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Corrosion of Metal Ties in Masonry Cladding

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Masonry is a popular cladding for buildings because of its high aesthetic value, its durability and its low maintenance requirements. Lateral support for masonry cladding is usually provided by metal ties, which are subject to compressive and tensile forces, displacement caused by in-plane movement of the cladding, and corrosion. This Update discusses the corrosion of ties.

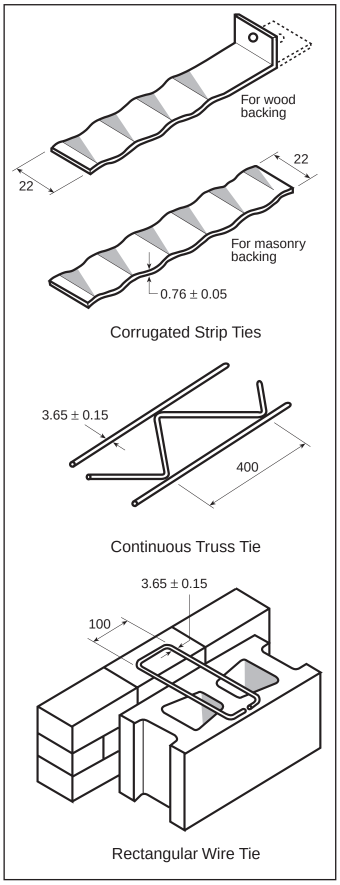

Figure 1. *Examples of common ties used in masonry cladding (from CSA A370)*

Metal ties in masonry cladding are expected to last as long as the building, generally 50 to 100 years but often longer in the case of institutional, cultural and religious buildings. The durability of these ties is largely dependent on the materials used and the exposure conditions as well as on the design, workmanship and level of maintenance of the cladding system.

Durability is difficult to predict since so many factors influence corrosion. The few Canadian investigations carried out to date have shown a large variation in the degree of corrosion — from none to extensive. As the design of buildings has changed (e.g., the use of insulation in cavities, the increase in building height, the use of thinner walls and the failure to provide adequate water-shedding details), the environmental impact on cladding has increased.

Early warning signs of corrosion will not be evident except in the case of thicker plate-type ties, where expansion caused by corrosion results in horizontal cracking in the mortar joint.

Corrosion of ties normally occurs first in the mortar joint because it is usually the wettest component to which the tie is exposed (Figure 2). Bowing of the cladding or sudden catastrophic collapse may occur when corrosion is well advanced, although collapse seldom occurs as the result of corrosion alone. The potential for cladding collapse depends on the number and location of ties that have corroded, on the loads on the cladding and on the presence of other lateral support for the cladding. Other contributing factors include an insufficient number of ties, poor installation of ties and the use of inappropriate ties.

Environmental, Design and Workmanship Factors

Environmental conditions that contribute to corrosion include:

- *Wetting.* The frequency and the length of time that the wall is exposed to moisture have the greatest impact on the degree of corrosion that will occur. Without moisture (e.g., in the form of water, dew, high humidity, etc.), corrosion does not occur. Buildings located in more severe driving-rain zones and the higher parts of buildings, such as parapets and corners, are most vulnerable. The CSA standard on masonry connectors includes a driving-rain index map, which gives a rough indication of areas of the country where cladding is likely to be wettest.
- *Pollutants.* Sulphur and nitrogen oxides in the air are major pollutants causing

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Figure 2. *A galvanized, corrugated strip tie corroded on the part of the tie that was embedded within the mortar joint*

increasing acidity in rainwater. In the industrial region of eastern North America, rainwater can have a pH of 4.3 or less (see box).

- *Chlorides.* Chlorides, which may be present as an additive to the mortar, can intensify corrosion (see box). Marine spray and de-icing salts are also sources of chlorides. De-icing salts can pose problems at the lower levels of buildings in close proximity to roads or sidewalks.
- *Temperature.* An increase in temperature of 10°C doubles the corrosion rate of steel in concrete. Corrosion is almost non-existent when the temperature drops below freezing; however, salts in the water may depress the freezing point and allow corrosion to occur.

The design and construction of building details also affect the rate of corrosion:

- *Inadequate flashings and drips.* When these have been designed or built improperly, concentrated wetting of the wall occurs allowing much more water penetration than does driving rain.
- *Drying inhibited.* Masonry cladding may take longer to dry if the cavity behind it is insulated. Walls with glazed brick or coatings, such as paint, will be particularly susceptible to this problem if they become wet, because the glazing or paint retards drying.
- *Air exfiltration.* Leakage of humid indoor air through the wall in winter can be a source of moisture if the air barrier system is inadequate. This condition is worst at the top of buildings, around window frames and in buildings with high humidity (swimming pools and museums).

