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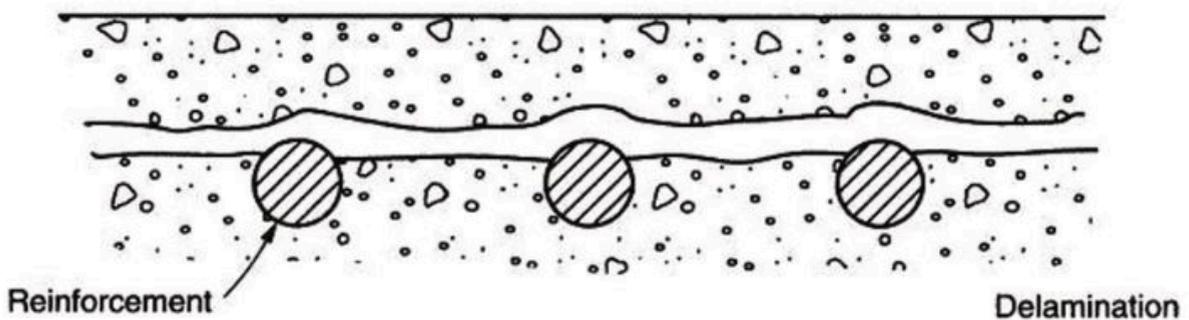
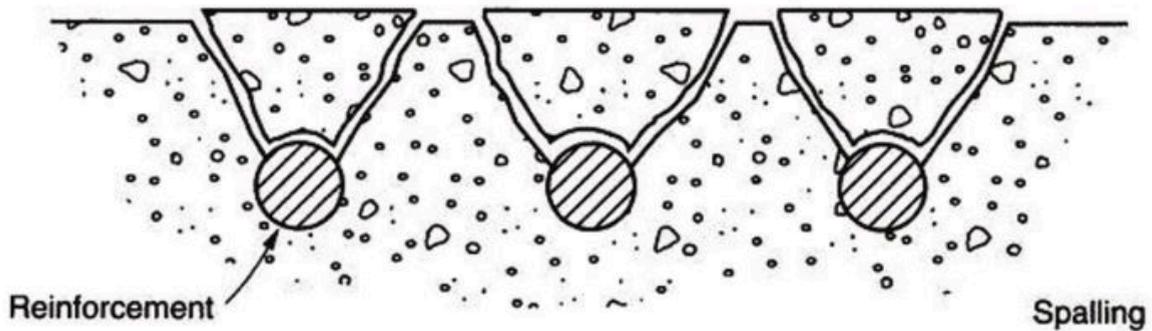
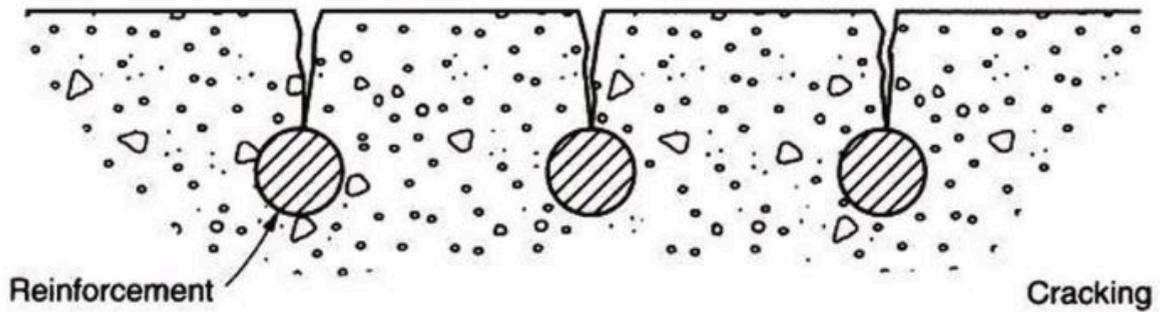
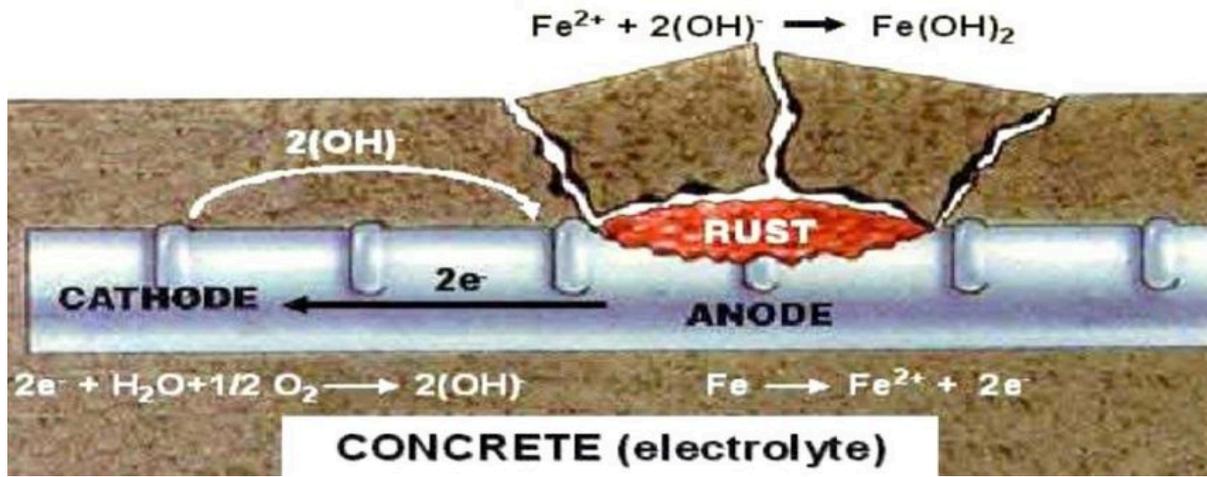
Steel Corrosion in Concrete

