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GALVANIC CORROSION OF METALS IN CEMENTING MATERIALS

by

Joseph W. Pitts

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS



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INTRODUCTION

The two cementing materials that are of concern in this paper are concrete and gypsum plaster. Galvanic corrosion of embedded metals is known to have caused failures in steel-reinforced concrete containing aluminum conduit and in gypsum plaster on metal lath. Inasmuch as concrete failures are much more numerous, the greater part of this discussion will involve concrete systems, although the basic cause of failure is the same in both systems.

ALUMINUM CONDUIT IN CONCRETE

The first publicized case of concrete failure attributed to corrosion of embedded aluminum conduit occurred in a hospital in Smith Falls, Ontario, Canada in the early 1950's. A comprehensive investigation of this failure was reported in 1955 by Wright^{1/}, who concluded that the failure resulted from galvanic corrosion of the aluminum in the steel-reinforced concrete that contained calcium chloride (CaCl_2). Several other investigations of the behavior of aluminum in concrete have been reported since then; a concise review of this literature is given by Monfore and Ost^{2/}.

A notable example of concrete failure of this type occurred in the Washington, D. C. area in the new District of Columbia Stadium. This stadium was completed late in 1961 and cracks began to appear a few months later. Figure 1 shows cracks that had developed in a ceiling and that had caused some concrete to spall off. Repair of defects such as these involved chipping away the sur-

rounding concrete, removing the corroded aluminum conduit, replacing it with steel conduit, and finally recasting fresh concrete. To date some 15,000 ft. of aluminum conduit have been replaced in the D. C. Stadium^{3/}.

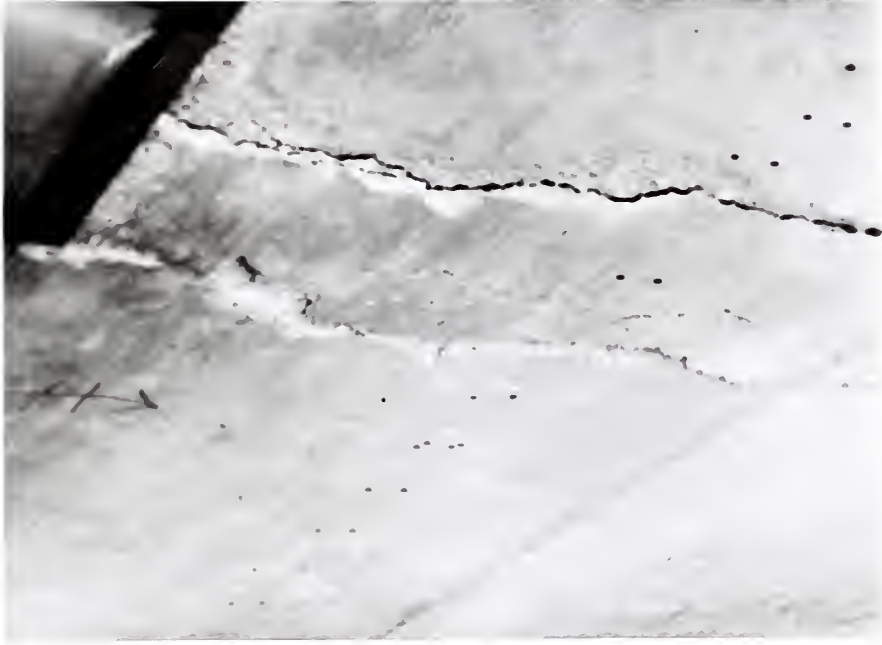


Figure 1. Cracks in a concrete ceiling of the District of Columbia Stadium. The cracks follow the path of the embedded aluminum conduit to the electrical fixture in upper left corner.

The D. C. Stadium example is fairly typical of concrete failures due to corrosion of aluminum conduit; i.e., cracks appear in the concrete and follow the path of the buried aluminum conduit. The cracks may be accompanied by chipping and spalling of the concrete. In some extreme cases the concrete

cracking has resulted in structural weakening of sections of buildings. In not all cases, however, does the concrete fail. The first symptom of trouble at Smith Falls was the inability of electricians to pull wires through the conduit. Examination of the conduit revealed that corrosion of the aluminum had collapsed the conduit walls due to pressure from the corrosion products. Apparently, the concrete was strong enough to resist cracking and hence the only indication of corrosion was the plugged conduit.

