

Corrosion of Submersible Transformers

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Outline

1. What is corrosion?

2. Types of corrosion

3. Submersible Transformer Corrosion

4. Corrosion Mitigation

What is Corrosion?



What is Corrosion?

Dictionary definition of “corrode”:

- **1** :to eat away by degrees as if by gnawing; especially :to wear away gradually usually by chemical action
- **2** :to weaken or destroy gradually :undermine

Corrosion is an issue for all industries





What is Corrosion?

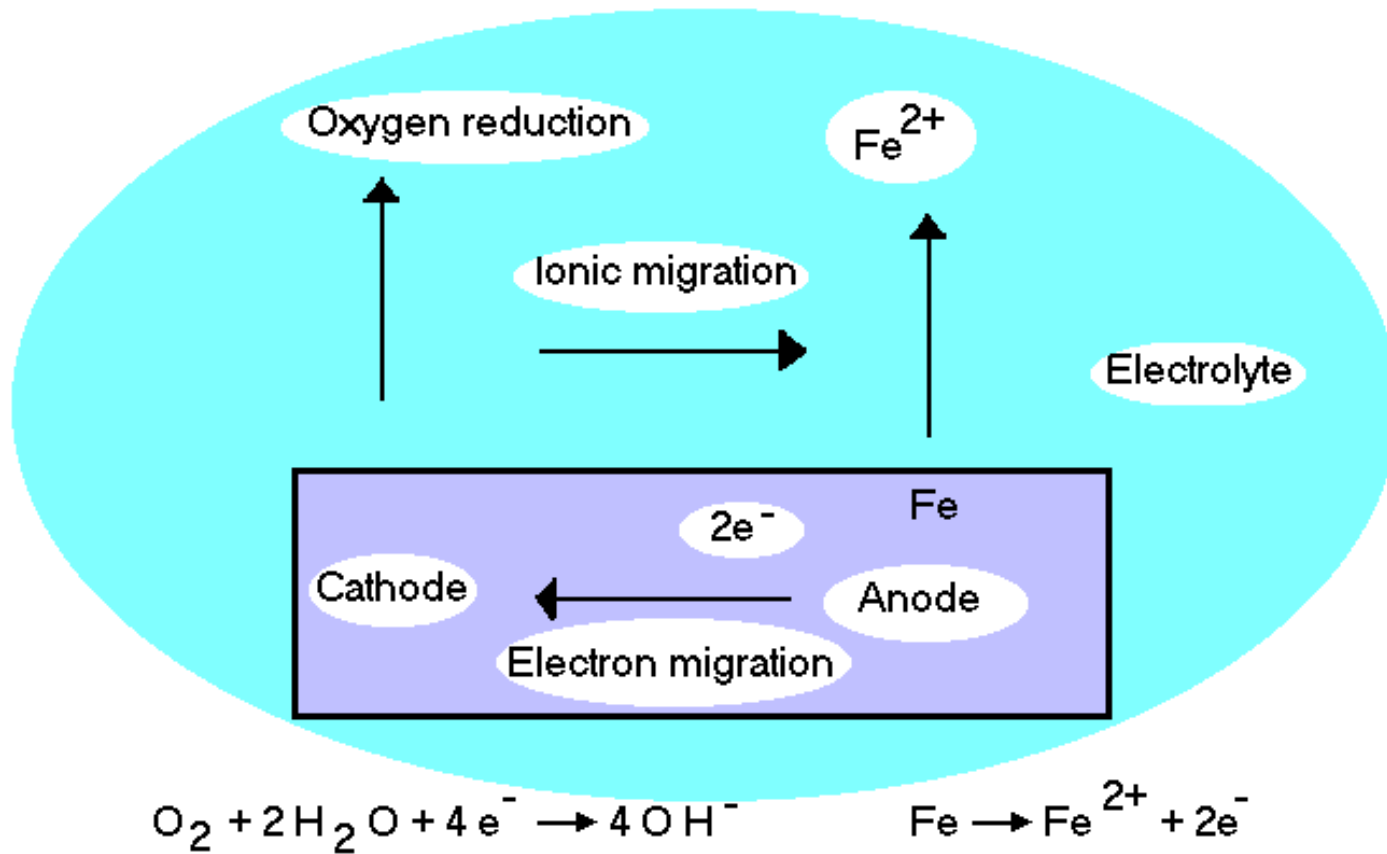
“Chemical action”

