PDHonline Course S174 (2 PDH)

Metal Deterioration

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2013

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This course involves the deterioration of metal components commonly used in the building and construction industry. Metal components used in buildings can include:

1. Exterior cladding, roofing and flashings.
2. Structural steel and embedded reinforcing steel.
3. Piping, storage tanks and mechanical ducts.

Source: Deepwater Corrosion Services, Inc.

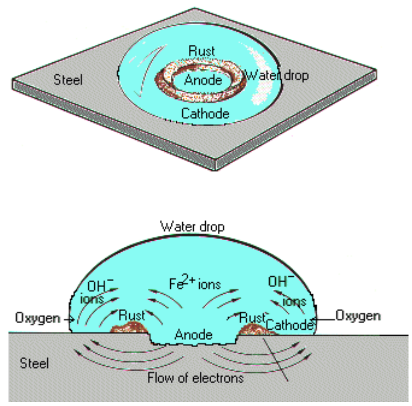
The deterioration or corrosion of metal structures is recognized as one of the most serious problems in the modern world which results in the loss each year of hundreds of billions of dollars in damage. Studies have determined that the annual metal deterioration and corrosion costs range from approximately 1 to 5 percent of the Gross National Product of each industrialized nation.

Deterioration specifically refers to any process involving the corrosion or degradation of metal structures or components. The best example of metal deterioration is the rusting of steel. Another good example of the deterioration of metal is galvanic corrosion, which occurs at the contact point of two dissimilar metals or alloys.

Source: Corrosion College

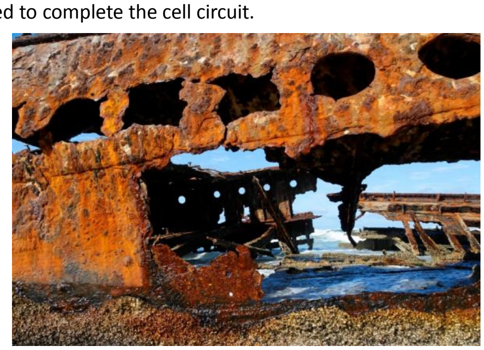
Corrosion is the disintegration of metal through an unintentional chemical or electrochemical action, starting at its surface. All metals exhibit a tendency to be oxidized, some more easily than others. The corrosion process is usually electrochemical in nature, having the essential features of a battery. When metal atoms are exposed to an environment containing water molecules they can give up electrons, become themselves positively charged ions (provided an electrical circuit can be completed). This effect can be concentrated locally to form a pit, a crack or it can extend across a wide area to produce general deterioration.

Corrosion is the primary means by which metals deteriorate. Most metals corrode when placed in contact with water (or moisture in the air), acids, bases, salts, oils and certain chemicals. Metals will also corrode when exposed to gaseous materials like acidic vapors, formaldehyde gas, ammonia gas and sulfur containing gases. In today's industrial world, the waste products of various chemical and manufacturing processes find their way into the air and waterways and serve as the source of many of the corrosive elements listed above.



Source: Gordon England

Metals have a natural tendency to revert to their oxidized form given the proper environment and opportunity. The appropriate circumstances necessary for the degradation of metals can vary greatly between environments. Free hydrogen ions found in all waters, soils and some gases can provide a means of removing the excess electrons from metals. In addition, oxygen in the air can encourage the oxidation of most metals and alloys. The electrical conductivity of water also increases with its dissolved mineral concentration. Therefore highly mineralized waters or soils readily conduct the electrical currents of electrolytic cells and can accelerate the corrosion process. The same can also be said for exposed atmospheric conditions where moisture is present in the form of vapor water or can condense and fall as rain concentrating the collection of salts, chemicals and other pollutants. The environment for many structures provides conditions that favor the formation of natural corrosion cells. The metals of a structure can serve as the anode, cathode and as the necessary conductor between any two metal components of the building. Free water, or as moisture in soil or air, provides the electrolyte required to complete the cell circuit.