STEEL TIE WIRES IN PLASTER

The corrosion of steel tie wires and the subsequent failure of a plastered surface is another example of damage to a cementing material due to galvanic corrosion of embedded metals. Failures of this type, however, are relatively rare. One such case occurred in 1963 when a suspended, plastered ceiling in

a military hospital fell only a few months after installation. It was subsequently determined that the cause of failure was galvanic corrosion of the steel tie wires in the system. Tie wires are light-gage wires used to tie the metal lath to the upper supporting members. This particular ceiling also contained a grid network of copper tubing for hot water radiant heating. Subsequent analysis of the plaster revealed that it unaccountably contained 4400 ppm of chloride ions.

MECHANISMS OF FAILURE

In both of the above systems the mechanism of corrosion is the same. Both contain the essential components of a galvanic cell--two dissimilar metals immersed in an electrolyte*. This is illustrated in Figure 2.

* An electrolyte is any electrically conducting medium containing free ions.

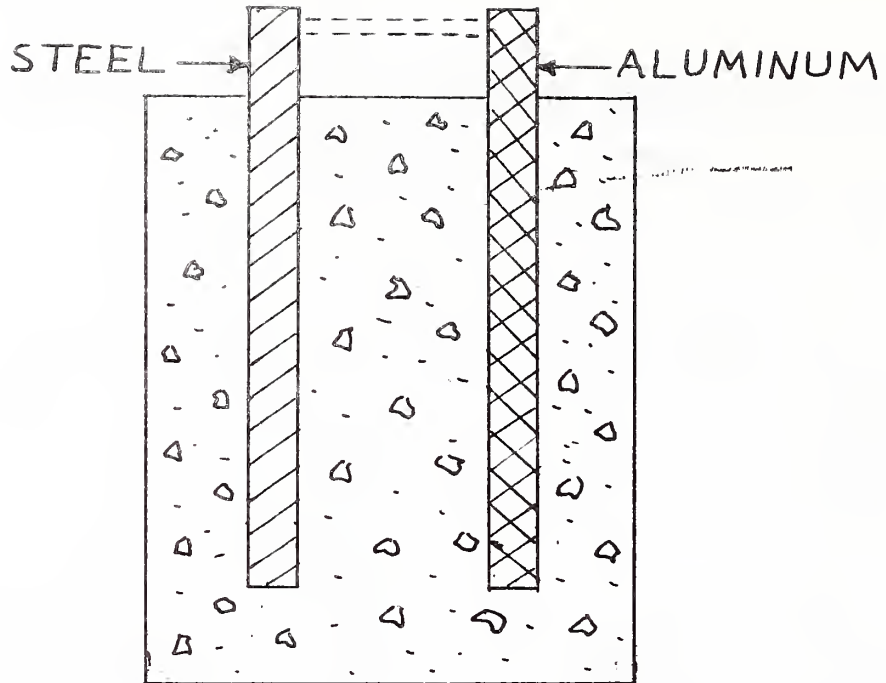


Figure 2. Schematic diagram showing two dissimilar metals embedded in a cementing material.

Consider first that Figure 2 is a simplified schematic diagram of the concrete-steel reinforcement-aluminum conduit system. During the time that the concrete is damp it is a fairly good electrolyte. The steel and aluminum serve as electrodes and, because of their different positions in the electrochemical series of elements, there is an electrical potential (voltage) developed between them. If an external connection is made between the steel and aluminum (as shown by the dashed lines in Figure 2) a current will flow in the circuit just as in any other galvanic cell battery. The aluminum, being more active (less noble in the electrochemical series), than steel (iron), becomes the anode and corrodes. The

steel becomes the cathode and tends to be protected. The intensity and duration of the current flow will depend on a number of variables, some of which will be discussed later. The mechanism of failure of the concrete is that the aluminum corrosion products occupy a larger volume than the aluminum plus its reactants. Thus, the increased volume requirement results in an internal pressure build-up around the conduit. If the conduit is thin-walled and deeply buried in strong concrete the pressure may collapse the conduit, as happened in the Smith Falls case. Otherwise, the concrete will crack.

Consider now that Figure 2 is a schematic diagram of the gypsum plaster-steel tie wire-copper tybing system. (It would appear that the system should include the metal lath, but because the lath had been pre-painted, it was electrically insulated from the system.) Let the electrode marked "aluminum" represent the copper tubing. Since copper is more noble than iron in the electrochemical series, it becomes the cathode and is protected, while the steel becomes the anode and corrodes. When the steel tie wires in a plastered ceiling corrode through or become sufficiently weakened, the plaster and metal lath will fall under their own weight.

