Paper No.
07262

NACE INTERNATIONAL CORROSION 2007 CONFERENCE & EXPO

FACTORS AFFECTING GASKET SELECTION

FOR STAINLESS STEELS IN SEAWATER

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ABSTRACT

High alloy stainless steels, such as superduplex and 6%Mo, have been extensively used for seawater cooling systems and in reverse osmosis desalination plants. From time to time corrosion has been observed at flange faces that is not attributable to poor quality material or excessively severe operating conditions. Over the last fifteen years there have been studies looking at corrosion of flanged joints. Some have investigated flange materials, while others have looked at different gasket materials. The present paper reviews the published data and presents some field experience from the authors' company. These are combined to present some recommendations on combinations to be avoided and the best choice of suitable gaskets for systems operating at different pressures.

Keywords: seawater, crevice corrosion, stainless steels, gaskets.

INTRODUCTION

Stainless steels have been increasingly used for seawater cooling systems, particularly the higher alloy materials, such as superduplex and superaustenitic. The main concern with stainless steels in seawater is crevice corrosion and one of the main creators of crevices is a flanged joint. Most flanges are designed in accordance with ASME B16.5 or an equivalent national standard. Stainless steels for flanges conform to ASTM A182 or an equivalent standard. Although there is a range of flange designs in use, by far the most common is the raised face weld neck flange. The gasket fits on the raised face, which is quite wide and at first glance it might be thought that this will create a tight, deep crevice, with a potentially high risk of corrosion. However, the raised face has a spiral or "gramophone" groove machined across it. This means that the face creates a series of relatively shallow, tight crevices, linked by much broader areas of a similar depth. This is a much less aggressive crevice arrangement. Less attention has been paid to the selection of the gasket material. It is clearly desirable to select gasket materials that will not exacerbate crevice attack and there is published data to show that some gasket materials create tighter and more aggressive crevice conditions than others. This paper reviews published data and also some service failures. It also makes recommendations on the most suitable gasket materials, both for normal low pressure (~10bar) cooling systems and the high pressure systems (~70bar) used in RO desalination plants.

ALLOYS

Before discussing gaskets we need to be aware of which stainless steels these are being used with. Low alloy stainless steels, such as 316L (UNS S31603) will suffer crevice corrosion in seawater and all waters containing more than ~1,000mg/l chloride[1]. Even higher alloy stainless steels, such as 904L (UNS N08904) and 22% Cr duplex (UNS S31803), suffer crevice corrosion in ambient temperature seawater[2]. Only alloys with a pitting resistance equivalent number (PREN) greater than 40 (where PREN = % Cr + 3.3 x % Mo + 16 x % N) have been shown to resist crevice corrosion in ambient temperature seawater[2]. This has become enshrined in standards such as the Norwegian oil and gas NORSOK document[3]. This essentially covers the superduplex and 6% Mo austenitic stainless steels. The nominal composition of these alloys is shown in Table 1. Both of these alloy types are covered by several UNS numbers and some variants of the 6% Mo alloys also contain copper, while some of the superduplex alloys also contain copper and/or tungsten.

LABORATORY TESTING

Traditionally, compressed asbestos fibre (CAF) gaskets were used in seawater cooling systems and these gave few problems. However, with the banning of CAF gaskets a wide variety of materials have been offered for use in gaskets. These include synthetic rubbers, such as neoprene, synthetic fibres, such as aramid, and PTFE. These have been evaluated in a number of laboratory tests.

Kain[4] tested a variety of gasket materials with 316L flanges in natural seawater in the temperature range 25° to 32°C for 28 days. His results are summarised in Table 2. Although crevice corrosion of 316 would be expected under these conditions, three gasket materials did not have any crevice corrosion on the flanges. In addition, three more materials gave only shallow attack. In contrast, the remaining five materials all had very deep attack on the flanges. One thing to remember with flanges conforming to ASME B16.5 is that the gasket face has a spiral "gramophone" groove machined on it. This means that instead of there being a deep, tight crevice across the whole of the gasketed face, it is a series of shallow, tight crevices connected by wider, shallower regions. This permits diffusion from the less tight regions, thus retarding the concentration of chloride in crevices that is the precursor to the initiation of crevice corrosion[5].