Source: Science Daily

Types of Metal Deterioration:

The different types of metal deterioration can be categorized according to their appearance and extent to which they can be readily observable.

1. Deterioration that can be identified by visual examination:
   - 1.1. Uniform Deterioration
   - 1.2. Pitting
   - 1.3. Crevice Deterioration
     - 1.3.1 Filiform Deterioration
     - 1.3.2 Pack Rust
   - 1.4. Galvanic Deterioration
   - 1.5. Lamellar Deterioration

2. Deterioration that may require supplementary means of visual examination:
   - 2.1. Deterioration by Erosion
   - 2.2. Deterioration by Cavitation
   - 2.3. Fretting Deterioration
   - 2.4. Intergranular Deterioration
   - 2.5. Exfoliation Deterioration

3. Verification of the presence of deterioration requiring inspection via microscope:

3.1. Environmental Cracking

3.1.1. Stress Corrosion Cracking

3.1.2. Corrosion Fatigue

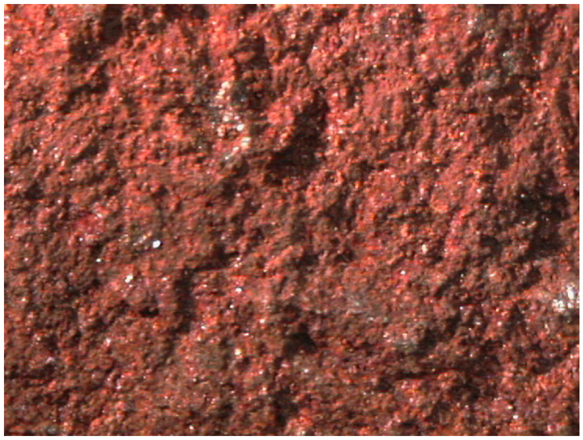
3.1.3. Hydrogen Embrittlement

1.1 Uniform Deterioration

Uniform deterioration is characterized by corrosive attack that occurs evenly over the entire surface area. Uniform deterioration is the most common form of corrosion however, this type of deterioration is predictable, therefore unforeseen failures occur very rarely. In most cases, uniform deterioration is objectionable only from an esthetic standpoint. As this type of deterioration occurs uniformly over the entire exposed surface, it can be easily controlled by using protective coatings or paints or by simply anticipating an allowance for the loss of section over the life of the material as is done frequently with the design of steel sheet piling (see Course No. S151). In some cases uniform deterioration adds color and appeal to a surface as is the case with copper roofs and weathering steels.

Source: India Institute of Technology

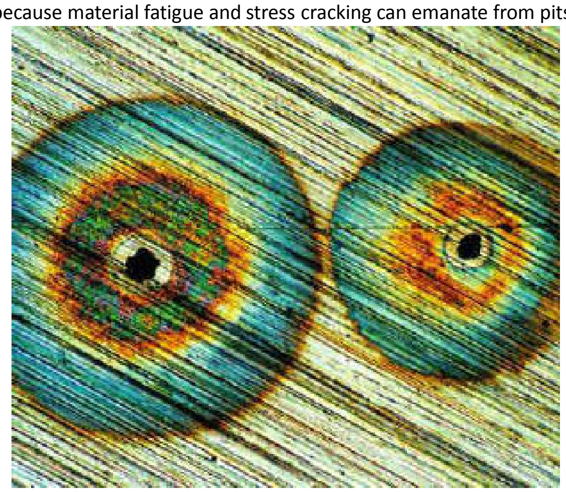
The breakdown of the protective coating system on a structure can often lead to uniform deterioration. For this reason the substrate should be examined closely for more advanced attack. Otherwise, the continued surface deterioration and underlying corrosion may lead to more serious types of decay. Dulling of a bright or polished surface, etching by acid cleaners, or oxidation (discoloration) of steel are examples of this type of surface deterioration. Even corrosion resistant alloys and stainless steels can become tarnished or oxidized in corrosive environments.



