


ENGINEERING MATERIALS *9th May, 2020*

CORROSION OF STEEL REINFORCEMENT IN CONCRETE

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Definition

ASTM terminology (G15) defines corrosion as “the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties”
It leads to steel mass loss, dimension change, and affect significantly their lifetime

1991 report FHWA in U. S. reported that 134,00 (23% of the total) bridges required immediate repair and 226,000 (39% of the total) were also deficient. The total repair cost was estimated at \$ 90 billion dollars

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Factors

- Carbonation
- Chlorides
- Moisture
- Oxygen diffusion
- Concrete mix variables
- Construction variables
- Temperature
- Humidity

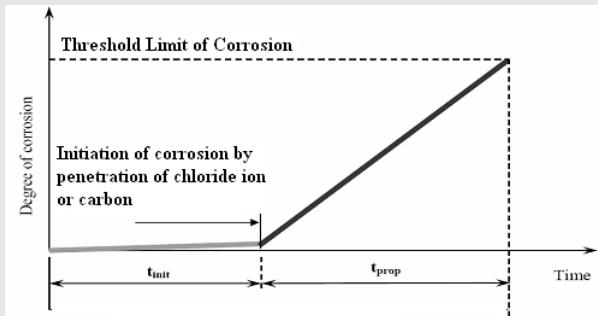
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State-of-the-Art



Corrosion Initiation-Corrosion Propagation

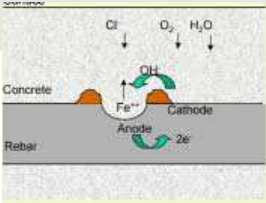
Tuutti, [1982]

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Corrosion Cell

Corrosion of steel reinforcement occurs by an electrochemical process which involves exchanges of electrons similar to that which occurs in a battery. The important part of the mechanism is the separation of negatively charged areas of metal or '**anodes**' where corrosion occurs and positively charged areas or '**cathodes**' where a harmless charge balancing reaction occurs. At the anode the iron dissolves and then reacts to form the solid corrosion product, rust. The rust is formed at the metal/oxide interface, forcing previously formed oxide away from the steel and compressing the concrete, causing it to spall.



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Corrosion Cell

Anodic reaction (involving ionization of metallic iron) will not progress far unless the electron flow to the cathode is maintained by the consumption of electrons.

For the cathode process, therefore the presence of both air and water at the surface of the cathode is absolutely necessary.

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Anode-Cathode Reaction

Anode: Fe $2e^- + Fe^{2+}$
(metallic iron)

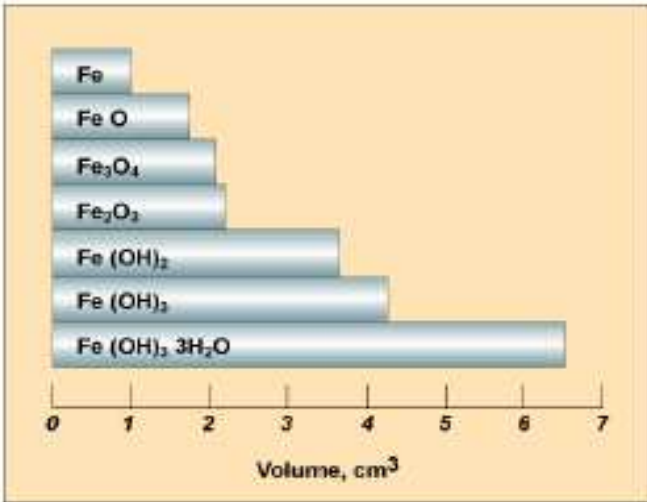
FeO (H₂O)_x
rust

Cathode: (1/2) O₂ + H₂O + 2e⁻ **2(OH)⁻**
air water

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Volume Increase



Product	Volume (cm ³)
Fe	1.0
FeO	1.5
Fe ₃ O ₄	2.0
Fe ₂ O ₃	2.5
Fe(OH) ₂	3.5
Fe(OH) ₃	4.5
Fe(OH) ₃ ·3H ₂ O	6.5

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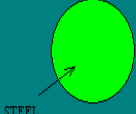


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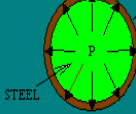
Corrosion Progress

CONCRETE



STEEL


CONCRETE



RUST

STEEL


CONCRETE



RUST

STEEL


CONCRETE



RUST

STEEL

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Passivity of Steel

Ordinary iron and steel products are normally covered by a **thin iron oxide film** that becomes impermeable and strongly adherent to the steel surface in an alkaline environment, thus **making the steel passive to corrosion**.

