flow differential aeration cell corrosion and differential-flow-rate cell corrosion in mind, as well as high velocity accelerated flow erosion damage.

## POLLUTION AND SULFIDES

Copper-nickel alloys such as Monel® and the aluminum and/or Ni-Al bronzes provide good general and localized corrosion resistance in seawater. The presence of leads to higher corrosion rates, particularly in higher flowing velocity waters common in pumps. Sulfides are generally present in polluted seawater either from industrial effluents or decaying organic materials. When the water supports biological activity, growth of active sulfate reducing bacteria can produce hydrogen sulfide.

## CHLORINATION

Biological activity in seawater often creates costly production disruptions, due to fouling at system intakes, within pumps, and

pipelines. To avoid marine bio-fouling, the conventional method to control biological growth and damage is through chlorination of the water in the circulation system. This is normally performed by adding a strong oxidizing biocide such as chlorine, or some hypochlorite solution; or by electrolyzing the water, continuously or intermittently.

To avoid marine bio-fouling, seawater is often chlorinated to levels less than 1 ppm free chlorine. Continuous free residual chlorine treatment levels of 0.1 to 0.2 ppm are common, but intermittent free residual chlorine treatments at higher levels of 0.5 to 1.0 ppm for 30 minutes, a few times a day, are also used effectively (Wallen, 1998; Wallen and Hendrikson, 1989). Up to 2 ppm chlorine does not appear to be detrimental to any stainless steel but higher levels can be damaging as the corrosion pitting potentials can be achieved. The majority of materials used in seawater will normally not suffer accelerated corrosion provided these levels are not exceeded.

If these levels are exceeded, severe erosion-corrosion in bronzes and localized corrosion in the form of pitting and crevice attack may occur in the conventional austenitic stainless steels. If the dosing levels are excessive, or not introduced far enough away from the pumps to ensure good mixing, erosion-corrosion damage to pump materials may occur.

In practice, the chlorine additions are often higher than necessary. Over-chlorination can cause serious corrosion of pumps, particularly in low flow areas where concentrations may increase. It should be recognized that the advantages of chlorination apply only when low residual levels are maintained to control marine growth. As chlorine concentrations rise and pass the level of oxygenation in the pump system (approximately 6 to 8 ppm for open seawater), chlorine reduction will become the predominant cathodic reaction, driving higher anodic current flow and increasing corrosion rates.

Chlorine dosing can be detrimental, unless closely controlled. Free chlorine is highly oxidizing and increases the corrosivity of seawater. At high chlorine residual levels the extent of corrosion can be severe as materials surface films become modified. In the presence of chlorine, many normally protective films on materials become unstable, and become altered to less protective forms, with decreased resistance to flow impingement and corrosion resistance. Proper water chemistry control should not be overlooked.

## STAINLESS STEELS FOR SEAWATER SERVICE

Over the last few decades there has been an increased interest in the use of both super-duplex and super-austenitic stainless steels for pumps used in marine environments to offer superior corrosion resistance. Highly corrosion resistant austenitic and duplex stainless steels (DSS) used for seawater generally contain higher levels of molybdenum and nitrogen enhancement. The combined effect of increased levels of chromium, molybdenum and nitrogen has been shown to provide exceptional benefits for localized corrosion resistance in seawater service. The higher alloyed super-duplexes usually contain at least 25 percent chromium, 3 percent molybdenum and 0.20 percent nitrogen or more, while the super-austenitics contain even higher chromium levels with 6 percent molybdenum or more.

The high localized corrosion resistance of these "super" higher alloy austenitic and duplex alloys is derived primarily from their higher alloy contents, which provide a pitting resistance equivalent factor (or PREN) value in excess of about 40 or better. Attempts have been made to establish a measure of the important alloying elements in a weighted form factor. The most widely used PREN formula used to calculate alloy ranking is shown below using weight factor multipliers for the key elements of chromium (Cr), molybdenum (Mo) and nitrogen (N) in the alloys:

$$\text{PREN} = \%Cr + (3.3 \times \%Mo) + (16 \times \%N) \quad (3)$$

Many investigators and much of the corrosion literature indicate that excellent resistance to localized corrosion in neutral and acid chloride containing media can be obtained by increased chromium, molybdenum and nitrogen contents. Elevation of nitrogen content led to improved corrosion resistance in the DSS alloys due to a better balance of alloying elements between the two phases with decreased susceptibility in alloy partitioning between the austenite and ferrite.