Selection of Materials for Ties

Resistance to corrosion in ties is provided by adding durable coatings such as zinc to mild steel (e.g., hot-dip galvanized steel is produced by immersing steel in a molten bath of zinc), or by using durable materials such as stainless steel. Because of its effectiveness and its relatively low cost, galvanized steel is the most popular material for ties.

The corrosion rate of zinc is much lower than that of mild steel — zinc corrodes 10 to 50 times more slowly than mild steel in most atmospheric environments. Zinc also provides better protection than most other coatings because it acts as a sacrificial

The Corrosion Process

Corrosion is the deterioration of a metal that occurs when it reacts to the environment. Metals revert to their stable, natural form through a process called oxidation, or rusting, in the case of steel. Corrosion is an electrochemical process that requires the presence of both oxygen and moisture in order to proceed at a significant rate. In this process, which can be compared to a battery, an electric current passes through a conducting solution, such as water, between two parts of the same metal or between different metals. The current flows from an anodic area (positive electrode), which corrodes, to a cathodic area (negative electrode), which does not corrode. Corrosion can occur uniformly over the whole surface or locally. This depends on various factors such as moisture distribution, local breakdown of protective layers and material composition.

If a stable layer of corrosion builds up on a metal surface, it can act as a barrier by isolating the metal from its environment, thereby greatly reducing the rate of further corrosion, as long as the layer remains intact. This is called passivation. Mortar initially provides an alkaline environment, which leads to the development of a protective oxide layer on mild steel. However, carbonation — the reaction of carbon dioxide in the presence of water with the alkalis in the mortar — reduces the alkalinity of mortars, lowering the pH from about 12 to 8. Carbonation is responsible for the greatest reduction of alkalinity, although industrial pollutants, such as sulphur dioxide (SO_2), can accelerate and further increase the reduction. (The pH is a measure of acidity or alkalinity. Pure water has a pH value of 7. Values that are higher than 7 are alkaline and those that are lower than 7 are acidic. Rainwater with a pH of 4.3 is twenty times more acidic than clean rain, which has a pH of 5.6.)

The presence of inorganic salts, such as chlorides, in the mortar may increase the likelihood and rate of corrosion by:

- maintaining higher moisture levels (deliquescence)
- affecting corrosion reactions, e.g., increasing the electrical conductivity
- attacking the passive protective layer thus causing localized corrosion (pitting).

anode — it corrodes while the steel does not. The zinc provides "cathodic protection" to the steel. The steel, which is less electrochemically active than the zinc, becomes cathodic relative to the zinc (see box). Because of this action, steel exposed by scratches and cuts in the zinc coating does not usually rust significantly until the neighbouring zinc is consumed.

The life of a zinc coating is determined by the exposure conditions and is proportional to its thickness. British field data have shown that in environments where ties are exposed to air and moisture for a significant part of their life, the rate of zinc loss is 10 to 20 g/m^2 a year. The few results available for the eastern United States and eastern Canada indicate that zinc-loss rates in these areas are similar to those of Great Britain. Assuming a rate of zinc loss of 15 g/m^2 per year, a coating thickness of 750 g/m^2 would be required to achieve a life of 50 years or more. For hot-dip galvanized ties, this thickness is only achievable on thicker ties.

Carbonation also has an impact on the rate of corrosion (see box). Tests done in Great Britain on samples of mortar from walls show that carbonation of a typical mortar bed is substantially complete in about ten years. Mild steel loses its protective layer when carbonation occurs, and its corrosion rate then rapidly increases. But if the steel is galvanized, the zinc protects the steel by forming a protective layer. While this layer can reduce the rate of corrosion to very low levels, it becomes less effective as the mortar carbonates. Nevertheless, the corrosion rate is still much lower than that of mild steel, and the corrosion products are less voluminous.

Coatings such as plastic, epoxy or copper are effective in resisting corrosion, but great care must be taken not to scratch or mar the coatings because neither material offers cathodic protection to the steel. Plastic- and epoxy-coated galvanized steel are likely to provide adequate corrosion resistance, as the additional coating will extend the life of the zinc coating; however, there is insufficient data available to estimate the service life of these materials.

