

## Corrosion of Nonferrous Metals in Contact with Concrete

Nonferrous metals are frequently used in construction in contact with portland cement concrete. Metals such as copper, zinc, aluminum, and lead—and alloys containing these metals—may be subject to corrosion when embedded or in surface contact with concrete.

Because of the damaging effects of corrosion to concrete structure or to embedded metallic elements, it is important to know what conditions lead to corrosion and the protective measures that may be taken.

The products of corrosion occupy a greater volume than the metal that has corroded. They may cause internal forces of expansion that can crack and loosen the surrounding concrete. Corrosion may not always damage the concrete, but may cause destruction of embedded metal elements such as conduits or piping.

In the case of surface contact between the metals and hardened concrete, corrosion may be less damaging because the products of corrosion gradually fill the air spaces between the surfaces of contact. This reduces the development of pressure.

Corrosion of embedded metals is caused by direct oxidation in strong alkaline solutions that normally occur in fresh concrete and mortar, or by galvanic currents between two dissimilar metals in the presence of an electrolyte. Galvanic currents are set up when an alloy or metal is not perfectly homogeneous, or when different parts of a metal have been subjected to different heat treatments or mechanical stresses.

Galvanic corrosion is influenced by differences in: (1) the composition of the solution at the two electrodes; (2) the nature of the metals of the electrodes; (3) environmental conditions, such as the presence of oxygen, chloride concentration, alkalinity, moisture, temperature or large air or liquid-filled spaces next to the metals. These conditions can be brought about by differences in external exposure, permeability, thickness or uniformity of the concrete.

Localized galvanic corrosion may occur when one metal is placed in two different electrolytes, or in an electrolyte of varying concentration. For example, piping should not rest directly on a sand, earth or insulating concrete base when concrete is to be placed over it. The piping in this situation makes contact with the base material and this contact can set up a flow of corrosion-causing current.

Corrosion of metals in concrete is an electrochemical process requiring the presence of moisture. The moisture conditions of concrete required to support active galvanic corrosion of susceptible metals is not known with accuracy. Moisture in concrete may be available: (1) when fresh concrete is placed containing mixing water that is only partly

used up as the cement hydrates. The remaining water migrates to exposed surfaces and evaporates. The length of time it takes for concrete to dry out is variable. It depends on such factors as relative humidity of the surrounding air, size and shape of the concrete mass, and concrete mix; (2) if hardened concrete is not dense and impervious, moisture may penetrate into the interior from the environment.

Corrosion reactions are strongly promoted by the presence of some of the halogen ions, particularly chlorides, which make moist concrete a strong conductive electrolyte. Chlorides also tend to break down the oxide film that normally forms on some metals as a protection against corrosion. Chlorides in concrete may originate from concrete admixtures, sea water, beach sand, or salt-containing aggregate. It is therefore recommended that if any material used to make concrete is suspected of containing chloride, it should be analyzed and rejected if chlorides are present.

Metals of dissimilar composition should not be embedded near or in direct contact with each other in moist or saturated concrete unless experience has shown that no detrimental galvanic action will occur. When it is not possible to separate the metals, impervious protective organic coatings such as bituminous coatings, phenolic varnish, chlorinated rubber, or coal tar-epoxies, should be used on the metal surfaces to prevent galvanic action.

The presence of stray currents flowing through the earth may lead to serious galvanic corrosion of long metallic elements encased in concrete in the ground. Corrosion by stray currents can be prevented by several methods such as conducting the stray currents away from the embedded metals back to their source or by interrupting the continuity of the embedded metallic elements by means of closely spaced insulating joints.

In all cases of embedment of nonferrous metals in concrete, dense quality concrete should be used and adequate concrete cover should be provided.

### Copper and Copper Alloys

Copper and copper alloys are practically immune to action from fresh concrete and mortar. Due to its permanency in the presence of moisture, copper and copper alloys may be safely embedded in fresh concrete. No destructive action will occur on the embedded area even when the concrete is kept saturated with moisture. The presence of soluble chlorides, however, may lead to corrosion, and it is therefore advisable to avoid embedding copper in concrete containing chlorides, especially if the concrete and metal are to be

exposed to moisture. Galvanic corrosion should be expected when copper and steel reinforcement are connected or in close proximity. Copper is strongly cathodic and will accelerate the corrosion of the steel if chlorides are present. When copper is used in conjunction with steel, it should be electrically insulated from the steel by means of an impervious organic coating or by use of short lengths of polyethylene tubing slit and slipped over the copper.

Copper coatings for the protection of a basic metal such as steel can protect only when they form a complete envelope. Breaks in the coating may create local galvanic cells and cause the exposed basic metal to corrode much more rapidly than it would if it were not coated.

## Zinc

Zinc is susceptible to attack by fresh concrete and mortar. This results in the evolution of hydrogen and the formation of calcium zincate which occupies a greater volume than the original metal and may exert expansive pressures around the embedded element.

The most frequent use of zinc in concrete is as a coating for steel. The film of zinc covering the steel is so thin that the expansive pressures generally do not cause any damage to the surrounding concrete. Whether cracking of the concrete occurs subsequently or not depends on many factors such as strength of concrete, amount of concrete cover, size of galvanized member, exposure conditions, and chemical composition of cement. To what extent the steel will be corroded cannot be stated with certainty, but galvanizing does furnish sacrificial protection to the steel. (Sacrificial protection means that the zinc will corrode and be thus sacrificed in order to protect the steel.)

