

B. 3 “Stress Corrosion Cracking and Pitting: Contaminating External Environments,” by Robert L. Tapping

Background

Since commercial nuclear power began, extensive research has been concerned with corrosion processes inside the piping and components. Most of this project is concerned with the results of this research including mitigations and improved procedures for operation. This chapter is concerned with corrosion in environments that are *outside* the piping and components. While the environments inside the boundaries of nuclear plants are reasonably well defined and monitored, there is a class of environments that occurs outside these pipes and components. Such environments are miscellaneous and result from impurities carried in the air, adventitious leaks, and animals including bacteria and fungi.

Many commonly used metallic materials are susceptible to localized and general corrosion when exposed to ambient, or external, conditions. Typically such corrosion occurs only when the external surface of the material or component is cool enough that ambient moisture, or in unusual circumstances, potentially corrosive non-aqueous vapors, can condense on the surface. For nuclear power plants the ambient external environment is assumed to be air, occasionally moist or wet and periodically contaminated with potentially corrosive species. The most important, and common, of these contaminants is the chloride ion, present either as salts from the local environment (sea air, for instance) or as a contaminant leached from the immediate environment, such as insulation. Sometimes contaminants arrive via animal wastes and at other infrequent times bacteria and fungi produce corrosive metabolic products.

In nuclear power plants, the most likely materials to be exposed to contaminated external environments are stainless steels (SS), usually austenitic stainless steels such as types 304 and 316, and carbon steels. The austenitic stainless steels are susceptible to stress corrosion cracking (SCC and pitting in chloride-contaminated aqueous solutions. Carbon steels may sustain [RT: a quirk of mine to avoid human emotions to describe physical processes; do as you wish] pitting in such environments. This Technical Supplement outlines the rationale behind judgments of susceptibility of nuclear power plant materials to contaminated external environments, predicted future behavior of these materials, and mitigation and life management strategies to avoid significant degradation or failures.

Factors Influencing Material Susceptibility in External Environments

This discussion emphasizes the corrosion behavior (susceptibility factors) for austenitic stainless steels and carbon steels in nuclear power plant systems where components fabricated from these materials present their outside surfaces to environments that may cause external damage. The knowledge bases underlying these susceptibility factors are discussed in the following sections. Note that for austenitic alloys and ferritic stainless steels also, containing more than about 20% Cr, the susceptibilities to such degradation is considerably less than that of the “18-8” Cr-Ni stainless steels, and commonly-used nickel-base alloys such as Incoloy 800 or 825. Thus a possible materials solution to under-deposit or marine corrosion could be selection of materials such as type 310 or 321 SS, or use of “superalloys such as AL-6X, or a Hastelloy.

However this is usually not a cost-effective solution for most nuclear applications, other than for steam condensers exposed to seawater or brackish water.

In the discussion that follows the modes of pitting and stress corrosion cracking are emphasized. These modes are the most likely to lead to damage especially as pitting might also initiate SCC or corrosion fatigue.

There are several different environments that can produce pitting and SCC. These include deposits that accumulate and crevices that form and contacts between metals or metals and non-metals. In addition bacteria and fungi can accumulate and through their metabolic processes can produce local corrosive conditions. The action of these microbes is favored by moisture and oxygen as well as nutrients. Finally, galvanic cells such as those as might occur with juxtaposed carbon and stainless steels. While the three sometimes lead to the terms "crevice corrosion, microbiological corrosion (MIC), and galvanic corrosion, these terms are really incorrect and are simply different environmental configurations where pitting and SCC both can occur.

With the configurations of crevices, MIC and galvanic juxtaposition, the chemistries that produce corrosion are acidic impurities in the atmosphere, salts such as chlorides from the ocean waters, the various chemistries of animal wastes, and acids from the metabolism of microbes. Also, corrosive chemicals are sometimes leached from insulation, polymers, paints, and floor dirt

Stress Corrosion Cracking:

SCC of austenitic SS occurs in low temperature environments only if the material is subject to high stress, the surface is abused by grinding or by poor machining practice, is exposed to a corrosive environment, and if the material is sensitized, for instance by heat treatment such as that which occurs on welding. Welding-induced residual stress is the most likely source of the high stresses necessary to initiate SCC, although fit-up stresses and other fabrication-related cold work (cold bending, for example) are other examples. Thus welds and bends are locations most likely to be susceptible to SCC. In the presence of chloride contamination (see below), the cracking usually takes the form of transgranular SCC (TGSCC).