Source: University of Utah

1.2 <u>Pitting</u>

Pitting is the deterioration of a metal surface, confined to a point or small area, which results in the formation of a cavity or hole in the material. Pitting is considered to be more dangerous than uniform deterioration because it is more difficult to detect, predict and design against. A small, narrow pit with minimal overall loss of material section can lead to the failure of an entire structure or system. Apart from the localized loss of material section, pitting can also cause stress risers. This is because material fatigue and stress cracking can emanate from pits.



Source: Rust Bullet

Pitting can be initiated by:

a. Localized chemical or mechanical damage to the surface.

b. Low dissolved oxygen concentrations.

c. High concentrations of chlorides.

d. Localized damage to, or poor application of, the protective coating system.

Source: J.E.I. Metallurgical, Inc.

1.3 Crevice Deterioration

Crevice deterioration is a localized form of corrosion usually associated with a stagnant solution on the surface of a metal. Localized stagnant environments tend to occur in crevices, or shielded areas, such as areas under gaskets, washers, insulation material, fastener heads, surface deposits, debonded coatings, threads, and clamps. Crevice deterioration is initiated by changes in the local surface chemistry within the crevice which can include:

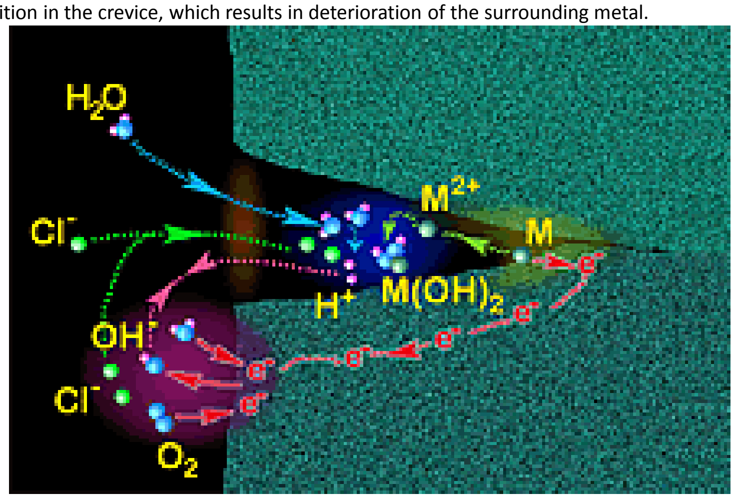
a. Lowering of oxygen content.

b. Depletion of natural corrosion inhibitors.

c. Creation of an acidic condition.

d. Build-up of chlorides.

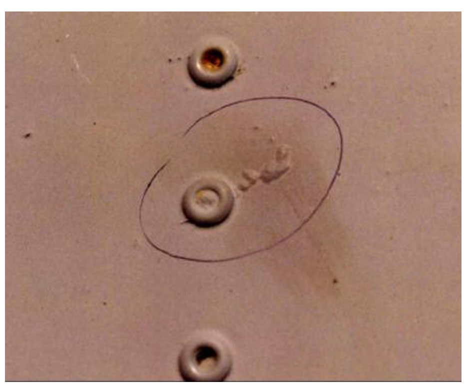
The most common form of crevice deterioration is oxygen differential cell corrosion. This occurs because moisture entrapped in a crevice has a lower oxygen content than when it is exposed on the surface of a metal. The lower oxygen content in the crevice forms an anode at the metal surface. The metal surface in contact with the portion of the moisture film exposed to air forms a cathode. This anodic imbalance can in turn lead to the creation of highly corrosive localized condition in the crevice, which results in deterioration of the surrounding metal.