Highly alloyed super-duplex stainless with PREN > 40 can successfully compete with the most resistant super-austenitics such as 254SMO/cast grade CK3MCuN and AL6XN/cast grade CN3MN in seawater. Nitrogen additions are extremely important in improving the pitting and crevice resistance of these alloys. For seawater services the duplex alloy selected should have a balanced nitrogen enhanced composition to provide for a PREN > 40 to ensure freedom from localized corrosion.

An excellent way to specify any high alloy duplex intended for seawater service would be to request that the chemical composition be balanced to provide a PREN greater than or equal to 40. This will ensure that the DSS selected has the optimum chemistry control to provide adequate localized corrosion resistance in most seawater environments.

SEAWATER CORROSION

Many pump applications today involve some extremely corrosive seawater services where the standard AISI type 316/316L and cast ACI type CF8M/CF3M austenitic stainless steel cast alloys are inadequate for the service environments. Higher levels of concentrated chlorides, chlorination, pollution, aeration, lowered pH, stagnant operation, high temperatures, high velocities, and other factors such as suspended solids or biological attack can influence the corrosion rate of materials in what is “normally” referred to as seawater.

These considerations have precipitated the development and availability of many newer highly alloyed corrosion resistant alloys to meet the requirements of present day services. In Tables 3 and 4 are a summary of the relative corrosion resistance of several materials considered from an earlier work (Oldfield and Masters, 1996). The scale shown is arbitrary and indicates the overall relative performance of the various materials under the appropriate headings shown. As these authors indicate, it is useful if the scale is used as a relative ranking system, rather than a specific detailed comparison (rank of 10 does not mean twice as good as 5). Rather than identify an overall winner, the strengths and weaknesses of the various materials are shown with regard to various damage mechanisms found in seawater pumps.

Table 3. Comparative Corrosion Performance, Part 1.

Arbitrary scale, higher is better	General Corrosion	Pitting Corrosion	Crevice Corrosion	Erosion Corrosion	Erosion Cavitation	Stress Corrosion
Bronze	8	9	9	7	5	-
Ni-Al-Bronze	9	10	8	8	8	10
Ni-Cu Alloy	10	5	2	10	8	?
Carbon	3	3	-	-	2	-
Stainless	10	4	3	10	7	8
6%Mo	10	9	8	10	8	8
Duplex	10	5	4	10	8	9
Super-Duplex	10	9	8	10	8	9
Ni Alloy 625	10	13	12	-	13	-
Ni Alloy C22	10	14	-	-	10	-
Titanium	10	15	10	-	9	-

Table 4. Comparative Corrosion Performance, Part 2.

Arbitrary scale, higher is better	Polluted Seawater	Corrosion Fatigue	Fouling Resistance	Galvanic	Wear & Gall
Bronze	-	-	10	5	10
Ni-Al-Bronze	4	9	8	6	10
Ni-Cu Alloy	?	?	4	8	5
Carbon	-	-	-	1	8
Stainless	4	6	1	4/7	6
6Mo	9	6	1	9	5
Duplex	5	9	1	8	4
Super-Duplex	9	9	1	10	3
Ni Alloy 625	-	12	1	10	3
Ni Alloy C22	-	-	1	10	3
Titanium	-	-	1	9	2

MATERIALS FOR SEAWATER PUMPS

Since the choice of materials for seawater is often confusing, this discussion will be limited to those most commonly used for seawater pumps as shown in Table 5. The choice of materials continues to grow as more and more specialty alloys are brought to the market. For large seawater intake pumps, the most likely choice of materials that are now commercially available includes the kinds of metallurgy shown in Table 5.

