

## □ Appendix A □

### DAMAGE/CORROSION MECHANISMS

**Caustic Gouging** – The dissolution of carbon steel by localized high concentrations of sodium hydroxide. This high-pH condition solubilizes the steel's protective magnetite layer and ultimately forms sodium ferroite ( $\text{NaFeO}_2$ ) and sodium ferrous hydroxide ( $\text{Na}_2\text{Fe(OH)}_2$ ). In-situ corrosion products remain in place and smoothed surfaces typically are present below the deposits in the attacked area.

**Corrosion** – Degradation of a material and its properties resulting from chemical or electrochemical reactions within the environment.

**Corrosion Fatigue** – Life reduction due to the occurrence of cyclic applied stress (fatigue) in a corrosive environment. Component lifetime under corrosion fatigue is less than if fatigue life and corrosion life had both been assessed separately because of continuous breaking of the protective oxide film by fatigue action.

**Creep** – The time-dependent, thermally-assisted deformation or strain of components under load (stress). Creep damage in a given material is a function of a combination of time, temperature, and stress, and results from a combination of high stress and high temperature relative to a material's creep limits. Damage occurs in three stages. Visible damage is induced during the tertiary stage. Isolated creep microvoids coalesce along grain or dendrite boundaries, resulting in fissure formation prior to stress rupture.

**Crevice Corrosion** – Localized corrosion resulting from the formation of a concentration cell in a crevice formed between two surfaces that shield it from the full oxygen content of the environment.

**Fatigue** – Repeated applied stress cycles that result in reduction of strength, crack initiation, and crack propagation. Most of a component's fatigue life occurs prior to crack initiation. Crack morphology varies based on type of fatigue loading (i.e. high-cycle, which typically is induced by vibration, or low-cycle, which is typically induced thermally) and environment (for example, corrosion fatigue cracks often are oxide-filled and produce secondary parallel cracks).

**Flow-Accelerated Corrosion (FAC)** - FAC is a phenomenon that affects the normally protective oxide layer formed on carbon or low-alloy steel. With FAC, the oxide layer dissolves into the flowing stream of water or a water-steam mixture. As the oxide layer becomes thinner and less protective, the corrosion rate increases. Eventually a steady state is reached where the oxide dissolution rate equals the oxidation rate, and no oxide exits on the metal to slow corrosion. It is important to note that in the FAC process, the protective oxide film is not mechanically removed. Rather, the oxide is dissolved. Thus, FAC may be defined as corrosion enhanced by mass transfer between a dissolving oxide film and a flowing fluid that is unsaturated in the dissolving species<sup>46,47</sup>. This mechanism is also known as flow-assisted corrosion or flow induced corrosion.

**Fretting; Fretting Corrosion** – Fretting refers to metal deterioration caused by repetitive slip (on the order of microns) at the interface between two contact surfaces. Small metallic particles spall during metal-to-metal contact and

continue to induce damage. This mechanism is often called fretting corrosion because of the red oxide produced by oxidation and fretting when one or both alloys are ferrous-based.

**Galvanic Corrosion** – Corrosion caused when a metal or alloy is electrically coupled to another metal or conducting nonmetal in the same electrolyte. When dissimilar metals are electrically coupled, the current flow between the metals causes increased corrosion of the less corrosion resistant metal, and decreased corrosion of the more corrosion resistant metal<sup>48</sup>.

**Gas-Side Decarburization** – A high-temperature gas-metal reaction whereby carbon (typically in the form of pearlite or iron carbides) is selectively removed from the surface of a metal alloy. High concentrations of carbon dioxide can combine with iron carbide in the steel to form iron and carbon monoxide at high temperatures. Reduction in the carbon content typically reduces surface strength.

**Gas-Side Dew Point Corrosion** – Corrosion caused by the formation of acids, typically sulfuric acid, when the combustion flue temperatures drop below the condensation point for the acid present as a vapor in the flue stream. This condition can cause pitting corrosion during shutdowns of equipment that typically sees elevated temperatures in service. Such corrosion most often occurs during the shutdown of components which operate above dew point temperature.

**General Corrosion** – Non-localized corrosion that occurs over a large percentage of the metal surface, resulting in uniform metal loss. Seawater flowing over carbon steel, for example, can generate general corrosion.

**High-Cycle Fatigue (Vibration)** – Fatigue associated with low-amplitude, high-frequency compression - relaxation cycles from vibrational loading.

**High Temperature Oxidation** - Also known as thermal oxidation, this is a reaction where a metal or alloy is converted to an oxide due to exposure to elevated metal temperatures in an environment that allows the metal to combine with oxygen at excessive rates.

**Hydrogen Damage** – A general term for the embrittlement, cracking, blistering, and hydride formation that can occur when hydrogen is present in some metals.