Source: The Multimedia Corrosion Guide

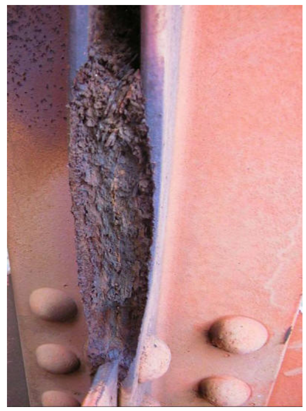
1.3.1 Filiform Deterioration

Filiform deterioration is a special form of crevice corrosion in which an aggressive chemical environment occurs under a protective film (or layer of insulation) that has been breached. This type of deterioration occurs when moisture penetrates the coating. Filiform deterioration normally starts at small, sometimes microscopic, defects in the coating. This type of deterioration is very common with epoxy coated reinforcing bars where a small area of the epoxy has either been chipped off or a holiday in the coating has occurred as a result of a poor application process. Fast drying paints are very susceptible to this type of deterioration, therefore their use should be avoided. A properly specified coating should provide low water vapor transmission characteristics and excellent adhesion. In addition, zinc-rich coatings should be considered for use on carbon steel because of their cathodic protection quality.



1.3.2 Pack Rust

Pack rust is a form a crevice deterioration that occurs at the interface of adjacent steel components. This particular form of corrosion is most often seen in steel structures exposed to open, moist or corrosive environments. As the byproduct of the deterioration accumulates in the crevice, gap or joint between the two members, the resulting internal pressures result in the distortion and damage of the adjacent parts.

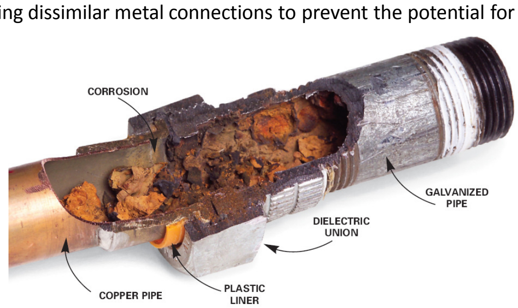


Source: Termarust Technologies

1.4 Galvanic Deterioration

Galvanic corrosion (also referred to as dissimilar metal corrosion; see Course No. S118) involves deterioration induced when two dissimilar materials are coupled in a corrosive environment. This type of deterioration occurs when two (or more) dissimilar metals are brought into contact in the presence of moisture. When a galvanic couple forms, one of the metals becomes the anode and corrodes faster than it would on its own, while the other metal becomes the cathode and corrodes slower than it would alone.

The driving force for this type of deterioration is the potential difference between the different metals. In a galvanic couple, the less noble metal will become the anode of the corrosion cell while the more noble metal will act as the cathode. Galvanic deterioration is one of the more common and destruction forms of corrosion. However, galvanic deterioration can be easily avoided by designing dissimilar metal connections to prevent the potential for this type of corrosion.



Source: The University of the Third Age

1.5 Lamellar Deterioration

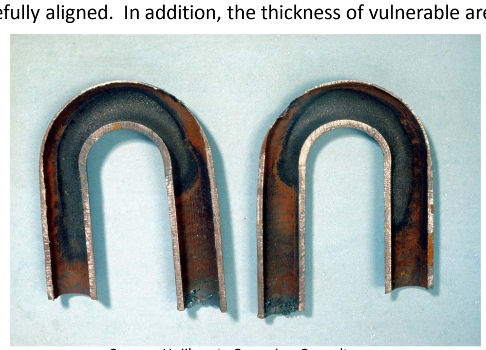
Deterioration that proceeds laterally from the site of the initial corrosion along planes parallel to the surface forming corrosion byproducts that force metal away from the body of the substrate, resulting in a layered appearance, is referred to as lamellar deterioration. Lamellar corrosion can also refer to a wide occurrence of exfoliation in lighter metals.

The following photos of carbon steel beams and the bolts (exposed in a wastewater plant) provide examples of lamellar delaminations.