Table 5. Common Alloys Used for Seawater Pumps.

• Austenitic Nickel Cast Iron [Ni-Resist & Ductile Ni-Resist]
• Aluminum-Bronze and Nickel-Aluminum Bronze
• Standard Austenitic Stainless [300 series and cast CF & CG types]
• Super-Austenitic Stainless[ 6% molybdenum with PREN > 45]
• Standard Duplex [Grades with PREN< 40]
• Super- Duplex Stainless [Grades with PREN> 40]
• Nickel Based Alloys [Inconel and Hastelloy]
• Titanium Alloys

Traditionally, pumps handling seawater have been constructed from austenitic cast-irons such as “Ni-resist,” copper-nickels, Monels®, aluminum-bronzes, and austenitic or duplex stainless steels. The trend has been toward more highly alloyed nitrogen enhanced super-austenitic or super-duplex and nickel-based alloys, which offer greater reliability, life extension performance, and value in highly chlorinated seawater environments.

The most common pump metallurgies for seawater services generally fall into one of the following category types:

- AISI type 316L fabrications or ACI type CF3M castings with type 316L, Nitronic 50 or type 2205 duplex stainless shafting
- Ni-resist or Ductile Ni-resist casings with ACI type CF3M impellers and type 316L, Nitronic 50 or type 2205 duplex stainless shafting
- Aluminum-bronze fabrications or castings with nickel-aluminum-bronze or ACI type CF3M impellers, and AISI type 316, Nitronic 50 or Monel® K500 shafting
- Standard duplex stainless fabrications or castings with duplex alloy 2205 shafting
- Super-duplex stainless with type 2507 super-duplex shafting
- Super-austenitic stainless with type 2507super-duplex shafting

The experience of users over the years and the many pumps in service around the world show that field problems using AISI type 316L with ACI type CF3M are practically nonexistent with proper controls. In some cases cathodic protection is required when intermittent services or stagnant conditions are present. However, in the majority of the more aggressive warmer water services, it must be admitted that higher alloyed materials like the super-austenitics and super-duplex alloys, and/or nickel-based alloys are the preferred materials of construction.

OTHER MANUFACTURING AND PROCESSING CONSIDERATIONS

Before discussing some of these considerations and some of the characteristic advantages and disadvantages of various materials used in seawater, the author wants to emphasize that the selection of a material must also consider the ability of a pump supplier to manufacture it, as well as the material’s availability, fabricability, castability, and weldability characteristics, which all affect delivery and cost.

From a manufacturing standpoint one must consider the fabricability and/or weldability, as well as the foundry castability characteristics of the alloy selected. These are just as important for the customer as well as supplier since the ability to produce pump components affects deliveries, installation, start-up, and repairs or modifications made in the field at some later time.

Some alloys are considered unweldable, while others are so difficult to cast or repair in complex geometry pump components they end up being a higher cost item even though they may initially appear to offer a lower cost alternative. An example of this is the usual casting and welding difficulties experienced with the cast-iron and Ni-resist alloys, bronzes, and other copper containing austenitic stainless steel alloys, such as the ACI type CN7M cast equivalents to alloys like alloy 20 and 904L.

- Ni-resist and ductile Ni-resist alloys are difficult to cast, and difficult to weld repair. They often crack due to residual stresses created during casting or welding, and weld repair is tricky due to alloy drossiness. Special filler metals, precautions and precise procedures must be followed to successfully repair these alloys when allowed by codes or specifications.
- The nickel-aluminum-bronze and aluminum-bronzes are also difficult to cast in large sections due to dross formation and their narrow solidification freezing range often results in cracking. These alloy systems can be welded with matching filler metals, but they require a special post weld heat treatment to prevent the dealloying of the aluminum phase (dealuminification) if used in chloride environments. A high temperature temper annealing heat treatment to ensure freedom from phase dealloying (dealuminification) in seawater service is a requirement now specified in the ASTM B148 standard for certain cast alloys. This often creates distortion and other manufacture delays if repairs are required late in the manufacture cycle.
- Casting and welding of the austenitic and duplex stainless and nickel-based alloys are relatively easy with low carbon grades, and post weld heat treatments are often not required, providing the ability to make field welds. The nickel-based alloys, as well as the ACI type CF and CG alloys are not difficult to cast or weld repair provided proper qualified procedures are followed.