**Liquid Droplet Erosion** - A wastage mechanism caused by impingement of droplets of a liquid entrained in a vapor or gas stream at high relative velocity to a solid surface.

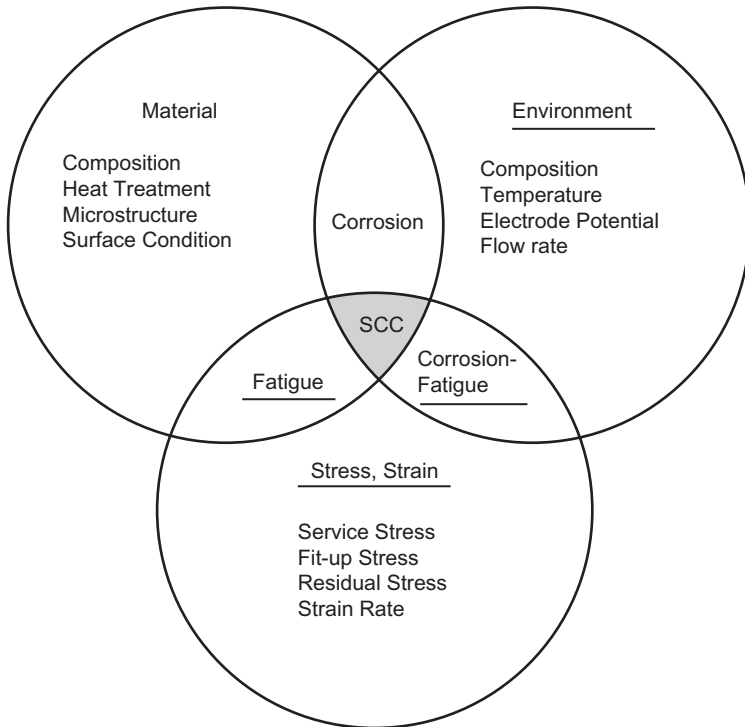
**Microbiologically Influenced Corrosion (MIC)** – MIC is an electrochemical process in which the source is biological. MIC is often caused by sulfate-reducing bacteria, but other biological initiators also exist. Chemistry changes can be brought about by the depletion in oxygen and the production of enzymes and waste metabolites. Direct metal dissolution can also be incurred due to oxidation-reduction reactions of the microorganism's metabolism. MIC can occur at temperatures up to 235 °F, and often occurs in stagnant flow conditions.

**Pitting Corrosion** – Corrosion of metal surfaces confined to small points or areas that takes the form of cavities in the surface. Pits result from localized galvanic cells which often are associated with local discontinuities including inclusions, local deposits, or local composition deviations.

**Phosphate Gouging** – The dissolution of carbon steel by localized high concentrations of mono- or di-sodium phosphate to form maricite ( $\text{NaFePO}_4$ ) and other sodium-iron-phosphate compounds. Crusty alternating black-and-white layered deposits may remain with knife-edge like surfaces in the gouged area. This form of corrosion also requires a phosphate concentrating mechanism, such as steam blanketing or boiling within porous deposits, and the development of a thermal barrier between the tube metal and the boiler water.

**Stress-Assisted Corrosion (SAC)** – Corrosion caused by a combination of high local stress, either applied or residual, and a corrosive environment. Highly localized stress can cause breaks in the protective oxide film, so that the presence of a corrosive environment initiates attack where the film is broken. Often the attack appears as cracks composed of a series of interconnected pits. (SAC is a process in which either an applied stress or residual stress is present that causes a break in the protective oxide that does not self-repair at a rate fast enough to prevent the corrosive environment from accelerating the corrosion).

**Stress Corrosion Cracking (SCC)** – A cracking process that requires the simultaneous action of a corrodent and sustained stress acting on a susceptible material. Cracking damage can appear as intergranular or transgranular, multi-branched cracks, depending on the alloy and the environment. Cracks are typically non-oxide-filled and branched along their lengths.



**Figure 4: Three Groups of Major Factors Determining Susceptibility to Stress Corrosion Cracking<sup>(49)</sup>**

Three groups of major factors determining susceptibility to stress corrosion cracking (SCC). Specific values are required within each group for SCC to occur. In contrast, corrosion, fatigue and corrosion-fatigue require specific values in only two groups of factors.

**Thermal Fatigue** – Fatigue associated with cyclic temperature changes that cause the metal to expand and contract. The mechanism is considered to be high-amplitude, low-frequency low-cycle fatigue.

**Under-deposit Corrosion** – Corrosion damage mechanisms where apparent surface deposits are present and damage occurs under the deposits. The deposit sources may have come from upstream or may have been generated by the corrosion mechanisms themselves. These mechanisms can include mechanisms such as caustic gouging, hydrogen damage, and phosphate corrosion.