Source: CH2M Hill

2.1 Deterioration by Erosion

Deterioration by erosion is an acceleration in the rate of corrosion in a metal due to the motion of a corrosive fluid against the surface. The increased turbulence caused by pitting on the internal surfaces of a pipe can result in rapidly increasing erosion rates and eventually a leak. Deterioration by erosion can also be aggravated by faulty workmanship. For example, burrs left at the ends of a cut pipe can upset smooth water flow, which can cause localized turbulence resulting in deterioration by erosion. Increased hardness in a metal does not necessarily guarantee a high degree of resistance to deterioration by erosion. However, the proper design of a system can have an impact on the effects of erosion. For example, it is generally desirable to reduce the fluid velocity by increasing the pipe diameter. At the same time, designs creating turbulence, flow restrictions and obstructions are undesirable. Welded and flanged pipe sections should always be carefully aligned. In addition, the thickness of vulnerable areas should be increased.



Source: Huijbregts Corrosion Consultancy

2.2 Deterioration by Cavitation

Cavitation occurs when a fluid's pressure drops below its vapor pressure causing gas pockets and bubbles to form and collapse. This condition can occur in an explosive and dramatic fashion. This form of deterioration can easily reduce the material thickness of pump impellers and other similar equipment components. Cavitation can also exacerbate deterioration by erosion at pipe elbows and tees. Cavitation can be controlled by reducing hydrodynamic pressure gradients and avoiding situations in which the system pressure drops below the vapor pressure of the liquid.

Source: Wikipedia

2.3 Fretting Deterioration

Fretting deterioration refers to damage that can occur at the interface of roughened surfaces that are in contact. This type of deterioration can be caused when the contact surfaces are transmitting a load or when the surfaces are exposed to repeated motion due to vibration. Grooves and other similar types of surface damage characterize this type of deterioration, which is typically found in machinery, bolted assemblies and ball or roller bearings.

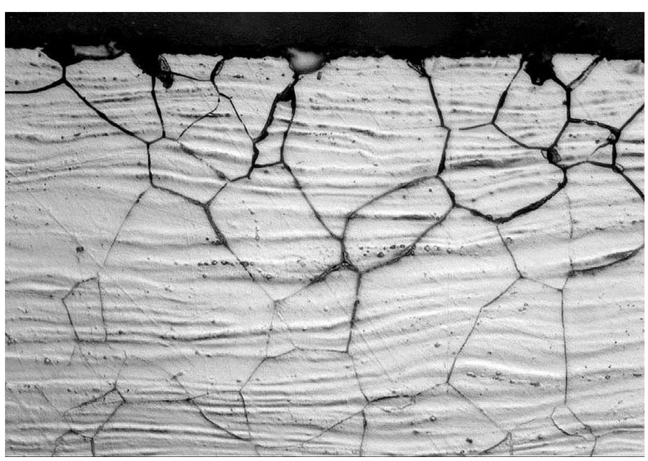
Source: Corrosion Technology Laboratory

2.4 Intergranular Deterioration

The microscopic structure of metals and alloys is made up of grains, separated by grain boundaries. Intergranular deterioration involves localized attack along these grain boundaries. The adjacent material grains can remain unaffected by this type of deterioration, however. This form of deterioration is usually associated with impurities within the metal that are concentrated at the grain boundaries. Intergranular deterioration occurs by the reduction of adequate corrosion resistance which in turn makes the grain boundary zone anodic relative to the remainder of the adjacent grain surface. The deterioration usually progresses along a narrow path of the grain boundary. In severe cases entire grains may be dislodged due to complete deterioration of the boundaries.

Source: Corrosion Technology Laboratory

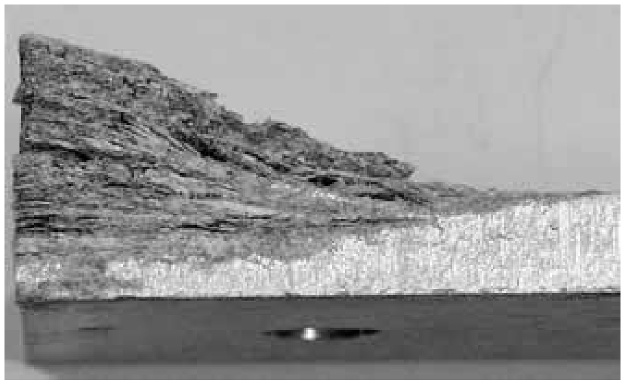
An example of intergranular deterioration involves weld decay. Reheating a welded component during a multi-pass welding procedure is a common cause of this problem. In austenitic stainless steels, titanium or niobium can react with carbon to form carbides in the heat affected zone of the weld to cause a specific type of intergranular corrosion known as knife-line attack. The carbides deposit next to the weld bead where they cannot diffuse due to the rapid cooling of the weld metal. The problem of knife-line attack can be corrected by reheating the welded metal to allow diffusion of the carbides to occur.



