Pitting & Crevice Corrosion of Stainless Steel

Stainless Steels are a family of alloys exhibiting good resistance to attack by many of the environments encountered in industry and in domestic, commercial and marine exposure. Their resistance is not perfect, however, and the large number of grades of stainless steel now available is largely because of this challenge of finding cost-effective resistance to these various environments.

The resistance of stainless steels to some environments can be described by corrosion resistance tables, as the corrosion which does occur is a fairly uniform metal thinning over time. This is termed "General Corrosion". "Localised Corrosion" by contrast results in attack at certain specific sites while other parts of the metal may remain totally unaffected.

This Atlas Tech Note describes two closely related forms of localised corrosion of stainless steels -**Pitting Corrosion** and **Crevice Corrosion**.

Studies of corrosion failures of stainless steel have indicated that pitting and crevice corrosion are major problems, and together account for perhaps 25% of all corrosion failures.

What is Pitting Corrosion?

Under certain specific conditions, particularly involving chlorides (such as sodium chloride in sea water) and exacerbated by elevated temperatures, small pits can form in the surface of the steel.

Dependent upon both the environment and the steel itself these small pits may continue to grow, and if they do can lead to perforation, while the majority of the steel surface may still be totally unaffected.

What is Crevice Corrosion?

Crevice Corrosion can be thought of as a special case of pitting corrosion, but one where the initial "pit" is provided by an external feature; examples of these features are sharp re-entrant corners, overlapping metal surfaces, non-metallic gaskets or incomplete weld penetration.

To function as a corrosion site a crevice has to be of sufficient width to permit entry of the corrodent, but sufficiently narrow to ensure that the corrodent remains stagnant. Accordingly crevice corrosion usually occurs in gaps a few micrometres wide, and is not found in grooves or slots in which circulation of the corrodent is possible.

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Environmental Factors

The severity of the environment is very largely dependent upon two factors - the chloride (Cl^-) content and the temperature - and the resistance of a particular steel to pitting and crevice corrosion is usually described in terms of what % Cl^- (or ppm Cl^-) and °C it can resist. It should be noted that the most common grade of stainless steel, Type 304, may be considered susceptible to pitting corrosion in sea water (2% or 20,000 ppm chloride) above about 10°C, and even in low chloride content water may be susceptible at only slightly elevated temperatures. A safe chloride level for warm ambient temperatures is generally about 150ppm (150mg/l). Grade 316 is more resistant and is commonly used in ambient sea water, but can be attacked in crevices or if the temperature increases even slightly.

The velocity of the liquid is also significant; a stagnant solution is more likely to result in pitting and crevice attack, particularly if there are particles to settle out of the liquid.

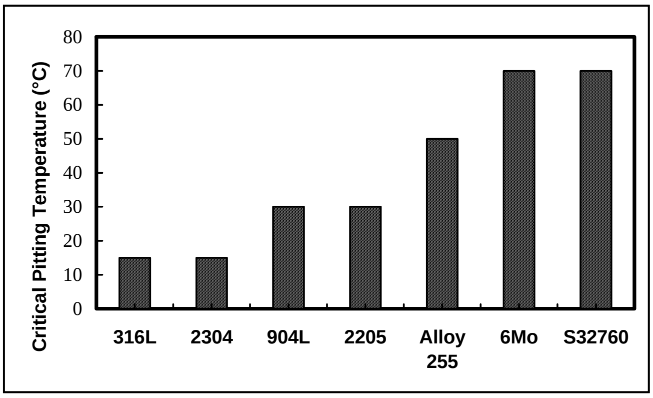
Note that there may also be a problem from stress corrosion cracking if austenitic stainless steels are used in chloride containing water at temperatures over about 60°C.

Which Steels are Susceptible?

All stainless steels can be considered susceptible, but their resistances vary widely. Their resistance to attack is largely a measure of their content of chromium, molybdenum and nitrogen. Another factor of importance is the presence of certain metallurgical phases (in particular the grades 303, 416 and 430F containing inclusions of manganese sulphide) have very low resistances, and ferrite may be harmful in austenitic grades in severe environments. A clean and smooth surface finish improves the resistance to attack. Contamination by mild steel or other "free iron" greatly accelerates attack initiation.

