EROSION AND CORROSION IN PIPING SYSTEMS FOR SEA WATER

AUGUST 2004
FOREWORD

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An updated list of Guidelines is available on request. The list is also given in the latest edition of the Introduction-booklets to the "Rules for Classification of Ships" and the "Rules for Classification of High Speed, Light Craft and Naval Surface Craft".

August 2004

This Guideline replaces Classification Note 13. No changes have been made other than editorial ones.
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1. Introduction
This publication contains practical information aimed at obtaining satisfactory reliability in piping systems for sea water. Class will be assigned on the basis of compliance with the relevant requirements in the rules, and this publication is written for guidance only.

Ferrous alloys and copper alloys are taking the dominant part in the piping systems for sea water today. The ferrous alloys may be cheaper to install compared to the copper alloys, but they possess relatively low corrosion resistance in sea water. Some copper alloys are regarded as very resistant in certain sea water conditions, but even most of these alloys may be subjected to certain types of corrosion which may be difficult to defeat. Corrosion cannot be completely avoided but can be reduced considerably and the effective lifetime of the piping system prolonged if its cause and development is known and the piping system is installed and operated with this knowledge in mind.

2. Types of Corrosion
2.1 General
Corrosion of a metal is a chemical or electro-chemical reaction between the metal surface and its environments. Sea water corrosion involves reactions where the metal surface is transformed into metal oxides or hydroxides (like rust).

The rate of sea water corrosion depends on several factors like environmental and metal impurities, temperature, oxygen access, metallic contact (conductive) with dissimilar metals, sea water flow velocities, type of metals, surface protection, stresses, etc. Below, the most commonly appearing types of corrosion in piping systems exposed to sea water are discussed.

2.2 Erosion Corrosion
This type of corrosion occurs when there is a simultaneous erosion and corrosion as a result of rapidly flowing liquid. Erosion corrosion is characterized by attack like small pits with bright surfaces free from corrosion products. These pits often have the form of a horse shoe with the nib pointing in the current direction. Erosion corrosion may occur where the velocity of liquid is too high. Most exposed are places where there are effects of turbulence, e.g. joints, bends etc. The corrosion rate will accelerate if the liquid contains gas bubbles and/or solid particles.

2.3 Galvanic Corrosion
Galvanic corrosion occurs when metals of different potential are connected together and simultaneously exposed to an electrolyte thus causing galvanic forces to be set up. The electrolyte may for instance be sea water. If a brass pipe is connected to a cast steel valve in a sea water circulating system, the cast steel valve, which has a lower potential than the brass pipe, will corrode more rapidly than without such a connection. This is a typical example of galvanic corrosion. The extent of galvanic corrosion will depend upon the dimension of the surface area of the more noble metal in relation to the less noble metal. If the surface area of the less noble metal is smaller than that of the more noble metal surface, the corrosion rate of the less noble metal will be increased. In case of opposite surface area relations the corrosion rate will be reduced. Ref. Table 1.

2.4 Selective Corrosion
Typical for this type of corrosion is that the structural elements of an alloy are corroding at different rates. The most typical example of this is dezincification of brass. With \( \alpha + \beta \) brass (Zn-content between approx. 38% to 46%), the \( \beta \)-phase (Zn-content from approx. 46% up to 50%) corrodes, because this is less noble than the \( \alpha \)-phase (Zn-content up to approx. 38%). Both copper and zinc from the \( \beta \)-phase is dissolving, and amorphous copper is “precipitated”. The mechanical properties of the alloy are drastically reduced. Aluminium bronzes containing 8% aluminium or more may be exposed to a type of corrosion very much similar to the one mentioned above. This type of corrosion, is called dealumination.

2.5 Deposit Attack
Deposit attack is found under non-metallic, but electrical conducting deposits or coatings. This is caused by the complication of liquid flowing to the area under the coating. This type of corrosion is often found under fouling on metal structures exposed to sea water.

2.6 Stress Corrosion
This type of corrosion may appear when a metallic material is simultaneously exposed to both tensile stresses and a corrosive medium. The tensile stresses may be remaining stresses from e.g. welding or cold-working, or it may be applied working stresses. Corrosion media contributing stress corrosion are specific to each metal:

- stainless steels: chlorides, bromides, hydro-sulphuric acid and alkalics
- copper alloys: nitrogen containing compounds, for instance ammonia.

3. Materials and Coating of Materials
3.1 Copper and Copper-Alloys
3.1.1 Copper
Copper, which usually is passive when connected to its own alloys, will be subjected to accelerating corrosion if connected to nickel-alloys or stainless steel. Further, copper and Cu-alloys have an unfavourable influence (galvanic effect) on aluminium and all copper/aluminium connections are therefore to be insulated.