Calcium chloride admixtures will cause corrosion of galvanized steel in concrete and may lead to severe cracking and spalling of the surrounding concrete. The use of calcium chloride admixtures should be avoided in concrete containing galvanized steel exposed to corrosive or wet environments.

Corrosion of zinc also may occur when it comes in surface contact with freshly hardened, moist concrete, and since some of the corrosion products may be removed by abrasion, rain or other causes, pitting of the surface may result.

If it is desirable to avoid any reaction between zinc and alkaline fresh concrete, the metal should be protected by an organic coating or passivated by a chromate treatment.

The effect on concrete performance by the addition of chromates is not yet fully known. It is therefore recommended, whenever a chromate treatment is required, to apply it to the galvanized surfaces, rather than add chromates to the concrete mixture. Chromate coating of galvanized surfaces can be readily done in most galvanizing plants and consists of either dipping the galvanized elements in a solution of sodium or potassium dichromate acidified with sulfuric acid, or spraying this solution on the galvanized surfaces. The chromate treatment is recommended for all galvanized elements that will be embedded in or will come in contact with concrete and mortar. Treated surface should be protected from water washing

away coating before concrete is placed.

Concrete containing galvanized reinforcing steel placed close to nongalvanized metal forms may have a tendency to stick to the forms. This form-sticking tendency also may occur if nongalvanized steel is placed in concrete close to galvanized forms or form liners. A remedial treatment that has been satisfactorily used to prevent form-sticking has been a 2% solution of sodium dichromate or a 5% solution of chromic acid (chromium trioxide solution) applied as a wash to the galvanized surfaces. (Note: For very thin coatings of electroplated zinc do not use acid solutions.)

## Aluminum

Aluminum suffers attack when embedded in concrete. Initially, when aluminum is placed in fresh concrete, a reaction occurs resulting in the formation of aluminum oxide and the evolution of hydrogen. The greater volume occupied by these products causes expansive pressures around the embedded metal and may lead to serious damage to the surrounding concrete.

Galvanic corrosion also will occur if aluminum and steel are both embedded in concrete and in contact with each other. If aluminum is to be embedded in reinforced concrete, it should be electrically insulated by a permanent coating. Bituminous paint, alkali-resistant lacquer such as methacrylate, or zinc chromate paint can be used.

If electrical insulation is not permanently maintained, the presence of chlorides will greatly accelerate corrosion of aluminum and cause serious damage. Because it is difficult to assure the permanency of the coating at present, aluminum should not be embedded in or come in contact with concrete containing chlorides.

If admixtures are to be used in concrete, they should not contain any chlorides.

In view of chemical similarities between calcium chloride and sodium chloride, aluminum should not be used in concrete in or near sea water.

Where unpainted aluminum is not embedded but is in contact with concrete or mortar under conditions of condensation or dampness, corrosion may occur. This can be prevented by coating as above or by the use of a moisture-proof membrane such as plastic film, bitumen impregnated paper or felt.

## Lead

Lead is attacked by fresh concrete and mortar and is converted to lead oxide or to a mixture of lead oxides. This corrosion tends to stop as the concrete cures and dries, but will continue in the presence of moisture. It may cause total destruction of an embedded lead pipe in a few years. If the lead is coupled to reinforcing steel in the concrete, galvanic cell action may be accelerated. Depending on the particular circumstances, either the lead or the steel will be attacked.

When lead is partially embedded in concrete and the remainder exposed to the air, a condition known as differential aeration occurs. The embedded lead has a different

## Miscellaneous Metallic Coatings

electrical potential than that exposed to the atmosphere and in the presence of water will form the anodic (positive) element of an electric cell. The portion in the air forms the cathodic (negative) element of the couple. The current flow will cause corrosion and gradual disintegration of the embedded lead.

Where it is necessary to embed lead in concrete, protection of the embedded portion with organic coatings is suggested. Where a lead strip connects two pieces of concrete, such as for an expansion joint, the air space between the two sections should be as small as possible so as to reduce differential aeration.

Generally, no damage will be observed in concrete because of the softness of the lead which will absorb the expansive pressures caused by the formation of corrosion products.

Nickel-plated steel will not corrode when embedded in chloride-free concrete and will provide protection to steel as long as no breaks or pinholes are present in the coating. The coating should be 3 to 5 mils thick to resist rough handling. Minor breaks in the coating may not be very detrimental in the case of embedment in chloride-free concrete. However, corrosion of the underlying steel would be strongly accelerated in the presence of chlorides.

Cadmium coatings will satisfactorily protect steel embedded in concrete, even in the presence of moisture and normal chloride concentrations. Minor imperfections or breaks in the coating will generally not promote corrosion of the underlying steel.

**KEY WORDS:** aluminum, cadmium, chlorides, coatings, concretes, copper, corrosion, durability, galvanic corrosion, lead (metal), metals, moisture, nickel, organic coatings, protective coatings, reinforcing steels, zinc.

**ABSTRACT:** The possibility of corrosion of nonferrous metals commonly used in construction in contact with fresh or hardened concrete is discussed, with particular reference to copper and copper alloys, zinc, aluminum, lead, nickel, and cadmium coatings. The presence of chlorides in the concrete and contact between dissimilar metals are cautioned against. Protective measures are suggested to prevent corrosive reactions between the concrete and the metals in contact with it.

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