- **Materials tend toward their lowest energy (original) state**
- **Electrochemical process where electrons and ions are exchanged**
- **4 components: Anode, Cathode, Metallic Path, Electrolyte**
 - Anode – oxidizes – “corrodes”
 - Cathode – reduces – gains electrons
 - Metallic Path – where the electrons move
 - Electrolyte – where the ions move (ie. water)
- **Example: a dry cell battery is a corrosion cell**
- **Any of these components missing = no corrosion**



What is Corrosion?

BASIC CORROSION CELL

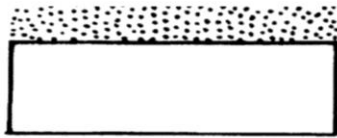


Source: <http://www.thermidaire.on.ca/di-cell.html>

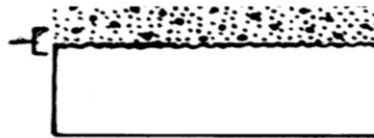
Types of Corrosion



Types of Corrosion



Uniform



Intergranular



Galvanic

Surface cracks Internal voids



Crevice



Pitting



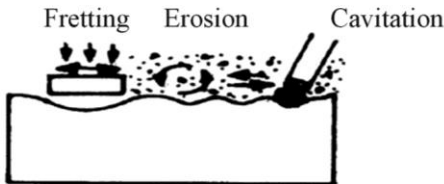
Hydrogen damage



Stress corrosion



Corrosion fatigue



Cavitation, erosion and fretting



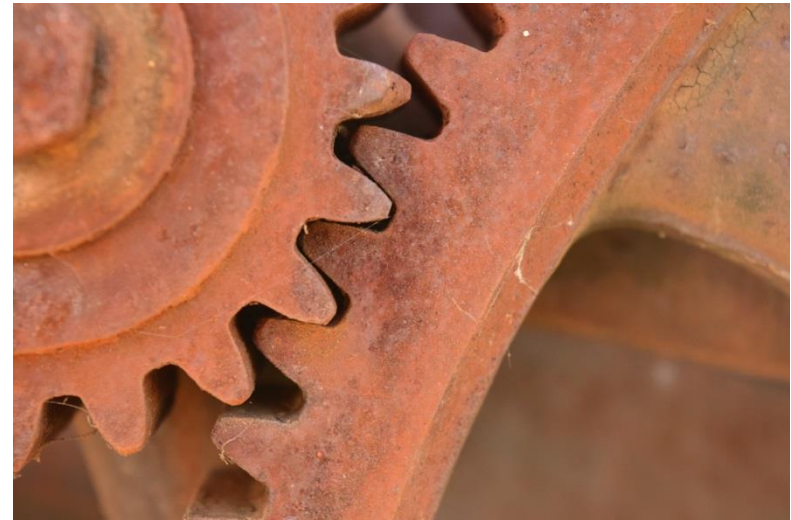
Hydrogen induced cracking

Source: http://www.researchgate.net/post/What_are_the_most_dangerous_types_of_corrosion_and_does_the_dangerous_vary_dependig_on_the_type_of_metal



Uniform Corrosion

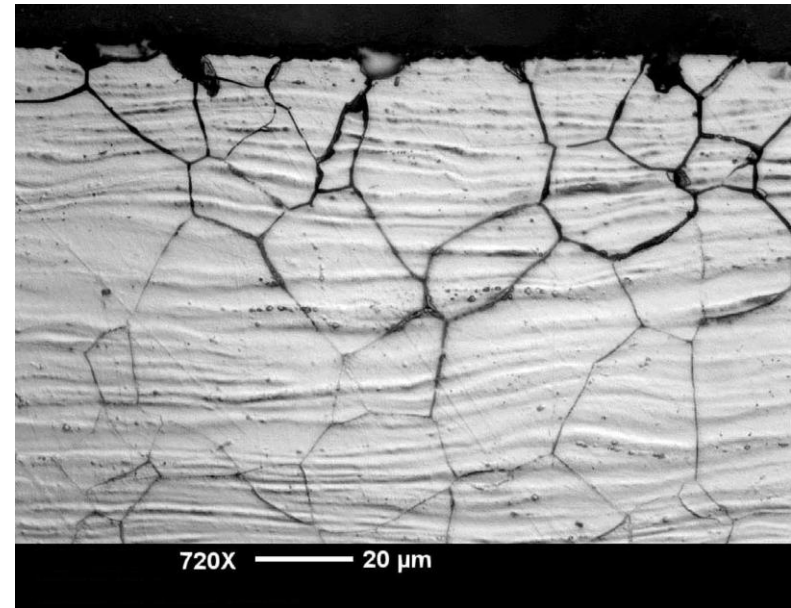
- **Sometimes referred to as General Corrosion**
- **Consistent and even in nature**
- **Can be inspected visually**
- **Slow corrosion rates**
- **Easiest to remedy**