Source: Wikipedia

2.5 Exfoliation Deterioration

Exfoliation is a particular form of intergranular deterioration associated with high strength aluminum alloys. Any alloy that has been extruded or otherwise worked heavily, resulting in a microscopic structure of elongated, flattened grains, is particularly prone to this type of deterioration. As deterioration occurs along the grain boundaries the resulting corrosion byproducts exert pressure between the adjacent grains resulting in a lifting or leafing effect. This type of deterioration often initiates at the end grains of the metal that are exposed at machined edges, holes or grooves and can progress through an entire section. The resulting appearance can be similar to that of lamellar delaminations exhibited by carbon steels.



Source: NDT Resource Center

3.1 Environmental Cracking

Environmental cracking refers to deterioration caused by a combination of conditions that can specifically result in one of the following forms of corrosion damage:

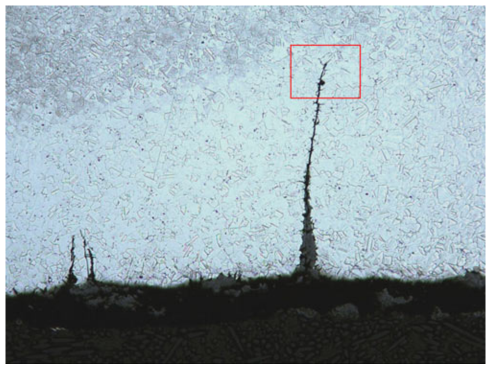
3.1.1 Stress Corrosion Cracking

Stresses that cause environmental cracking can arise from cold working, welding, grinding, thermal treatment or externally applied loads (that induce tensile forces). Deterioration associated with stress corrosion cracking is induced by the combination of tensile stresses and a corrosive environment. Typically, the surface of the metal does not exhibit signs of deterioration except for the presence of microscopic cracks that penetrate into the material. Under a microscope, the cracks can have a brittle appearance. Stress corrosion cracking has the potential to result in catastrophic material failure as the detection of the microscopic cracks can be very difficult and the type deterioration associated with the phenomenon is not easily predicted.

Source: The Multimedia Corrosion Guide

3.1.2 Corrosion Fatigue

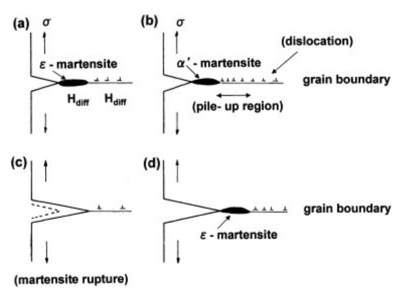
Corrosion fatigue is the result of the combined action of alternating or cyclical material stresses in the presence of a corrosive environment. The fatigue process affects the nature protective passive film of the material allowing accelerated deterioration to occur. The presence of a corrosive environment in turn allows for more rapid crack growth. In addition, the presence of a corrosive environment will reduce the normal fatigue limit of a ferrous alloy, regardless of the stress level. No metal is immune from some reduction of its resistance to cyclic fatigue stresses if the metal is in a corrosive environment. Even relatively mild corrosive environments can reduce the fatigue strength of aluminum structures considerably. Control of corrosion fatigue can be accomplished by lowering the cyclic stresses and elimination of or protection from the corrosive environment.



Source: Metallurgical Technologies, Inc.