Copper-ions in solution have a restraining effect on the formation of marine growth (fouling). The effect increases with increasing content of copper in the alloy. If copper tubes are to be used in connection with galvanized steel tubes, it is most important that the copper tubes are fitted after the steel tubes in the flow direction. If the fitting is reversed, copper-ions will deposition the zinc or steel surface forming local galvanic elements leading to pitting corrosion.

3.1.2 Brass
Brass comprises a large group of copper alloys which contains up to approx. 50% Zinc. Other elements which may be added are: Lead (Pb), Tin (Sn), Iron (Fe), Magnesium (Mn), Nickel (Ni), Aluminium (Al) and Silicon (Si). The brasses can be divided into three main groups:

- Alpha-brass, with Zn-content up to approx. 38%
- Alpha + Beta-brass, with Zn-content from approx. 38% up to 46%
- Beta-brass, with Zn-content from approx. 46% up to 50%.

With a Zn-content exceeding approx. 50%, the Gamma-phase may be significant. This phase is very brittle and the alloys are of no practical use. Generally, the Zn-content increases the tensile strength and hardness, while the elongation decreases.

The Alpha-brass can be used in stagnant pure sea water, on the assumption that the brass is alloyed with 0.02-0.6% Arsenic (As). If also alloyed with about 2-3% Aluminium (Al) which increases the tensile strength, the alloy can be used for running sea water at velocities up to 3 m/sec.

The Alpha + Beta-brass and Beta-brass are very prone to dez-
incification and are therefore not recommended for use in connection with sea water.

### 3.1.3 Ledged Gunmetal

Copper and the following metals as main elements Tin (Sn), Zinc (Zn) and Lead (Pb) are usually called gunmetal ("rødmønnet"). Ledged gunmetals with high tin content (at least 5% Sn) such as RG5 are comparatively resistant to corrosion in sea water provided the water is pure. In sulphide polluted sea water, alloys with higher content of Sn, for inst. RG7 and RG10, are quite resistant.

### 3.1.4 Aluminiumbronze

Aluminiumbronzes are alloys of copper and aluminium (usually up to about 10% Al and containing small additions of Iron (Fe), Nickel (Ni) and Manganese (Mn). Typical Aluminiumbronzes are:

- NS 1598, containing about 9-10% Al, 2.5% Fe, 5% Ni, 1% Mn
- NS 1670, containing about 9-10% Al, 4.5% Fe, 5% Ni, 1% Mn.

Copper-Manganese-Aluminium. Typical composition: 70% Cu, 3% Ni, 7.5% Al, 2.6% Fe and 10% Mn. These alloys are resistant to pure sea water and are recommended used in parts subjected to erosion. The alloys are susceptible to corrosion attack in sulphide polluted water.

### 3.1.5 Copper-Nickel Alloys with Iron

The most commonly used alloys of this type are:

- Copper-nickel 90/10 containing:
  - 9-11% Ni, 1-1.8% Fe, 0.5-1% Mn and the rest Cu
- Copper-nickel 70/30 containing:
  - 30-32% Ni, 0.4-1% Fe, 0.5-1.5% Mn and the rest Cu.

These alloys form protection layers with good attachment, resistant against corrosion and erosion at high velocity, even if air bubbles are present in the water. The alloys are also resistant to influence from polluted dock- and coastal-waters, as long as the protection layer has been formed.

### 3.2 Ferrous Materials

Examinations carried out regarding corrosion of mild steel, cast steel, grey cast iron, nodular cast iron, Cu-alloyed and Ni-alloyed nodular cast iron, prove that mild steel and cast steel show greater tendency to crevice - and pitting corrosion at high flow velocity compared with cast alloys with high carbon content.

Ferrous alloys with 1% Cu or 1.5% Ni have apparently small advantages regarding corrosion resistance in sea water.

Even if the material reacts with oxygen and forms a thick passivating layer, it may be attacked by chlorine-ions. This phenomenon is increasing in water with low oxygen content, for instance in stagnant water or water with low flow velocity and water where the possibility of marine growth (fouling) is present.

For piping systems exposed to sea water, chromium/nickel steel 18/8 are normally not to be recommended.

Chromium/Nickel steel 18/8 with Molybdenum may be used provided the piping system can be carefully cleaned from all possible sea water (Chlorine ion) remainings with fresh water immediately after the sea water carrying is terminated.

### 3.3 Coating

#### 3.3.1 General

To protect piping systems for sea water against corrosion, an internal coating may be applied. A 100% effective protection is not always possible, and as cracks or other defects in the coating may result in serious pitting corrosion, it is essential that the coating is applied and inspected by experienced personnel, preferably from the manufacturer of the coating or coating system.