Intergranular Corrosion

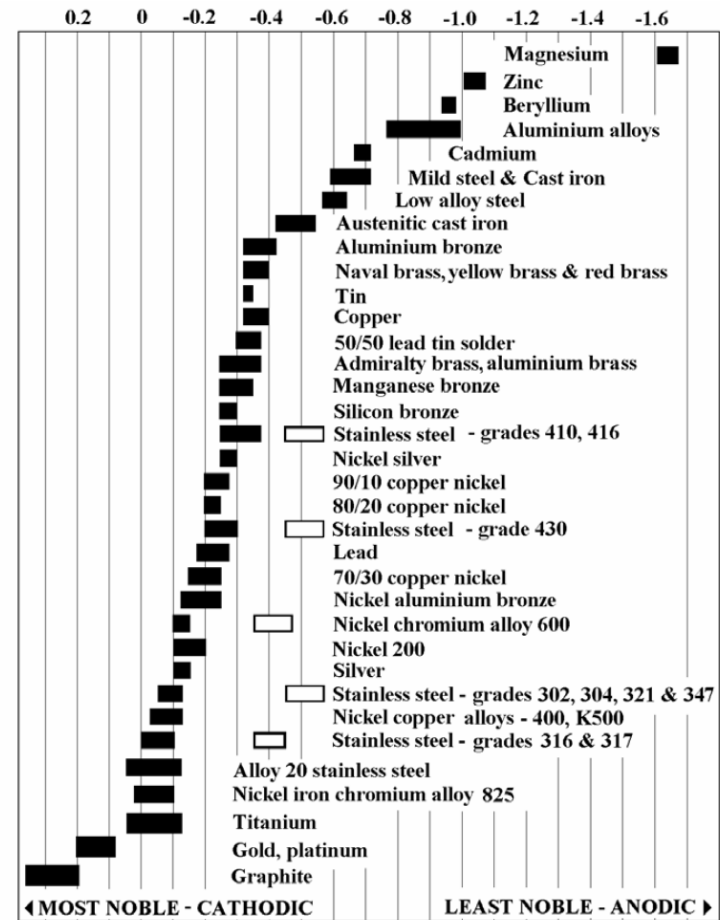
- **Attack at the grain boundaries of the microstructure of the metal**
- **Usually requires microscopy**
- **Potentially rapid corrosion rates**
- **Difficult to remedy**





Galvanic Corrosion

- Dissimilar metals in contact
- Metal which is more active in the galvanic series corrodes
- Potentially rapid corrosion rates (driving force)
- Easy to remedy (replace or separate)



Source: <http://l-36.com/corrosion.php>



Crevice Corrosion

- **Small crevice created by geometry (e.g. around bolt heads)**
- **Can be created by inert/non-metals**
- **Oxygen concentration cell**
- **Potentially rapid corrosion rates**
- **May be difficult to remedy after design**