The corrosive environment responsible for most external ambient temperature is oxygenated water contaminated with chloride ions. The usual temperature range of concern is from about 50°C (120°F) to about 100°C (212°F). The upper temperature depends on the dew point of the environment; typically the surface must be wet at least part of the time for SCC to occur. The source of the chloride is usually either ambient air or adjacent materials. Marine coastal environments are those most commonly chloride-contaminated, but nearby industrial sources may also occur if the power plant is situated near a large industrial complex that can emit chloride- or chlorine-contaminated air. Note that external pipe surfaces routinely exposed to rain, or frequently washed down, are at little risk of TGSCC or pitting, even in marine environments, since the rain and washing will remove the soluble chlorides.

Pipe insulation or polymeric materials such as tape are often contaminated with chloride, although the insulation sometimes contains a chemical inhibitor to reduce corrosion. For SCC to occur under insulation, or some other chloride-containing material, the material surface must be wet and in intimate contact with the insulation. Wet insulation is the

worst case, since the insulation provides a crevice environment as well as a chloride-contamination source, resulting in an increase in chloride concentration in the crevice with time. As noted above, a crevice environment can build up with time, so SCC conditions may not develop for several years.

SCC of carbon steels is unlikely to occur under these conditions but can possibly occur in the range of 100C if sufficient water and stress are available.

Pitting

Pitting of stainless steels occurs under the same conditions as noted above for SCC, with the important exception that pitting does not require high stresses or sensitized material. Thus pitting can develop anywhere on a stainless steel component exposed to chloride contamination in a crevice environment. Austenitic SS with molybdenum additions (type 316SS, for example) are more resistant to pitting than non-Mo stainless steels such as type 304SS.

Pitting of carbon steels also can occur in external environments, although typically such pitting usually is associated with deposits or other crevices. Otherwise, carbon steels usually exhibit general or uniform corrosion in the presence of wet chloride-contaminated external environments.

Typical Occurrences of (TG) SCC and Pitting in Power Plants

The most common occurrences of TGSCC or pitting of austenitic SS (primarily types 304 and 316) are under wet insulation or where piping is exposed to marine air and deposits can build up. Insulation can become wetted by water leakage from adjacent components, by washing or by soaking as a result of fire sprinkler action. Chlorides in the insulation leach out and deposit on the piping, eventually reaching concentrations sufficient to cause SCC (highly stressed areas, typically near joints/welds or at bends) or pitting. Examples of this are SCC of instrument lines and other small diameter lines.

Inspection and Remediation Strategies

Inspection strategies require an assessment of which sections of piping are exposed to conditions which can promote SCC or pitting. These locations are those which can be wetted and which are in contact with chloride-contaminated insulation or coatings/adhesives/tapes, or where deposits can build up and chloride contamination is also present. Typical areas at risk are in the temperature range 60°C to about 100°C. Visual inspection for water drips, wet areas on the pipe, deposits and rust stains are a first step required to focus any further inspection. Where insulation or other coverings are present, these may need to be removed to allow an effective visual inspection. If any welds, bends or other stressed areas show any visual evidence for possible corrosive conditions, non-destructive examinations (NDE) should be carried out. Surface eddy current, ultrasonic inspection, magnetic particle, radiography or equivalent alternative and qualified procedures may be used for these inspections.

Mitigation strategies center around preventing wetting of the pipe surface or any surrounding materials that might contain chlorides. Most insulation contains corrosion inhibitors that are designed to prevent corrosion of adjacent contacted surfaces, but this needs to be verified for specific plants. Much of the insulation in power plants is covered

with metallic water-resistant jackets, and this is a good mitigation strategy, although it does interfere with any subsequent inspections. For piping exposed to outdoor environments, the mitigation strategy is to keep the piping clean and free of deposits. This is of most concern in marine environments, or areas where chloride-contaminated deposits may build up. Washing down such piping periodically is a good counter-measure. For piping that does not see high temperature internal fluids, coatings are a good corrosion prevention approach.

As noted earlier, a possible remediation strategy is to use highly corrosion-resistant materials for components exposed to potentially corrosive external environments, rather than 18-8 stainless steels or carbon steels, but this is not normally a cost-effective solution compared to good maintenance practices.