Measurement of Resistance to Attack

Laboratory tests have been developed to measure the resistance of metals to both pitting and crevice corrosion. This testing has two main aims - firstly to enable ranking of each alloy in order of resistance, and secondly as a quality control measure, to ensure that particular batches of steel have been produced not just with correct composition, but also have been properly rolled and heat treated.



The most commonly used test is that in ASTM G48, which measures resistance to a solution of 6% ferric chloride, at a temperature appropriate for the alloy, shown in the graph above.

If an artificial crevice is added to the sample the test measures crevice corrosion resistance rather than pitting resistance.

The temperature which is just high enough to cause failure of this test is termed the Critical Pitting Temperature (CPT) or the Critical Crevice Temperature (CCT).

Alternative laboratory tests can be carried out using electrochemical cells with a variety of test solutions. The results obtained in laboratory tests are approximate only, as factors such as surface finish, water velocity, water contaminants and metallurgical condition of the steel are all important.

Pitting Resistance Equivalent Number (PRE)

From experience it has been found that an estimate of resistance to pitting can be made by calculation from the composition as the Pitting Resistance Equivalent Number:

PRE = % Cr + 3.3 x %Mo + 16 x %N

Various multipliers (up to 30) for Nitrogen have been used in this equation; with the higher values often used for the austenitic stainless steel grades; in any case the effect of nitrogen is very important, hence the requirement by many suppliers (including Atlas) that the highly resistant grade 2205 have a <u>minimum</u> nitrogen content of 0.14%. This also explains the trend in extremely high pitting resistant alloys for even higher nitrogen levels. The super duplex grade UR52N+ (UNS S32520/S32550) typically contains 0.2% nitrogen, while the super austenitic grade 4565S (UNS S34565) typically contains 0.45% nitrogen.

Effect of Welding

The welding process results in metallurgical changes in both fusion zone and heat affected zone. In most alloy systems some degradation in pitting and crevice corrosion resistance occurs in welding, but these effects can be minimised if proper materials and practices are used. Proper materials usually involves over-alloyed consumables and practices includes proper heat inputs. It is important that correct information be sought from suppliers.

Again looking at the extremely high pitting resistant alloys it has been found that the high molybdenum alloys are particularly susceptible to fusion zone micro-segregation, leading to lowered pitting resistance. Alloys such as 4565S which achieve their pitting resistance by high nitrogen rather than very high molybdenum levels have been found to be less affected by weld segregation.

Measures to Reduce Pitting and Crevice Corrosion

- Control the environment to low chloride content and low temperature if possible. Fully understand the environment.
- Use alloys sufficiently high in chromium, molybdenum and/or nitrogen to ensure resistance.
- Prepare surfaces to best possible finish. Mirror-finish resists pitting best.
- Remove all contaminants, especially free-iron, by passivation (refer Atlas Tech Note 5).
- Design and fabricate to avoid crevices.
- Design and fabricate to avoid trapped and pooled liquids
- Weld with correct consumables and practices and inspect to check for inadvertent crevices.
- Pickle to remove all weld scale (refer Atlas Tech Note 5).

References & Further Information

1. Atlas website has information covering many of the grades and products mentioned in this Tech Note.
2. Gümpel, P. and Ladwein, T., "High Strength Austenitic Stainless Steels for Use in Marine Environments". Eighth International Conference on Offshore Mechanics and Arctic Engineering. The Hague, March 1989.
3. Sedriks, A.J., "Corrosion of Stainless Steels", John Wiley & Sons, New York, 1996.
4. Turnbull, B.W., "A Guide to the Corrosion Resistance of Stainless Steel and Nickel Based Alloys", Australian Defence Industries, 1991.
5. Watts, M.R., "Material Development to Meet Today's Demands", Inspection, Repair and Maintenance Conference, Aberdeen, November 1988.

Atlas Specialty Metals Technical Services Department

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