Following a series of failures of 6% Mo stainless steel flanges in the North Sea, Rogne et al[6] examined some weld overlays for 6% Mo to improve the resistance to crevice corrosion resistance. At the same time they examined two gasket materials, PTFE and aramid fibre. The tests were carried out at +600mV SCE, simulating that in chlorinated seawater, and the threshold temperatures for crevice corrosion were determined. The results are summarised in Figure 1. The results show that PTFE creates a much more severe crevice than aramid fibre, particularly for the nickel alloys. It is interesting that an alloy 625 (UNS N06625) weld overlay was inferior to a wrought 6% Mo flange with the same gasket material. This demonstrates that a material with a high resistance to crevice corrosion as a wrought alloy may not necessarily confer equivalent resistance when used as a weld overlay.

Rogne et al carried out a more extensive series of tests on 6% Mo material with a range of gasket materials[7]. The results, in Figure 2, show that higher critical crevice temperatures (CCT) were obtained for aramid fibre compared with both PTFE and POM. The authors showed that the gaskets giving the highest CCT values also absorbed the most water. This meant there was more water within a gasket that could diffuse into the tightest regions to delay the onset of crevice corrosion. In addition, materials such as PTFE can deform to fit the flange face, creating tighter crevices.

One factor that is often discussed is that of gaskets containing graphite. Graphite is very noble and is a very efficient reducer of dissolved oxygen, which is the cathodic reaction in seawater systems. Turnbull[8] investigated the properties of graphite and showed that up to about +400mV SCE, coupling high alloy stainless steel to graphite should retard the reduction of pH in the crevice. This possible beneficial effect of graphite has not been demonstrated in practice. Kain[4] tested 316 with graphite gaskets and reported deep attack, but this alloy suffers crevice corrosion at potentials around +400mV SCE, while higher alloy stainless steels are resistant at this potential. Turnbull also pointed out[8] that at the potentials achieved in chlorinated seawater (+600mV SCE) the graphite will stimulate acidification and thus exacerbate crevice corrosion. As most stainless steel seawater systems are chlorinated, this means that graphite-containing gaskets will increase the risk of crevice corrosion.

Martin et al[9] conducted tests on alloy 625 (UNS N06625) in seawater at a potential of +300mV and 65°C, using fluoropolymer (FKM) gaskets to create crevices. In the first test severe crevice corrosion occurred. In the second test a different batch of the same gasket material was used and no crevice corrosion occurred. The reason for the superior performance of the alloy 625 in the second test was judged to be because of a deposit in the crevices from the gasket material. This was identified as a talc-related compound from a mould release agent used during the manufacture of the gaskets. This compound gave better crevice corrosion to alloy 625 compared with higher alloy nickel-base materials creviced with the original fluoropolymer gasket material. Proper characterisation of this compound may offer a method of reducing the risk of crevice corrosion in the future.

HIGH PRESSURE GASKETS

Most seawater cooling systems are rated up to 10 bar, but the high pressure section of an RO desalination plant operates at pressures from 65 bar to 100 bar. At these pressures conventional gaskets are not suitable to retain the pressure at flanged joints. It is common to use metal gaskets either as a “V” or spirally wound. The most common type of these gaskets utilise 316 stainless steel or alloy 400 (UNS N04400). Both alloys suffer severe attack in crevices in seawater, and this can lead to attack on high alloy stainless steels adjacent to them[2, 10]. The reason for this is that when 316 stainless steel (or alloy 400) corrodes, the pH of the localised water drops sharply. The solution can eventually become sufficiently acid (pH<1) to promote attack on both super austenitic stainless steels[10] and superduplex stainless steels[2].