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A Critical Issue

When it comes to structural concrete, the most pressing durability concern worldwide is corrosion of reinforcement steel in concrete. Corrosion is defined as an electrochemical process in which oxidation of iron at an "anode" coincides with a reduction of water and oxygen at a "cathode". The resulting corrosion products, such as rust, take up more space than the original iron, oxygen, and water. This growth of volume inside a concrete structure can cause cracking, spalling, debonding from critical steel reinforcement, or even delamination of an entire concrete face.



Corrosion of steel occurs when steel is exposed to water and oxygen. Typically, exterior concrete in service would have sufficient water and oxygen to initiate corrosion. However, concrete is initially tremendously protective of steel reinforcement, as the high alkalinity of concrete forms a dense layer of iron oxide on the surface of the steel to protect it from water and oxygen. This iron oxide is referred to as a passive layer. As long as the concrete retains its high alkalinity and is not exposed to chlorides, the steel will be passive indefinitely. The issues arise when one or both of those statements no longer hold true.

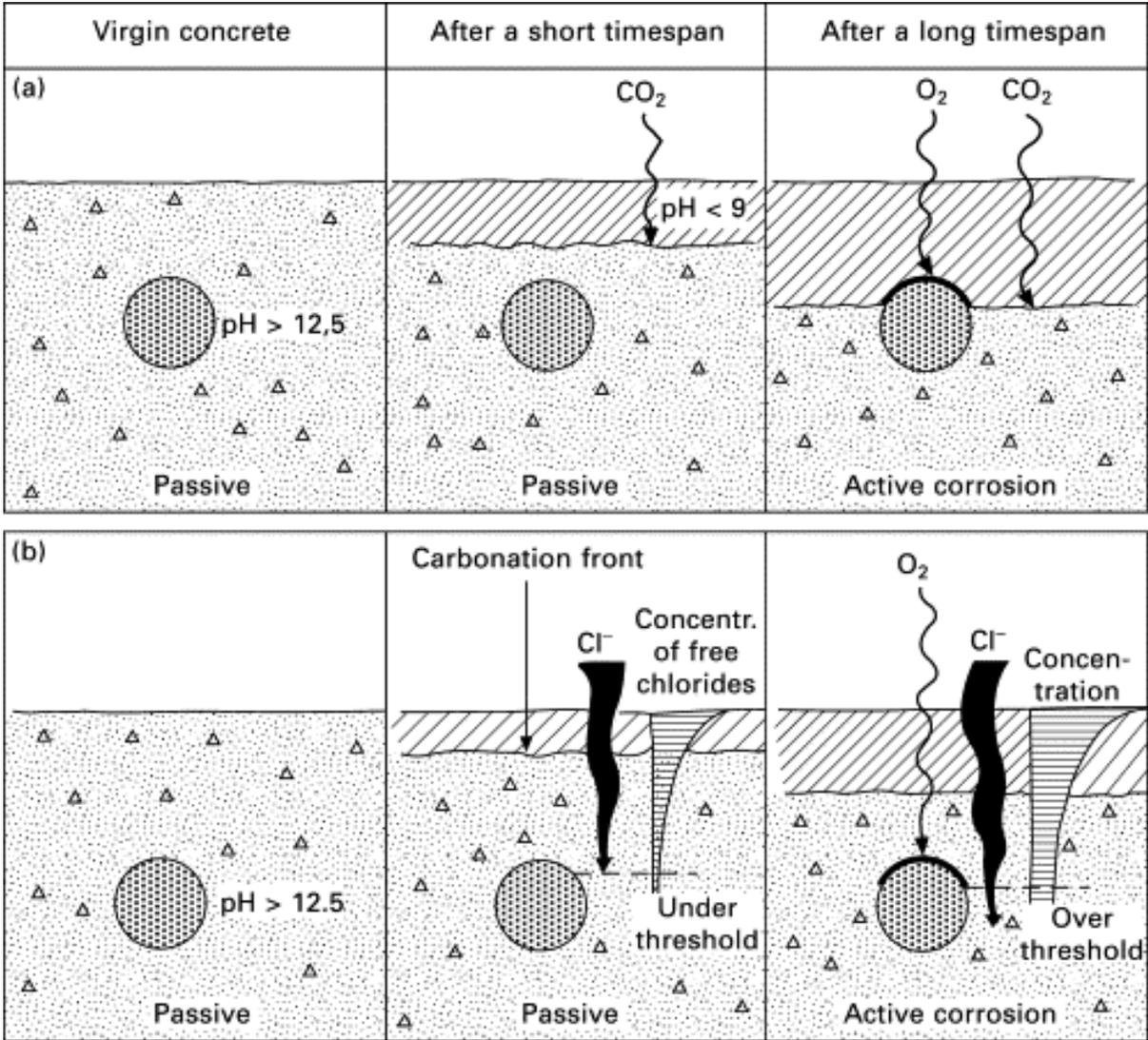
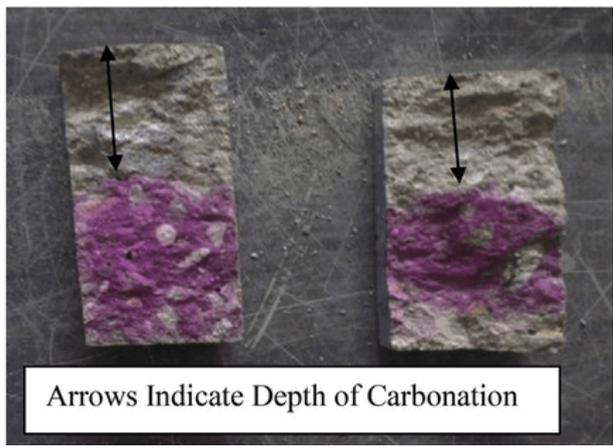
Causes of Corrosion

Chlorides

The passive layer of iron oxide protects steel reinforcement in concrete unless there is a sufficient concentration of chlorides at the steel surface. The required concentration of chlorides varies based on a large number of factors such as carbonation levels, w/cm ratio, the SCM usage, the type of chloride penetrating the concrete, the chemical makeup of the cement, the type and shape of the steel surface, temperature, humidity, access to oxygen, etc. A standard number that is often cited for average conditions is .05-.1% by mass of concrete. These chlorides could be from an internal source, such as calcium chloride accelerators, salts in mixing water, and sea-dredged aggregates. External sources of chlorides include deicing salts, exposure to seawater, and exposure to chemicals high in chlorides.