Coatings may be organic types like elastomers (natural and synthetic rubber), thermoplastics and thermosetting plastics or inorganic types like zinc and cadmium. Most of the paint systems used apply coatings of organic materials.

#### 3.3.2 Rubber

Some types of rubber materials tend to change their volume after having been exposed to water. Increasing temperature will increase this tendency. Such types should not be used.

In order to obtain a good adhesion between the rubber and the pipe surfaces, the surface preparation should be at least blast cleaned to Sa 2.5 according to the Swedish standard SIS 055900, or equivalent standard. The rubber lining should be applied and tested according to the specification from the manufacturer. Spark testing should be carried out to check that the lining is without holes or porosity.

#### 3.3.3 Polyamide

Polyamide is a thermoplastic, and special types of this material can be applied as corrosion protection coating by electrostatic spraying of polyamide powder. A primer is necessary to obtain good adhesion of the coating and to ensure the corrosion protection effect of the system. The thickness of the coating should generally be 300-500 μm (microns). The surfaces to be protected should be blast cleaned to Sa 2.5 according to SIS 055900, or equivalent standard.

#### 3.3.4 Epoxy

Epoxy is a thermosetting plastic. Epoxy coatings generally consist of two components and may be applied as powder systems or paints with solvents. The properties of the system can be changed by using different resins or curing agents.

The powder systems seem to give a better protection of the piping systems than the epoxy paints with solvents. Electrostatically sprayed epoxy powder coating should be applied to a thickness of about 300 μm (microns). The steel surfaces should be blast cleaned to Sa2.5 according to Swedish standard SIS 055900 or equivalent, and the application should be inspected in accordance with the manufacturer's specification.

When using epoxy paints with solvents the coating should be applied to a thickness of about 300-400 μm on a surface prepared as for the powder system and in accordance with the manufacturer's specification.

### 4. Lay-Out of the Piping System

#### 4.1 General Principles

The location of sea suctions should be arranged so that the smallest possible quantity of air is drawn into the system, even during heavy rolling. The sea suctions should not be placed immediately below the bilge keels.

Sudden changes in flow direction should be avoided. Copper pipe bends should not have a smaller bend radius than 4 times the pipe diameter, and the bends should have no wrinkles. Branches should make the most acute angle possible to the flow direction in the main pipe, and the branch connection should be well rounded. Sudden changes of pipe cross-section should be avoided. If large diameter variations are necessary, there should be a tapered transition between the different diameters, having a taper not greater than 1:5.

Packings should not protrude inside the pipes.

The lay-out of the piping system should avoid possibilities for
4.2 Electrical Contact between Alloys of Different Potential

The degree of galvanic corrosion will depend on many different parameters of which the most important ones are:
- chemical composition of the alloys coupled together
- the relative areas of the metals exposed (ref. item 2.0)
- the salt content and other impurities of the sea water
- the temperature and the velocity of the sea water.

It is difficult to give a general list showing which alloys can be coupled together and which to be avoided. In general, a combination of alloys close in chemical composition alloys varying in chemical composition are coupled together, e.g. cast iron and brass galvanic corrosion is much more probable. Ref. item 2.3.

Table 1 gives guidelines on coupling together different metallic pipe materials in pure sea water.

5. Flow Velocity

5.1 General

Regarding corrosion attack, the local water flow velocity is decisive. Every bend (branching, blocking device and other special details in a piping system disturb the flow forming turbulence which increases the local velocity. Regarding the material’s ability to withstand corrosion due to higher water flow velocities, the materials may be divided into two groups as follows:
- Materials which have low corrosion resistance to high flow velocity. (Mild steel, Cu and Cu/Zn alloys)
- Materials which have good corrosion resistance to high flow velocity. (Cu/Ni alloys and stainless steels).

Regarding allowable flow velocity in piping systems, the following table may be used as a guidance:

<table>
<thead>
<tr>
<th>Material</th>
<th>Flow velocity (laminar flow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-brasses</td>
<td>≤ 3 m/sec.</td>
</tr>
<tr>
<td>Cu/Ni 90/10</td>
<td>≤ 3.5 m/sec.</td>
</tr>
<tr>
<td>Cu/Ni 70/30</td>
<td>≤ 4.5 m/sec.</td>
</tr>
<tr>
<td>Steel tubes, galvanized</td>
<td>≤ 2 m/sec.</td>
</tr>
</tbody>
</table>

6. Joining of Materials

6.1 Corrosion in Material Joints

Welding, soldering and brazing together pipes and tubes involve introduction of material structures (micro- and macro-structure, surface condition, etc.) which deviate from those of the parent material. Furthermore, the chemical composition of the solder, weld metal and Heat Affected Zone (HAZ) may be deviating, the extent depending on solder (brazing) or welding method.