Source: Wikipedia



Pitting Corrosion

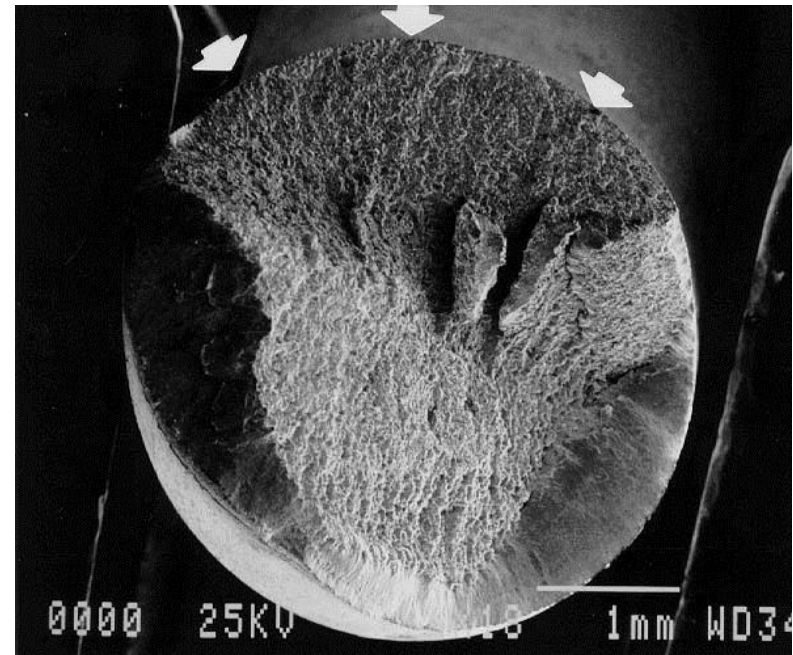
- **Pits created by localized attack**
- **Can be created by oxygen concentration cells, surface contaminants, microbes, etc.**
- **Microbiologically Influenced Corrosion (MIC)**
- **Typically rapid corrosion rates**
- **May be difficult to remedy**





Hydrogen Damage/Cracking

- Diffusion of hydrogen molecules within the microstructure
- Can cause different phenomena: cracking, embrittlement, defects, porosity, etc.
- Typically rapid/sudden failure
- May be difficult to remedy



Source: <https://corrosion.ksc.nasa.gov/hydrodam.htm>



Stress Corrosion

- **Tensile stress combined with corrosion effects**
- **Typically rapid propagation of cracks (sudden failure)**
- **Stainless steel is susceptible based on environment (Cl)**
- **May be difficult to remedy**

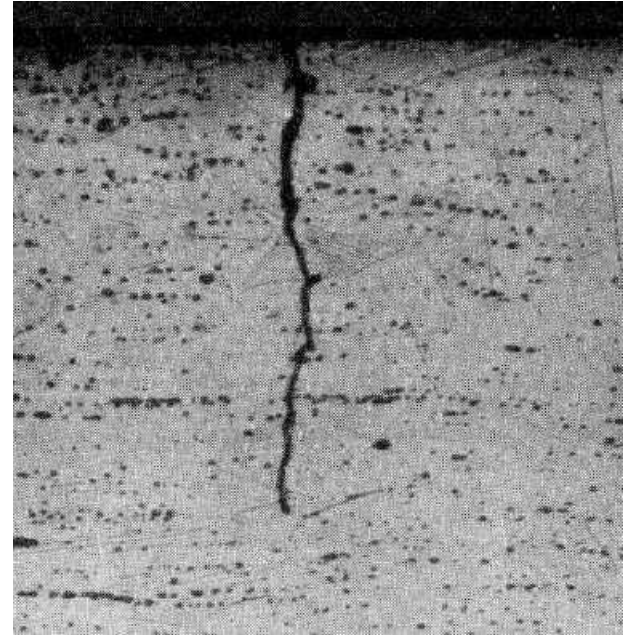


Source: <https://corrosion.ksc.nasa.gov/stresscor.htm>



Corrosion Fatigue

- **Fatigue (cyclical) loading combined with corrosion effects**
- **Typically less branching of cracks vs SCC**
- **Typically rapid propagation of cracks similar to SCC**
- **May be difficult to remedy**



Source: http://chemical-biological.tpub.com/TM-1-1500-335-23/css/TM-1-1500-335-23_189.htm



Cavitation, Erosion & Fretting

- **Mechanical action combined with corrosion effects**
- **Cavitation – bubbles**
- **Erosion – particles (sand/silt)**
- **Fretting – surfaces moving against each other**
- **Can be rapid or slow depending on factors**
- **Varying difficulty in remedy based on factors**