Other metals are also used for spiral wound gaskets, but only those that are seawater resistant and galvanically compatible with high alloy stainless steel should be used. Table 3 shows some alloys commonly used for high pressure gaskets and which ones are suitable for use with high alloy stainless steel in seawater[11]. The choice will depend on price and availability.

Graphite is sometimes used as a filler in spiral wound gaskets. Provided it never contacts seawater, it should not cause a corrosion problem. If the windings are damaged prior to installation, so that the graphite is exposed to seawater, then there is a possibility of galvanic corrosion of the flange faces.

Another method of coupling in high pressure systems is the Victaulic-type joint. In this, both pipes have a square cut groove on the outside of the pipe, some 15mm or so from the end. A rubber boot slips over both pipe ends and it is held in place with a clamp, as shown in Figure 3. The sealing boot is usually made of a synthetic rubber. The crevice created by such a seal is relatively tight and deep and it has caused corrosion of low alloy materials, such as 316L, in seawater, as shown in Figure 4[12]. Crevice corrosion with this type of joint and high alloy stainless steels is rare and corrosion is usually due to poor heat treatment of the stainless steel.

SERVICE EXPERIENCE

Over the last 15 years a number of problems with leakage at flanges due to corrosion have been reported for 6% Mo austenitic and superduplex stainless steels. A few of these have been due to metallurgical problems, such as sigma phase due to incorrect heat treatment[13]. However, more have concerned the use of graphite-containing gaskets in chlorinated seawater service.

Strandmyr and Hagerup reported problems with graphite-containing gaskets on 6% Mo stainless steel flanges on several North Sea platforms[13]. The problems were solved by re-machining the flange face and changing to neoprene gaskets. Shrive[14] reported a similar problem on the Rob Roy/Ivanhoe platform, with superduplex stainless steel. Again the problem was solved by re-machining the flange faces and changing, this time, to synthetic fibre gaskets. The author has also seen the problem in superduplex flanges on the seawater feed piping at an RO desalination plant in the Middle East. Figure 5 shows the typical appearance of the attack.

There have been a number of problems reported with spiral wound gaskets, where the metal was not compatible with high alloy stainless steel in seawater. Strandmyr et al[13] reported problems with 316L stainless steel gaskets. The authors have seen problems with 316L and alloy 400 (UNS N04400). Amon et al[15] reported failures of superduplex flanges joined with both alloy 825 (N08825) and alloy 718 (N07718) gaskets in natural seawater. The solution to these problems has been to re-machine the flange faces and change to synthetic fibre or neoprene gaskets for low pressure systems. For high pressure systems, where a spiral wound gasket is essential to ensure a tight seal, a gasket made from one of the compatible alloys in the left hand column of Table 3, has been used.

PTFE has not often been used for gaskets in seawater systems and reported cases of failures are rare. Figure 6 shows corrosion of a superduplex stainless steel flange from on RO desalination plant where PTFE had been used. In this case, the gasket was a 316L spiral wound gasket coated in PTFE, because the joint was in the high pressure section (70 bar). A change was made to a compatible metal gasket with no coating.

It must be remembered that not all corrosion at flanged joints is due to poor gasket selection. Corrosion can also be caused by over chlorination or too high a seawater temperature. Francis and Byrne[16] showed that the temperature and chlorine limits are linked and they presented recommendations for superduplex stainless steel based on a combination of laboratory testing and service experience (Table 4). Corrosion problems due to incorrect material heat treatment were mentioned above.

RECOMMENDATIONS

Based on the foregoing testing and service experience, the following recommendations are made for gaskets for high alloy stainless steels in seawater.