This means that metallic iron is not available for the anodic reaction until the passivity of steel has been destroyed.

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Types of Corrosion

1. Pitting Corrosion	• 70% of Failure
2. Uniform Corrosion	• 30% of Failure

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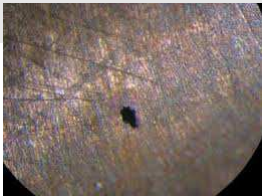


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Pitting Corrosion

Pitting corrosion is caused by depassivation of a small area, localized form of corrosion that leads to the creation of small holes (pin holes) in the material. Pitting is considered to be more dangerous than uniform corrosion damage because it is more difficult to predict and design against. Corrosion products often cover the pits making the detection often very difficult.




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Pitting Corrosion


- Depending on the Cl^-/OH^- ratio, the protective film is destroyed even at pH values considerably above 11.5.
- When Cl^-/OH^- molar ratio is higher than 0.6, steel is no longer protected, probably because the iron-oxide film becomes either permeable or unstable under these conditions.
- The threshold chloride content to initiate corrosion is reported to be in the range 0.6 to 0.9 kg Cl^- per cubic meter of concrete.
- When large amounts of chloride are present, concrete tends to hold more moisture, which also increases the risk of steel corrosion by lowering the electrical resistivity of concrete.

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Uniform Corrosion

Uniform corrosion The most widespread form of corrosion that is observed, uniform corrosion is characterized by corrosive attack proceeding evenly over the entire surface area, or a large fraction of the area of the metal under attack.



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Uniform Corrosion

- Protective film on steel is stable as long as the pH of the solution stays above 11.5.
- When concrete has high permeability and when alkalies and most of the calcium hydroxide have either been carbonated or leached away), the pH of concrete in the vicinity of steel may have been reduced to less than 11.5.
- This would destroy the passivity of steel.

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Corrosion



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Control of Corrosion


Waterproof membranes are used when they are protected from physical damage by asphaltic concrete wearing surfaces; therefore, their surface life is limited to the life of the asphaltic concrete, which is about 15 years.

Overlay of watertight concrete of 37.5 to 63 mm thick, provides a more durable protection to the penetration of aggressive fluids into reinforced or prestressed concrete members.

Protective coatings for reinforcing steel are of two types:

- Aanodic coatings (e.g., zinc-coated steel) very limited use due to concern regarding the long-term durability.
- Barrier coatings (e.g., epoxy-coated steel), long-time performance of epoxy-coated rebars is still under investigation in many countries.

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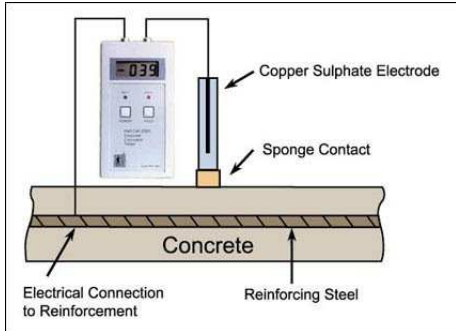


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Corrosion Monitoring

1. Half cell potential
2. Linear polarization
3. AC Impedance method



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Half Cell Potential ASTM C876

vs. Cu/CuSO ₄ (mV)	vs. Ag/AgCl (mV)	Corrosion Probability
E > -200	E > -150	90% No Chance
-200 > E > -350	-150 > E > -300	Uncertain
-350 > E	-300 > E	90% Chance

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Thank You!

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