Carbonation

Another cause of corrosion in concrete is the carbonation of the concrete surrounding steel reinforcement. As you might have seen in many environmental articles of late, concrete is a carbon sink. Carbon dioxide will bond with calcium hydroxide (remember the C-H from [Tech Bulletin #3](#)?) to form calcium carbonate. Calcium carbonate is essentially limestone and is a hard material, and therefore strength is not affected. The reaction does, however, drop the pH of concrete from approximately 13 to 8. At a pH of 8, that dense passive layer of iron oxide destabilizes and, if water and oxygen are present, the steel will start to corrode. Carbonation of concrete happens significantly quicker in concretes with a high w/cm ratio, as well as concrete's with a lot of SCMs. (A quick aside, this is one of the few drawbacks of SCMs... as CO₂ penetrates concrete, it will bond with the nearest C-H it can find. If there is very little C-H present due to SCM usage, it takes less CO₂ ingress to fully react with the C-H that is present). Carbonation also happens quicker in dry environments. This is not a big deal in most situations as a dry environment does not provide the water necessary for corrosion. However, the highest risk areas for corrosion are often the underside of bridges, as they are protected from direct water, allowing for relatively quick carbonation, but have a high enough humidity to allow for corrosion. A pH indicator can be applied to a concrete core to assess carbonation ingress (see below).



Corrosion Resistance



Now that we know what causes corrosion, we can begin to take steps to reduce corrosion potential. Some of these include:

- - **Using non-chloride deicers or accelerators.** Utilizing non-chloride chemicals reduces the abundance of chlorides that might be present or penetrate the concrete to the steel surface.
- - **Use a low w/cm ratio mix design.** Lower w/cm ratio concrete has less permeability both for chloride ingress and carbon penetration. All concrete exposed to deicing salts should have a w/cm ratio .45 or below. Concrete with high exposure to chlorides AND reinforcing steel should target a w/cm ratio of .40.
- - **Increasing depth of cover.** The deeper reinforcing steel is embedded in concrete, the further chlorides or CO_2 needs to penetrate to initiate corrosion.
- - **Use SCM's.** SCMs such as fly ash, slag, or silica fume significantly increase the resistance to chloride penetration. However, they *decrease* the resistance to carbonation. In most instances, the trade-off is worth it.
- - **Proper Curing.** Proper curing helps minimize permeability and therefore chloride penetration at the surface.
- - **Application of sealers or other membranes.** A sealer can help prevent water-borne chloride intrusion into the concrete by means of a barrier on the concrete surface. Sealers do not last forever, so this is simply a delaying tactic.
- - **Corrosion Inhibitors.** Corrosion inhibitors, such as GCP's DCI, are often a calcium nitrate solution that works by increasing the chloride concentration needed to initiate corrosion at the surface of the steel. Corrosion inhibitors are a linear dose admixture, in that the more one uses, the more the concentration threshold increases.
- - **Epoxy Coated Rebar.** Epoxy coated rebar is an often used strategy for protecting steel from corrosion. Lab tests show the epoxy is resistant to corrosion producing mechanisms, but recent investigations done by the Virginia and Florida DOTs suggest that the epoxy may debond from the rebar

in as little as four years. If this is the case, when the carbonation front or chloride penetration reaches the rebar, there will be no protection to prevent corrosion.

- - **Galvanized, MMFX or Stainless Steel Rebar.** Using metals resistant to corrosion can delay (galvanized) or prevent (stainless) corrosion. These methods, while effective, can be extremely expensive.
- - **FRP Rebar.** Fiber-reinforced polymer bars are a new wave to hit the market. As they are non-metallic, there is no concern for corrosion.



- - **Cathodic Protection.** This works by installing a sacrificial anode connected by wire to the rebar system. The anode is often made up of a highly corrosive metal like magnesium or zinc. This is often done as part of repair to an already corroding system, but can be installed with new construction as well. The sacrificial anode corrodes in lieu of the steel, protecting the structural reinforcement system. In new construction, the sacrificial anode is often placed in the concrete. In a repair situation, it may be outside the structure.



It's Elemental

It is important to remember that for corrosion to occur, there needs to be ample water, oxygen, AND either carbonation or chlorides. If you have a climate controlled building, and there is a vapor barrier under the slab, there will be no access to water, and no risk of corrosion. In this instance, it's even acceptable to use calcium chloride admixtures with steel. Similarly, concrete underwater in the ocean has no risk of corrosion due to a lack of oxygen.

[Read the whole story](#)

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