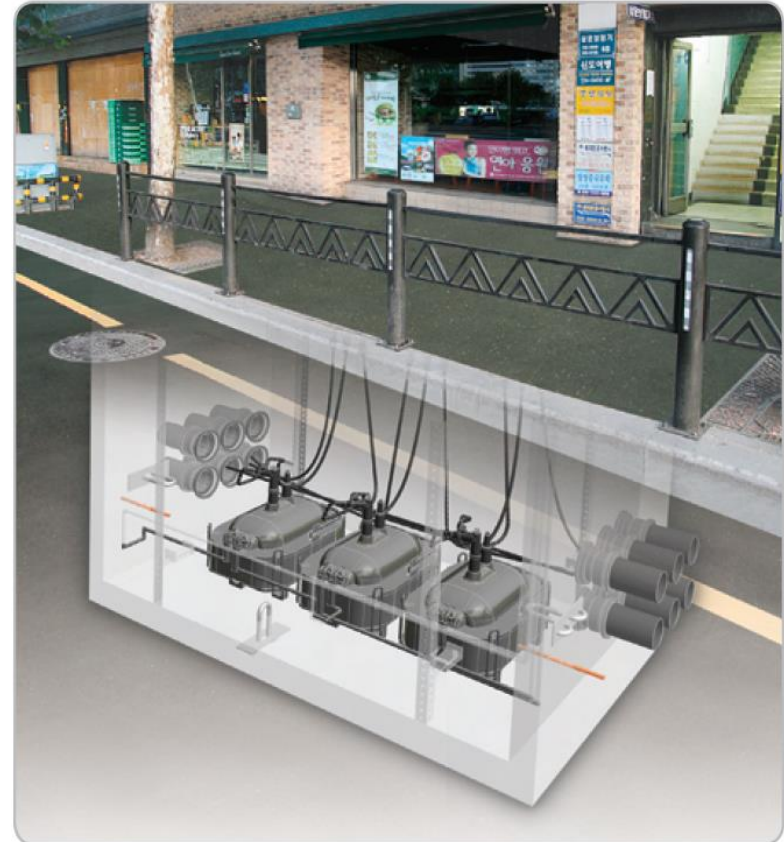
Source: Wikipedia

Submersible Transformer Corrosion



Exterior Service Environment

- Heat/Humidity
- Possible flooding
- Possible contaminants from the surface environment
- Possible microbiological considerations
- Possible vibrations
- Possible UV exposure (grated)





Possible Corrosion Types

- **Uniform**
- **Galvanic**
- **Crevice**
- **Pitting - MIC**
- **Hydrogen Damage/Cracking**
- **Stress Corrosion**
- **Corrosion Fatigue**
- **Cavitation, Erosion, Fretting**



Corrosion Mitigation



Corrosion Mitigation

Materials Selection

- Typically carbon steels and stainless steel exteriors
- Determine appropriate material for the service environment (hydrogen damage, stress corrosion, hydrocarbons)
- Compatible (similar potential on the galvanic series)

Things to watch:

- There is no one attainable material suitable for all environments (ie. some grades of stainless steels may not be suitable in seawater)
- Components small and large should be compatible (bolts/washers)
- May not solve issues with crevice, cavitation, erosion or fretting
- Cost – combine with other mitigation methods



Corrosion Mitigation

Coatings

- **Barrier against environment**
- **Epoxies and polyurethanes most common**
- **Appropriate system for the service environment (UV resistance, immersion service, anti-fouling, etc.)**
- **Emissivity considerations**
- **Compatibility with substrate**

Things to watch:

- **Stainless steels may not work as well when coated (passivity)**
- **Surface preparation is key**
- **Strict quality control for defects, pinholes, missed areas**
- **Thickness may not = life expectancy**



Corrosion Mitigation


Cathodic Protection

- **Essentially a corrosion cell – subject becomes the cathode**
- **Sacrificial (galvanic) and impressed current systems**
 - Sacrificial – uses relative potential to drive reaction
 - Impressed Current – current is applied to drive reaction
- **4 components of a electrochemical cell required for operation**

Things to watch:

- **Sacrificial vs Impressed**
- **Anode size and placement**
- **Interference and stray current**

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Questions?

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