Life Management Issues

Current industrial practice should include routine visual inspections for wetted, rust-stained, or fouled areas of low temperature piping. This would be an effective mitigation strategy for the longer term if accompanied by cleaning/washing and/or NDE as appropriate. It is not clear if visual inspections are a routine practice at nuclear power plants; many incidents of TGSCC of low temperature piping are managed by repair following detection of a leak. This is feasible because the low temperature piping sections or systems may be isolated and repaired on-line.

References for B.3

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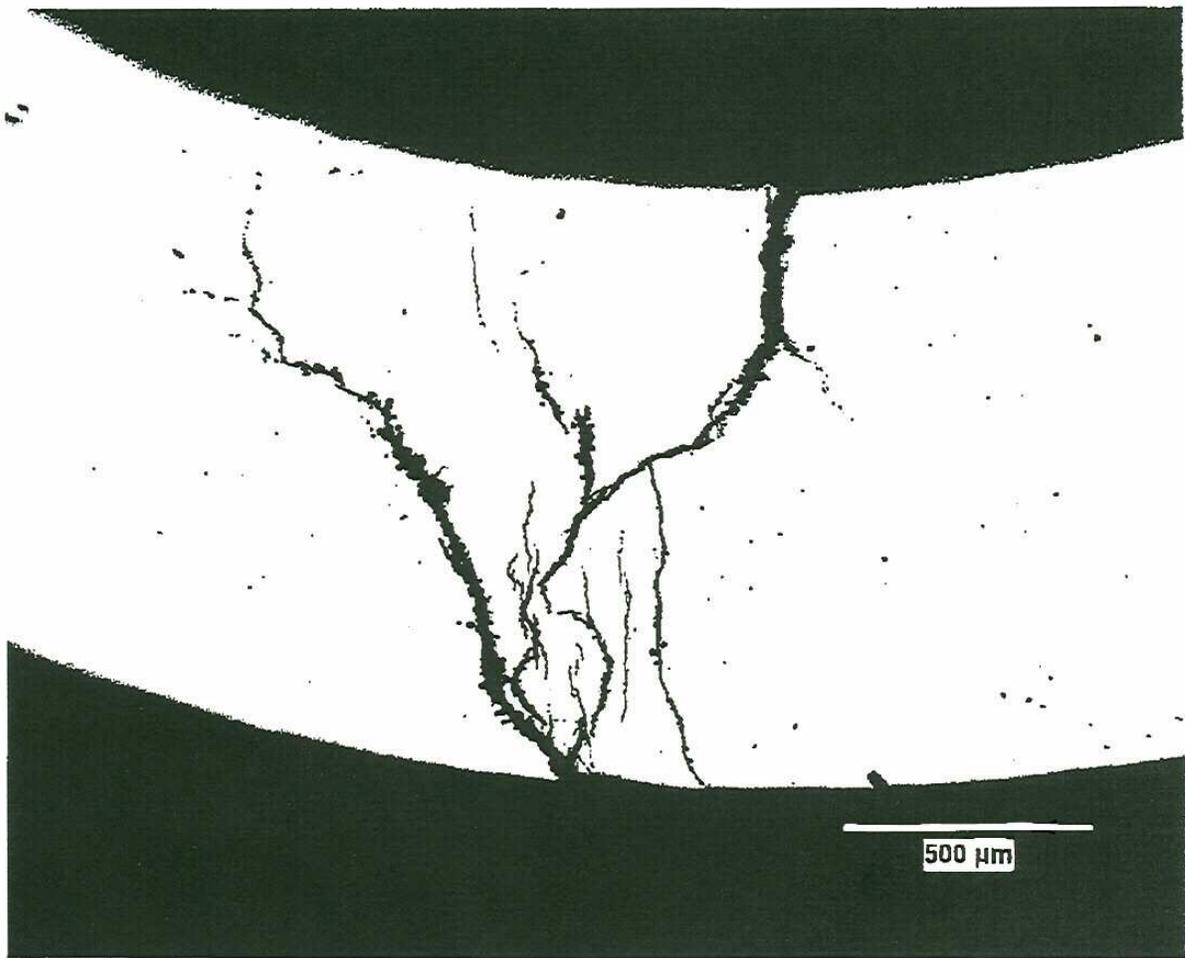


Figure B.3.1: Cross-Section of OD-initiated transgranular cracking in a cold-worked stainless steel line.