A. Low Pressure Systems (up to 10 bar).

   1. Avoid the use of PTFE or graphite loaded gaskets.

   2. Use gaskets made of synthetic rubber, rubber bonded aramid or synthetic fibre.

B. High Pressure Systems (10 bar to 100 bar)

   1. Avoid PTFE coated gaskets.

   2. Graphite- containing gaskets are acceptable provided the graphite is sealed from the seawater and is never wetted.

   3. <u>Only</u> metals compatible with high alloy stainless steel should be used for spiral wound gaskets.
      (Superduplex, 6% Mo austenitic, Ni-Cr-Mo alloys where Mo >7%, titanium).

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TABLE 1
NOMINAL COMPOSITION OF THE HIGH PREN STAINLESS STEELS SUITABLE FOR USE IN SEAWATER

ALLOY	NOMINAL COMPOSITION (wt%)					
	Fe	Cr	Ni	Mo	N	Others +
Super Austenitic	bal *	20	18 – 25	6	0.2	(Cu)
Super Duplex	bal	25	7	3.5	0.25	(Cu) (W)

bal * = balance
\+ = optional elements

TABLE 2
RESULTS OF CREVICE CORROSION TESTS WITH 316L FLANGES AND VARIOUS GASKETS IN SEAWATER AT ~28°C (REF 4)

Gasket Material	No of Flanges Attacked	Maximum Depth (mm)
Neoprene	0/2	0.00
Butyl Rubber	0/2	0.00
Fluoroelastomer	0/2	0.00
Red – rubber	1/2	0.01
EPDM	1/2	0.05
Nitrile	2/2	0.03
Carbon fibre + nitrile	2/2	0.77
Aramid fibre + nitrile	2/2	2.10
PTFE	2/2	1.05
Glass filled PTFE	1/2	1.40
Graphite/SS	1/2	0.69
PCA *	2/2	0.01

***** Perspex crevice assembly (ASTM G78)

TABLE 3
SOME METALS COMMONLY USED FOR SPIRAL GASKETS AND THEIR COMPATIBILITY WITH HIGH ALLOY STAINLESS STEELS (REF 10)

Alloys Compatible with High Alloy Stainless Steels	Alloys that Should NOT be used with High Alloy Stainless Steels
Superduplex stainless steel	22% Cr duplex stainless steel
6% Mo austenitic stainless steel	Alloy 400
Alloy 625	316 stainless steel
Alloy C-276	317L
Alloy 59	904L
Titanium	Alloy 825
	Alloy 20

TABLE 4
RECOMMENDED MAXIMUM CHLORINE LEVELS FOR SUPERDUPLEX STAINLESS STEEL AT DIFFERENT SEAWATER TEMPERATURES (REF 14)

Temperature (C°)	Chlorine (mg/l)
10	200
20	5.0
30	1.0
40	0.7

FIGURE 1 Critical crevice temperature at +600mV SCE for 6%Mo stainless steel with various gasket materials (Ref 6)