These factors may have influence on the corrosion resistance of the piping system and cause selective corrosion attacks on the joints. In sea water the relatively smaller joint may be anodic in relation to the larger surrounding parent material (cathode). This will introduce an accelerated galvanic corrosion of the joints.

In 6.2 and 6.3 below, some general guidelines are given to the welding and soldering/ brazing of different pipe materials for marine application.

6.2 Welding

Bronzes have normally better weldability than brass since bronzes contain no or very small amounts of zinc. Both these alloys may be welded satisfactorily by coated electrodes provided that the slag is removed very carefully between layers. By using gas-shielded arc welding processes (MIG, TIG) the difficulties due to the slag may be eliminated.

The most applied alloys of this kind in shipbuilding are aluminium brass, aluminium bronze and copper nickels.

**Aluminium brass**

Gas-shielded arc welding is recommended. both TIG and MIG may be applied.

Normally, TIG welding with plain tungsten electrode is used. The problem of zinc fumes may be considerably reduced by using an alpha aluminium bronze filler rod, for example 93/7 or 95/5.

Aluminium brass pipes have to be in stress relieved condition prior to welding. If the pipes should be cold worked (bending), the cold worked regions should be stress relieved at approx. 400°C. Cleanliness before welding is of paramount importance.

Vertical and overhead welding is very difficult for this material, and welding in flat position is recommended.

To assist in obtaining good penetration and neat underbeads, it is good practice to apply a thin film of proprietary aluminium bronze grade brazing flux. Whereas the use of a flux assists in obtaining good penetration, the use of argon backing only serves to prevent additional oxidation.

Post-weld stress relieving is advisable where there is a risk of stress corrosion cracking.

**Aluminium bronze**

Arc welding with coated electrodes and/or gas-shielded metal (MIG) is normally to be used. Argon-shielded tungsten welding (TIG) should be used with care, due to the higher heat input of this process. There are available several different filler metals, and the choice of filler metal should follow that recommended by the filler metal manufacturer.

All bronze alloys should preferably be welded in flat position. The weld groove should be kept clean and dry. Coated electrodes should be dried prior to welding. Preheat and stress relief should follow that required for the alloy in question.

**Copper-nickel alloys**

Nearly all welding techniques may be applied to the copper-nickel alloys. Electrodes of the 70/30 copper-nickel composition (CuNi) type are employed for all alloy compositions.

Vertical and overhead welding can be accomplished with minor modifications of the settings employed for downhand welding. Careful manipulation of the electrode is required to obtain satisfactory bead contour. Preheating is not necessary. Some copper-nickel alloys respond to heat treatment. Post-weld heat treatment may therefore be advisable for some alloys because of aging and overaging occurring during welding.

**Austenitic Chromium-Nickel Stainless Steel**

The austenitic stainless steels have normally excellent weldability and can be welded with all common welding processes. Since these steels are not hardened by heat treatment, neither preheat nor postheat is needed to ensure weld joints with good strength and ductility. Some times postheat treatment, however, may be used to remove stresses and increase corrosion resistance suitable for the specific requirements.

Some steel types [according to AISI (AISI is short for American Iron and Steel Institute) 301, 302, 304, 305, 308, 310, 316 and 317] precipitate intergranular chromium carbides when in temperature range of about 430 to 870°C. Carbide precipita-
tion in base metal will occur in narrow zones near a weld in the Heat Affected Zone (HAZ).

The likelihood of corrosive attack on weld-sensitized material is not so great in the higher chromium types (309 and 310). Similarly, the types containing molybdenum (316 and 317) may display a little less to heat affected zone attack.

Cold working creates slip bands that act as grain boundaries to promote carbide precipitation. Welding processes with rapid cooling rates reduce the time within the dangerous temperature range. Steels where the carbon is stabilized with strong carbide-forming elements like Nb, Ta and Ti and steels having an extra-low carbon content are less sensitive.

For the low-carbon types (according to AISI 304L, 309S, 310S and 316L) the problem of chromium carbide precipitation during welding and stress-relief heat treatment is eliminated.

The following type of corrosion may occur in weldments:

Pitting Corrosion
Chloride solutions like stagnant sea water may cause relatively rapid pitting. The steels containing molybdenum are less sensitive. However, corrosion may occur especially along the oxide gradient in HAZ of unsatisfactorily passivated pipes.