Earlier generation duplex alloys without nitrogen enhancements were difficult to cast and weld repair without cracking. Most duplex varieties today are nitrogen strengthened, and weld repaired with nitrogen enhanced filler materials that are over-alloyed in nickel to control and maintain proper microstructure balance. Depending upon the alloy selected and weld procedure used, post weld heat treatment may or may not be required depending on carbon content and ferrite control.

In order to select cost-effective materials for seawater pumps there are other manufacturing and materials processing considerations that must be considered. Comparative characteristics shown in Table 6 highlight several important manufacturing, materials processing and foundry material property considerations. Many are interrelated and make selection more difficult when deciding which factors should be weighted one way or the other, particularly when engineers or project managers have different opinions regarding materials.

Table 6. Relative Ranking of Select Material Properties.

Property	TI	Super Duplex	Super Austenitic	NAB	CF8M
Castability	1	3	4	3	4
Strength	3	4	2	2	1
Pressure Tightness	3	3	3	2	3
Corrosion Resistance	5	4	4	2(A)	1(B)
Weldability	2	3	4	2	4
Machinability	1	3	3	3	4
Availability	1	3	3	4	4
Cost	1	2	2	3	4
<b>Total Ranking</b>	<b>17</b>	<b>25</b>	<b>25</b>	<b>21</b>	<b>25</b>

Higher number indicate better value.  
 Note (A): Reduced ranking if H<sub>2</sub>S or Ammonia compounds present in service.  
 Note (B): Pitting and Crevice corrosion if stagnant without cathodic protection (CP). Higher for continuous running service in aerated seawater with (CP).

Table 6 (modified after Francis and Philips, 2003) indicates a conservative ranking based on years of foundry alloy experience with pump castings. Again, the scale shown is arbitrary and indicates an overall relative performance of the various materials under the appropriate headings shown to determine an overall value factor. Materials showing the highest overall weight factor numbers indicate the best overall value for seawater service.

As previously discussed, there are a number of material factors that must be considered for seawater pump materials. Selecting which factors are important and attaching a weighted value to them is often based upon preference and personal work experience in working with these materials. The main material characteristic properties to consider are shown in Table 6. Since pumps often are produced from cast alloys, the castability, pressure tightness and soundness of the metal along with the materials weldability are of major interest.

Some highly corrosion resistant materials are more difficult to cast, have high associated costs and are more difficult to obtain even though corrosion performance is better. While corrosion resistance is an important factor, it is not the only factor to consider, particularly when immunity to seawater corrosion is not needed and not the most economical option. The factors shown are some of the more common materials characteristics that should be evaluated when selecting seawater pump materials. As the relative ranking indicates both the super-duplex and super-austenitic materials offer good performance value for seawater service.

Availability and on-time delivery is not always appreciated by the end user. Some pump geometries are very complicated and very difficult to cast soundly with good pressure tightness and little need for extensive weld repairs. Certain alloys are more difficult due to the nature of the metal fluidity, cracking tendencies upon cooling and solidification characteristics of the geometry.

Just because the pump materials selected are higher cost than an alternative suitable material, it does not mean that the final pump cost will be substantially higher. Often it will be more cost effective to select a higher cost material that is more castable and weldable, and one that can be produced, manufactured and delivered on time.

As the relative merits of different materials are considered, an overall assessment must be made on the materials options available as shown in Table 6 against the selected property criteria of interest. The ranking is somewhat subjective based upon experience but can be used to help rank factors of interest for large seawater pumps. As shown here there are three material option groups with similar overall performance rankings. In some service applications some of these factors will have greater importance than others and may be weight factored differently at different times, and on different projects depending upon reliability requirements.