3.1.3 Hydrogen Embrittlement

Hydrogen dissolves in all metals to a some extent. For example, the diffusion coefficient for hydrogen in ferritic steel at room temperature is similar to the diffusion coefficient for salt in water. The dissolved hydrogen assists in the fracture of the metal by making cleavage easier by assisting in the development of local plastic material deformations. This effect leads to the embrittlement of the metal. Examples of hydrogen embrittlement include cracking of welds or hardened steels that have been exposed to conditions in which hydrogen has been injected into the materials.

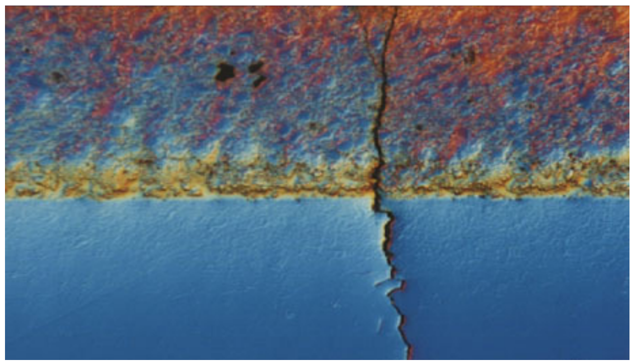


Source: Corrosion Science

Hydrogen has a relatively low solubility in ferritic iron, but a relatively high diffusion coefficient. In contrast the holes in an austenite metal lattice are larger, but the channels between them are smaller. Therefore materials such as austenitic stainless steel have a higher hydrogen solubility and a lower diffusion coefficient. Consequently, it usually takes much longer for austenitic metals to become embrittled by hydrogen than it does for ferritic materials. Austenitic alloys are often regarded as immune from the effects of hydrogen.

Hydrogen embrittlement is not a permanent condition. If cracking does not occur and the environmental conditions are changed so that no hydrogen is generated on the surface of the metal, the hydrogen can diffuse itself from the steel, so that ductility is restored.

To address the problem of hydrogen embrittlement emphasis should be placed on controlling the amount of residual hydrogen in the metal, limiting the amount of hydrogen that can be picked up during processing, employing low or no embrittlement plating or coating processes and restricting the amount of in-situ hydrogen that can be introduced to the metal during the service life of the material. A good example of the prevention of the potential for hydrogen embrittlement includes the use and proper storage of low-hydrogen electrodes for welding operations.



Source: The Hendrix Group

The Detection of Metal Deterioration

Corrosion detection includes both Non-Destructive Evaluation (NDE) and Non-Destructive Inspection (NDI). No single means of corrosion detection is either ideal or suitable for all forms of corrosion. The following table summarizes the major advantages and disadvantages of the primary methods used to detect the presence of deterioration as well as the type of corrosion it is used to detect.

Summary of Corrosion Detection NDE and NDI Technologies

Technology	Advantages	Disadvantages	Primarily Detects
Visual	Relatively inexpensive and allows for large coverage area.	Highly subjective and measurements are not precise. Limited to surface inspection and can be labor intensive.	Surface deterioration, exfoliation, pitting and exposed intergranular corrosion.
Eddy Current	Relatively inexpensive and portable. Good resolution with multiple layer capability.	Low throughput and interpretation of output is difficult.	Surface and subsurface flaws such as cracks, exfoliation corrosion around fasteners and corrosion thinning.
Ultrasonic	Good resolution. Can detect material thickness and loss of section.	Single sided and cannot assess multiple layers. Low throughput.	Material loss, delaminations and voids.
Radiography	Good resolution allowing easy image interpretation.	Expensive and bulky equipment. Requires radiation safety measures.	Surface and subsurface corrosion flaws.
Thermography	Large area scans with relatively high throughput. Allows for macro view of structure.	Complex equipment. Layered structures can be a problem. Does not allow for precision measurements.	Surface corrosion.
Automated	Improves productivity.	Does not always provide reliability and adequate quality assurance.	Intended for manufactured items in controlled environment.