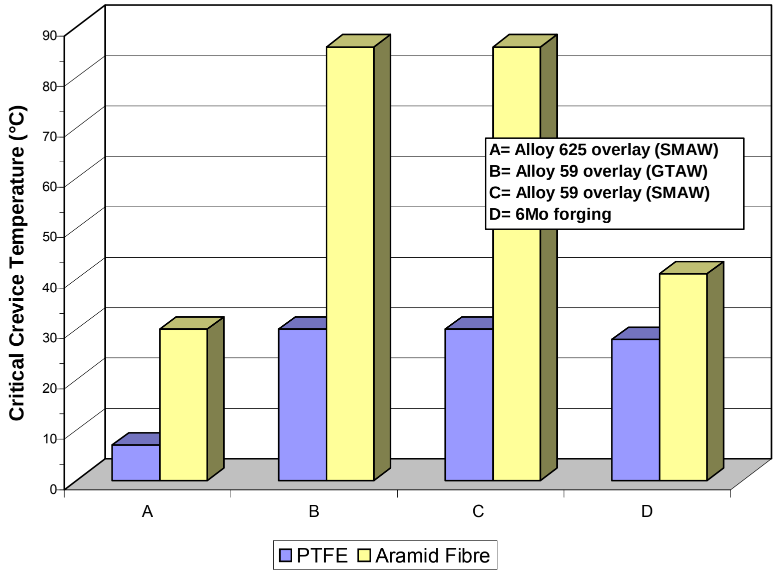
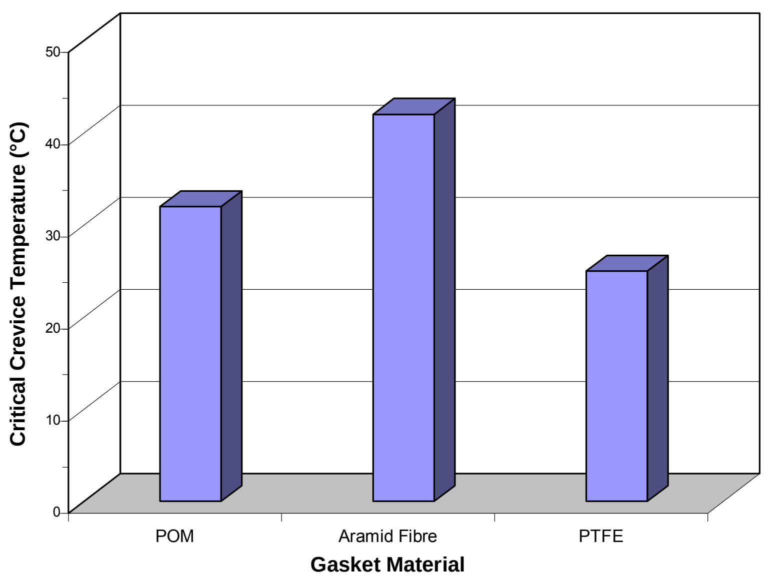


FIGURE 2 Critical crevice temperature at +600mV SCE for 6%Mo stainless steel with different gasket materials (Ref 7)



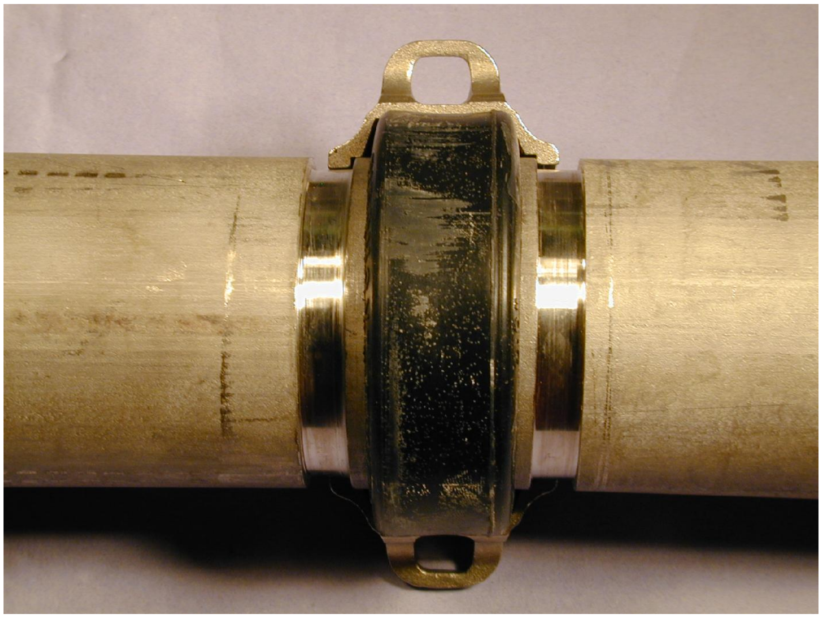


FIGURE 3 - High pressure pipe joint with one half of clamp removed.

FIGURE 4 - Crevice corrosion of 316L at high pressure pipe joint.

FIGURE 5 - Corrosion of a superduplex flange with a graphite-containing gasket.

FIGURE 6 - Corrosion of a superduplex flange with a PTFE coated gasket.