As demonstrated above, there are a large number of variables and materials characteristics that can influence materials selection for seawater pump services. It is important to identify the materials selection criteria early that will be of greatest importance on each project application.

## PUMP MATERIALS OPTIONS

The application and service conditions will also affect the rate of corrosion. A pump that sits idle for long periods of time, such as a vertical fire pump on an offshore installation, will experience a different rate of corrosion than a pump constructed of the same materials operating continuously. Many materials are regarded as corrosion resistant in fast flowing seawater, but under stagnant conditions they may be susceptible to pitting and crevice corrosion attack.

Conventional cast pump metals and alloys that have been used are subject to varying degrees of corrosion when exposed to seawater. The material selection is generally a balance between reliability and cost. For example, plain carbon steel that has been the most widely used structural material is abundantly available and is inexpensive, has adequate mechanical properties but has a high general corrosion rate particularly where water velocities are high. The copper-base alloys are widely used in seawater applications due to their naturally occurring and protective oxide film, which provides good antifouling characteristics. These alloys are, however, sensitive to ammonia and sulfide containing waters and high water velocities induced erosion limitations. Titanium

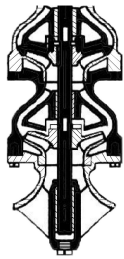


offers excellent corrosion resistance but has high costs. Some nickel-base alloys have very good resistance to most seawater corrosion, and stress corrosion cracking in marine environments. However, the relatively high cost of titanium and nickel-base alloys limit their use to specialized applications.

Super-austenitic and super-duplex stainless steels have proven to be the most satisfactory materials for marine applications due to their excellent corrosion resistance even at high water velocities, good mechanical properties and fabricability. In addition, they are attractive from a commercial standpoint due to their availability and relatively low cost compared to nickel alloys.

Today the vertical turbine and horizontal barrel type multistage pumps are proven designs accepted in many seawater systems due to their adaptability to changing system needs. The materials options presented for vertical turbine pumps are applicable to many pump types, which also include split casing and multistage pump designs, and are presented here to highlight some materials design options. Selecting the correct pump depends upon the proper selection of alloys for the application and service environment. There are a large number of pump alloys and materials selection options for seawater services, so recommendations on design and materials selection will only be provided in general terms.

The flexibility of vertical turbine and multistage pump design lies in their ability to meet many system design requirements by multistaging. The ability and ease of changing the number of pump stages offer advantages if it becomes necessary to modify the hydraulic characteristics of the system. Stages can be added if changes in the system head curve occur as a result of modifications or increase pipe friction due to system corrosion. This condition is quite common in seawater pumping systems operating over time. Figure 3 shows some typical vertical turbine pump material options for illustration purposes (Gutierrez, et al., 2007).



COMPONENT	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5	OPTION 6
	LOWEST COST	MEDIUM COST	MEDIUM COST	HIGHER COST	HIGHEST COST	HIGHEST COST
BOWLS	(Minimum Useful Life Expected) 316 SS / carbon steel construction	(Good Service Life) 316SS construction	(Good Service Life) Al-BRZ/Ni-Al-BRZ construction	(Very Good Service Life) Duplex 2205 CD4MCuN construction	(Excellent Service Life) Super Duplex	(Excellent Service Life) Super Austenitic
IMPELLERS	CF-8M 316 SS	CF-8M 316 SS	Al-BRZ CA85	Duplex Alloy CD4MCuN ASTM A890 Grade 1B	Alloy 2507 ASTM A890 Grade 5A	Alloy 6% Mo/ly
COLUMN/ DISCH. HEAD	Coated Carbon Steel/ 316SS flanges	316 SS	Al-BRZ w/Nickel	Duplex Alloy 2205	2507	Alloy 6% Mo/ly
SHAFTING	316 SS	316 SS or Nitronic 50	Nitronic 50* or Monel K500	Duplex Alloy 2205	2507	Duplex Alloy 2205
BEARINGS	Bronze or Rubber	Bronze or Rubber	Bronze or Rubber	Bronze, Rubber or Hardfacing on metal shell	Bronze, Rubber or Hardfacing on metal shell	Bronze, Rubber or Hardfacing on metal shell
BOLTING	316SS	316SS	Monel	Duplex Alloy 2205	2507 4% Mo/ly	Alloy
KEYS/ COLLETS	316SS	316SS	Monel* or Nitronic	Duplex Alloy 2205	2507	Alloy 6% Mo/ly