Intergranular Corrosion
If 18-8 steel is welded without taking precautions to avoid intergranular precipitation, attack may occur along the boundaries.

Stress-corrosion Cracking
The presence of chlorides in a solution or vapour may, when coupled with stress, produce fine cracks. The actual cracking is believed to be preceded by microscopic pits which concentrate the stress and initiates cracking. The residual stress from welding is sufficiently high to provide the stress necessary in this cracking mechanism. Higher nickel-containing steels show greatest resistance to stress-corrosion cracking.

6.3 Brazing/Soldering
Soldering is not discussed here since this joining method has a rather limited application for the materials and purposes in question.

Brazing is, however, an effective means of joining copper alloys. Silver base filler metals with brazing temperatures from 620°C-870°C are commonly used. Standard brazing procedures apply to copper alloys.

Aluminium brass
All joining surfaces must be thoroughly cleaned by mechanical or other means before joining.

For adequate resistance to corrosion by sea water the silver base filler metal should normally contain min. 49% silver. Some manufacturers, however, say min. 43% silver.

Care should be taken to avoid overheating or stressing the parts being joined whilst they are at brazing temperature.

All remnants of brazing flux should be thoroughly washed off as soon as the brazing operation is completed and the joint has cooled a little, as flux residues can be corrosive.

Aluminium bronze
Aluminium bronze can be brazed with silver bearing filler metals and appropriate flux, for example AWS Type 4. That mentioned above for aluminium brass may mainly be followed for aluminium bronze.

Copper-nickel alloys
Copper-nickel alloys can be brazed with B Ag and B Cu P brazing alloys. However, the B Cu P filler metal is not recommended on alloys containing more than 10% nickel because a brittle phosphide may be formed. Also, service in sulphurous atmospheres above room temperature is not recommended for B Cu P brazing alloys.

The base metal must be free of sulphur or lead. Standard solvent or alkaline degreasing may be used. AWS Type 3 flux is suitable for most applications. All remnants of brazing flux should be thoroughly washed off.

Copper-nickel alloys are susceptible to intergranular penetration by molten filler metal in the stressed condition. To prevent cracking, they should be stress relieved before brazing.

7. Cathodic Protection
One of the most commonly used types of corrosion protection is to make the susceptible material cathodic relative to its environments. There exist two different methods giving such a cathodic protection, namely by application of sacrificial anodes and impressed current.

Although pipes and piping systems are difficult to protect effectively cathodically due to the difficulty of getting satisfactory current distribution, sea water inlets and heat exchangers (closed circuit) may to some extent be protected.

The most commonly used sacrificial anodes for such systems are made of Zn-, Al-, or Mg-alloys.

The starting-up period has a great influence on the lifetime for the sea water circulating system. If the system is being pressure tested, this should be done by using fresh water, and after the pressure test, the system should remain completely filled for some time, preferably until the system is taken into service. However, if it has to be drained, one should be sure that there is no water left. If water is remaining locally, this may initiate local corrosion attacks.

During the starting-up period there will normally be formed a film or layer on the inner surface of the pipes. If the water is clean and contains oxygen, this will be a clean oxide layer which will prevent corrosion. This process is called passivation. If there is not sufficient oxygen in the water, the passivation process may be impeded or reduced.

Therefore it is important that the sea water is clean and fresh (contains enough oxygen) the first period (3-4 weeks) after the system is put into operation. Ferrosulphate may be added to accelerate the passivation process.
Appendix A
Extracts from “Corrosion Handbook” by H. H. Uhlig (1958)

Table 1

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<thead>
<tr>
<th>Coupled with</th>
<th>AREA EXPOSED</th>
<th>Galvanized steel</th>
<th>Aluminium alloys</th>
<th>Mild steel</th>
<th>Low alloy steel</th>
<th>Cast Iron</th>
<th>-12% Cr Steel</th>
<th>Lead/Tin Solder</th>
<th>-25% Cr Steel</th>
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<th>Aust. Cr-Ni-Mo steel</th>
<th>Aust. Cr-Ni steel</th>
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- The corrosion of the metal under consideration will be reduced considerably in the vicinity of the contact.
- The corrosion of the metal under consideration will be reduced slightly.
- The galvanic effect will be slight with the direction uncertain.
- The corrosion of the metal under consideration will be increased slightly.
- The corrosion of the metal under consideration will be increased moderately.
- The corrosion of the metal under consideration will be increased considerably.

S Exposed area of metal under consideration is small compared with the area of the metal with which it is coupled.
E Exposed area of metal under consideration is approximately equal to that of the metal with which it is coupled.
L Exposed area of metal under consideration is large compared with the area of the metal with which it is coupled.