Materials with high inherent corrosion resistance, such as copper, phosphor-bronze and austenitic stainless steel, can provide an alternative to coated mild steel. Austenitic stainless steel, which contains chrome and nickel, is the most economical and popular of these — ties made from this type of material are expected to provide a life in excess of 100 years. Type 304 (chrome-nickel) steel is suitable for nearly all situations; however, if high levels of chlorides are present, type 316 (chrome-nickel-molybdenum) steel should be considered because of its greater resistance to chloride-induced corrosion. Ties made of type 304 steel cost two to three times more than hot-dip galvanized ties; those made from type 316 steel are even more expensive and are usually only available by special order.

Incompatible materials

Increased corrosion may occur if dissimilar metals are in contact with one another in the presence of moisture resulting in a current flow between them. Combining metals with large electrochemical potential differences should be avoided. If different metals are combined, they should be electrically isolated from each other with non-conductive bushings, washers and/or membranes or, at the very least, the smaller component must be more corrosion resistant than the larger one. For example, in the case of shelf angles for masonry cladding, it is important never to use mild steel bolts with stainless steel shelf angles, since the bolts — relatively small compared to the shelf angle — will corrode even more quickly than if they were attached to a mild steel angle.

Design, Specification and Maintenance

Cladding system details must be easy to build, thereby reducing the potential for poor workmanship during construction.

The specification of the proper ties and subsequent verification that these ties have, in fact, been delivered to the site are critical. For the inexperienced, the difference between plain, galvanized and stainless steel ties may not be obvious. Packaging for wall ties delivered to site should therefore be clearly labelled with the manufacturer's name, the type of tie, its material, and the thickness and type of any coating. Type 304 stainless steel can be separated from plain or galvanized steel because it is not normally attracted by a magnet.

Galvanized ties should not have any coating defects. Hot-dip galvanized ties should not be bent as the zinc coating may flake off or crack. (It is important to choose ties that are pre-bent and of the correct length so that they won't require bending on site.) Welded connections should be checked to ensure that they were not made after the tie was galvanized. Unprotected welded connections are likely to be more susceptible to corrosion because of in-built stresses and variations in material properties caused by the welding (making some areas anodic relative to others, and hence more likely to corrode).

Maintenance of the ties themselves is not an option because they are hidden from view and inaccessible after construction; however, regular maintenance of water-control features — flashings, drips and gutters — improves long-term durability by limiting the ingress of water into the wall.

Code Requirements

Corrosion resistance requirements in Canadian standards have been based on past experience and individual judgement. But historically, these requirements were not adequate, or were not enforced. For example, the requirement for corrugated strip ties for housing and small buildings, found in Part 9 of the 1985 edition of the National Building Code of Canada (NBC), did not provide limits on corrosion resistance and, in addition, the minimum thickness was very small (0.41 mm). In buildings constructed to meet these requirements, ties have corroded through in less than 10 years.

Code requirements since 1985 have become stricter as more data has become available on the performance of ties. Part 9 of the 1995 NBC contains the same requirements for galvanized ties as the current CSA Standard on Connectors for Masonry, A370, which contains *minimum* corrosion protection requirements. This standard sets requirements according to the exposure environment:

- Cladding on buildings higher than 11 m in areas of moderate or severe driving rain exposure is required to have stainless steel ties or the equivalent in corrosion resistance.
- Cladding in a sheltered exposure or on buildings less than 11 m high may use hot-dip galvanized ties. The minimum thickness of the zinc coating is dependent on the type of tie:
  – 458 g/m^2 for wire ties
  – 305 to 610 g/m^2 on each face for strip or plate-type ties. (The thinnest coating of 305 g/m^2 is only allowed for corrugated strip ties, which have restrictions placed on their use: the maximum cavity width is 25 mm, and they cannot be used on buildings higher than 11 m).

A more effective approach to corrosion protection for galvanized steel wall ties would be to specify a single coating thickness for a given environment. This would lead to a more uniform service life. In Britain the required coating of 940 g/m^2 provides an estimated service life of at least 60 years in exposed conditions.

Conclusion

When selecting appropriate ties to support masonry cladding, it is important to know the environmental factors to which the building will be subjected so that ties of the proper type and materials can be chosen. It is also important to design the cladding to minimize water penetration into the wall and to maximize the ability of the wall to get rid of any water that does penetrate.

Ties with high corrosion resistance, such as those made of stainless steel, should be considered for buildings that:

- require a long design life
- are adjacent to heavy industry
- are located in marine climates
- are taller than 11 m and located in moderate and severe driving rain zones.

In these cases, the extra cost of more durable ties is very small insurance to pay for avoiding potential repair costs.

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