When quoting these different material constructions, the following items should be taken into consideration:

1. Temperature and Abrasives: the maximum temperature limits and PPM of abrasives for the various constructions will generally depend on the bearing materials:

Bearing Type	Degrees F	Abrasives	
		Maximum PPM of TS 5	Comments
a. Rubber Bearings	32 to 150	5000	Above 100 PPM Hardface Shaft
b. Bronze Bearings	-50 to 180	50	
c. Hardfacing Coating	-100 to 300	5000	Shaft must also be Coated
d. Carbon	-380 to 700	10	Alternative Bearing Material

2. 316SS materials are susceptible to localized corrosion (pitting) when the sea water is not moving along the material surface. This can occur when the pump is in still water and/or the unit is not in operation (intermittent service).

\* Factory Choice

Figure 3. Typical Vertical Pump Materials Options.

• **Lowest Cost Option 1**—is listed as a basis for cost comparison. Although this combination has been used in seawater, service life is limited with coated carbon steel and repairs are predictable depending upon coatings integrity. This combination of castings in 316SS/CF8M and columns in coated carbon steel with 316 SS flanges is the lowest cost material offered for seawater service. In addition cathodic protection should be provided to protect against accelerated localized pitting and crevice corrosion damage.

• **Medium Cost Option 2**—changing materials to an all type 316 SS with higher strength Nitronic 50 shafting is considered to offer good corrosion resistance and pump life when handling flowing seawater. However, in both Options 1 and 2 the 316 SS material is subject to

pitting in stagnant conditions unless cathodic protection is provided and has relative good characteristics in flowing applications only. These materials have a tendency to pit in stagnant waters, and cathodic protection should be used to provide protection under stagnant or intermittent standby services.

• **Medium Cost Option 3**—Aluminum-bronze, nickel-aluminum bronze and Ni-resist casting alloys are considered to provide good corrosion resistance when handling flowing seawater and provide good service life. This construction is the most common due to the several advantages offered by the Al-bronze group. Al-bronze resist marine fouling, resist pitting in stagnant water, and offer good cavitation and erosion protection, but these alloys have a tendency to pit in stagnant waters, and erosion losses in higher flow conditions are more likely in larger pumps operating at higher flow velocities. When Ni-resist or bronze are used with type 316 stainless internals the cathodic protection provided to the stainless can be a useful design option to protect the stainless from localized corrosion damage. With this Ni-resist/316 SS or bronze/316 SS combination, the Ni-resist or bronze bowls will provide some cathodic protection to the 316 SS impeller during prolonged down-times to help prevent pitting. However, bronze alloys can be damaged in seawater with hydrogen sulfide, so the seawater must be unpolluted and free of sulfides.

• **Higher Cost Option 4**—Utilizing standard duplex (2205 types or cast CD4MCuN) stainless steels with PREN less than 40 provides good economy in a continuous service application, but can corrode due to pitting in stagnant conditions with fewer risks of localized corrosion associated with the austenitic type 316 SS constructions. Under stagnant conditions, localized pitting resistance is improved by these higher alloyed duplex stainless alloys, but crevice corrosion damage under deposits is still likely. In warmer seawater damage is still a concern, and standard duplex should be selected with caution. Cathodic protection is also recommended for these lower alloy duplex grades.

• **Highest Cost Options 5 and 6**—Utilize either an all super-duplex or super-austenitic 6 percent molybdenum type alloy construction. While the most costly combination without going to higher cost nickel-based alloys or titanium constructions, provides excellent service life and corrosion resistance in the warmer and more highly corrosive Middle East seawater. These higher alloy stainless grades are the preferred seawater materials for pump reliability and long service life.