In actual building construction the dissimilar metals in the two systems discussed will, for practical reasons, nearly always be in electrical contact. The contact may be external to the cementing material, as shown in Figure 2, but usually the contact will be both external and internal. The galvanic cell principle applies in both cases. The only difference is that when contact is internal, corrosion will tend to be greater near the junction.

VARIABLES

It is obvious that everytime a builder buries aluminum conduit in reinforced concrete or puts any two dissimilar metals in a cementing material he is, unwittingly or not, building a giant battery. How effective the battery will be in corroding the anode depends on a number of variables. First, the cementing material obviously must be electrically conductive to be an electrolyte. Freshly mixed commercial concretes and plasters always contain enough dissolved ionized compounds to make them fairly good conductors. But their conductivities decrease as the cements dry out because both the number of free ions and the ionic mobilities decrease. The rate of drying varies depending on the season of the year and other conditions. Thus, the drying period may extend indefinitely; in fact, the gel-like structure of cement never completely dries out.

Another factor that has a tremendous effect on the conductivity of concrete is the amount of accelerator that is added to the concrete. It is common practice during cold weather construction to add calcium chloride (up to 2% by weight of cement) to concrete to hasten the set. CaCl_2 tends to increase corrosion in two ways: (1) It enhances the activity of the galvanic cell by increasing its conductivity. Studies in our laboratory^{4/} in connection with the gypsum plaster failure showed that the conductivity of a commercial gypsum plaster was increased by about five times when 1% CaCl_2 was added. A comparable increase in the conductivity of portland cement concrete might be expected. (2) The second function of CaCl_2 is chemical in nature. Normally in concrete without chloride, the aluminum initially reacts with the

cement, but the reaction products form a protective film which inhibits further corrosion^{5/}. When the concrete contains CaCl_2 , however, the chloride ion diffuses to the anode where it tends to break down the protective film on the aluminum and form a non-protective hydrated aluminum chloride compound.

Another significant variable affecting the rate of corrosion is the proximity of the two dissimilar metals in the concrete. If the two metals are externally connected, but do not touch within the concrete, the farther they are spaced apart in the concrete the less the corrosion will be. This is the result of simply increasing the internal resistance of the galvanic cell, thereby reducing the current flow. Walton, et al^{4/} found that if they decreased the spacing of steel and aluminum electrodes in a chloride-free concrete from 4-inch separation to 1/8-inch separation, they increased the total current flow by a factor of about three.

The final variable in this discussion is the ratio of the anode area to the cathode area. Increasing this ratio reduces the current density at the anode and thereby minimizes the corrosion damage per unit area. An excellent example of this effect is the gypsum plaster-steel tie wire corrosion case. The metal lath had been pre-painted to prevent rusting while exposed to the weather on the job site (a common practice). The painted lath was, thus, electrically insulated from the system. This left only the steel tie wires acting as an anode. Consequently, the small exposed area of the tie wires coupled to the large exposed area of the copper tubing (cathode) resulted in a high current density at the anode. Had the lath not been painted, the total area of the anode (steel lath plus tie wire) would have been tremendously greater, resulting in a low, probably harmless, current density.

RECOMMENDATIONS

If dissimilar metals are to be used in cementing materials, the following precautions are recommended:

1. Avoid contact if practicable.
2. Keep the electrical conductivity of the cementing material to a minimum.
 - a. Forbid the use of CaCl_2 or other ionic compounds; also, prevent the accidental or thoughtless contamination of the cementing material, such as for example, by the use of sea water for mixing water.
 - b. Prevent abnormally delayed drying and subsequent exposure to moisture.
3. Keep the ratio of the anode area to the cathode area at a maximum. Do not coat the anode unless the coating will remain continuous or unless the intense localized corrosion that may occur at a few discontinuities can be tolerated. An old axiom in corrosion control is: If one of two dissimilar metals is to be coated, coat the cathode.
4. Space the dissimilar metals as far apart as possible.

There are other more sophisticated methods of corrosion prevention for specialized applications, such as for example, impressed current techniques; but these are beyond the scope of this paper.

SUMMARY

A brief summary has been presented of some corrosion problems that have developed in recent years because of the use of dissimilar metals embedded in cementing materials. It was shown how the use of dissimilar metals embedded in a cementing material forms a short-circuited galvanic cell battery. The resulting corrosion of the anode has led to failures of steel-reinforced concrete containing aluminum conduit and of gypsum plaster on metal lath, where the plaster contained embedded copper tubing. Examples of failures were cited. Some of the variables that affect the degree of corrosion were discussed and some general precautionary measures were recommended.

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