• With the Option 5, the super duplex alloys having PREN values over 40 offers corrosion resistance advantages over Al-bronzes and Ni-Al-bronzes. The super duplex alloys resist polluted waters with sulfides, as well as localized pitting and crevice corrosion under stagnant or idle conditions, and offers good cavitation and erosion-corrosion protection. Additionally, in normal 8 pH ambient seawater super duplex will perform well with up to 50,000 ppm of chlorides and higher. These grades provide excellent cavitation resistance, superior localized pitting and crevice corrosion resistance and excellent flow velocity erosion resistance properties. As with all stainless steels, fouling organisms can collect on their surfaces unless treated with biocides.

• The last Option 6, the highest cost in the selection chart, utilizes the 6 percent molybdenum super-austenitic stainless steels such as ASTM A743/A744 grades CK3MCuN (cast 254SMO type) and/or CN3MN (cast AL6XN type). These super-austenitic stainless alloys provide excellent corrosion resistance that allows operation in ambient seawater at normal 8 pH and up to 100,000 ppm of chlorides and higher. These grades provide excellent cavitation resistance, superior localized pitting and crevice corrosion resistance and excellent flow velocity erosion resistance properties. As with all stainless steels, fouling organisms can collect on their surfaces unless treated with biocides.

## CONCLUSION

The proper selection of materials for seawater pumps depends on many factors, including service conditions, pump design, abrasive qualities of the seawater, material availability and cost. Since pump operating conditions and practices determine performance of any material, it is the pump user's responsibility to determine and approve acceptable materials for the environment under which the pumps will operate.

- The conventional austenitic stainless steels are the most cost effective choice for normal seawater services, provided the appropriate precautions are taken to ensure that a minimum flow of 3 to 5 ft/sec (0.9 to 1.5 m/sec) is maintained, and stagnant conditions are avoided. If the pump is to operate with stagnant or idle periods, then freshwater flushing should be included to protect the wetted surfaces from localized attack or cathodic protection system utilized to protect against localized pitting and crevice damage.

- Ni-resist, copper-nickels, aluminum-bronze and nickel-aluminum-bronze alloys should perform well in unpolluted seawater provided the velocity limitations are not exceeded. Except for the possible use of Ni-resist or nickel-aluminum-bronze for large intake pump casings, the conventional austenitic stainless steels such as CF8M should be considered as a minimum alloy choice for seawater with the super-duplex and super-austenitics preferred for seawater pumps. These alloys are highly useful when galvanic protection is used within the pump design utilizing the benefit of galvanic effects.

- In more demanding seawater services, where operating or environmental conditions require greater corrosion resistance, one of the nitrogen enhanced super-austenitic 6 percent molybdenum, or super-duplex alloys with higher alloy content PREN > 40 may be needed. These highly alloyed austenitics and duplex alloys offer a substantial life cycle cost savings, and provide economic alternative to the more costly nickel based or titanium alloys, particularly in warmer and more aggressive highly concentrated Middle East Gulf seawater.

- If total immunity from localized attack in seawater is required, then one of the more costly nickel-based Inconel® or titanium alloys are generally called for.

In summary: When selecting a material for seawater service, consider all the variables in the environment and the operating process conditions that may occur. Once the conditions are known, look at the long-term economics—this will often be a higher cost material and not one with the lowest initial cost, but one offering the longest lifetime benefit providing lower maintenance and associated shutdown costs, with greater reliability.

Answers to the following questions will help determine which type of pump construction best meets your or the user's needs.

- First, how much initial construction expense do you want to invest, and how long do you expect the pumps will be in service?
- Will the pumps operate continuously or intermittently?
- Is the seawater being chemically treated?
- Will cathodic protection be used to allow for lower cost protected alloys?
- Is there a willingness to invest in more expensive materials initially to reduce the total cost of ownership (life cycle costs) associated with maintenance expenses, parts and pump replacement.

Answers to these questions will indicate whether the protection afforded by the more expensive super-austenitic or super-duplex materials is appropriate.

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