TECH NOTE 1.3.8

CONCRETE SPALLING

WHAT IS SPALLING?

Spalling is the deterioration of steel reinforced concrete, and is characterised by the appearance of cracks and red rust. In severe cases, concrete sections completely break away from the reinforcing steel bar (known as “rebar”), exposing the rebar to the elements.

Spalling is often referred to as “concrete cancer”, as (like cancer) the problem is not obvious initially, and as the problem advances, the treatment becomes increasingly difficult and costly.

HOW SERIOUS IS SPALLING?

According to the Weekend Australian (July 11-12, 1998) the Institute of Engineers Australia said that this “insidious structural affliction cost Australians over $100 million per year.” Given the increase in atmospheric carbon dioxide since then, and recent building design trends towards unpainted concrete, it can be assumed that this figure has increased since 1998.

This burdensome cost is entirely avoidable by good building design and high quality protective coatings.

WHAT CAUSES SPALLING?

Either of two unrelated mechanisms can cause concrete spalling, carbonation and incipient anode formation.[i]

1. CARBONATION OF CONCRETE

Mild steel rapidly corrodes in the presence of moisture, oxygen and ions (ie salts). If, however, it is embedded in fresh concrete, the **high alkalinity** of the concrete passivates the surface of the steel, providing an excellent barrier to oxidation.

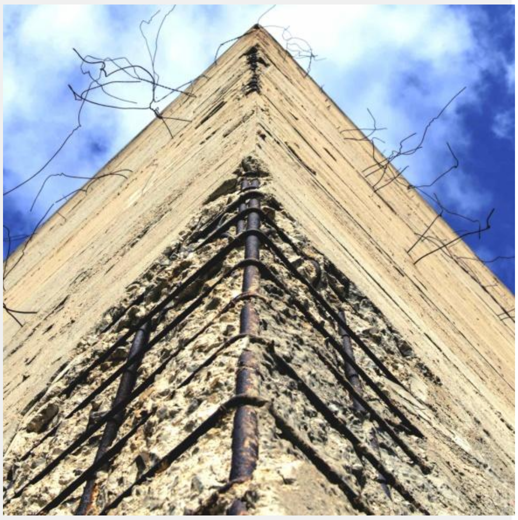
Unfortunately, concrete is also quite porous, and readily absorbs moisture (H_2O), carbon dioxide (CO_2), and many other acidic chemicals in the air and in rainwater. These acidic chemicals neutralise the calcium hydroxide, ($Ca(OH)_2$) in cement.

$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$

This neutralisation process is known as “carbonation” of the concrete, and the point at which alkaline concrete becomes neutral is called the “carbonation front.” The carbonation front begins at the surface of the concrete and steadily moves towards the rebars.

When the carbonation front reaches the rebar, the alkalinity at the rebar drops, and the rebar loses its only protection against corrosion.

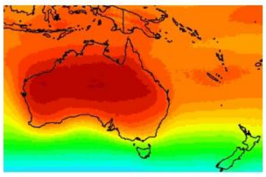
When the embedded steel rebar corrodes, the corrosion products take up eight (8) times the volume of the original steel. This expansion within the concrete exerts a far greater force than the concrete’s flexural strength will allow, resulting in cracks in the concrete around the affected steel. The cracks expose the steel to further corrosion and cause more concrete breakdown.



Rebars without adequate concrete cover nor protective anti-carbonation coating were left to corrode and caused catastrophic spalling.

There is almost as much steel in a concrete building as in a steel building

Deep cracks are the first signs of concrete spalling



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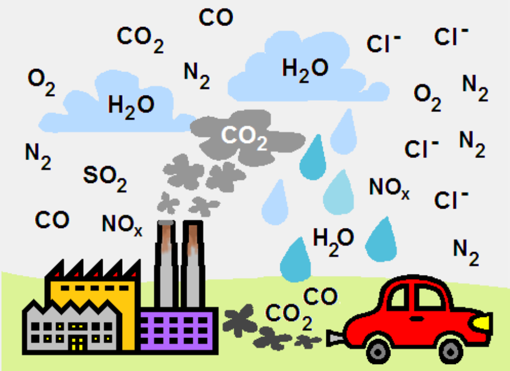
Whilst the oxidation-reduction reactions between iron metal, oxygen and water can get somewhat complicated, the simplistic equation below clearly shows that the oxidation process produces a very large and complex molecule of greater volume than the original iron metal.

$4Fe$	+	$3O_2$	+	nH_2O	$\rightarrow$	$2Fe_2O_3 \cdot nH_2O$
Iron		Oxygen		Water		Big RUST molecule

2. INCIPIENT ANODE FORMATION

A totally different cause of concrete spalling is often found along the Australian coastline. Coastal air is laden with chloride ions (from seawater salt). As concrete is porous, it readily allows chloride ions to move easily through the concrete matrix and form incipient anodes on the surface of the steel rebar, causing nodules of rust on the steel surface. Even though the concrete may still have a high alkalinity, the surface passivation of the steel is disrupted by the chloride ions. The rust nodules create internal stresses in the concrete, which result in cracks in the concrete around the affected steel. The cracks expose the rebar to more chloride ion attack and further corrosion, exacerbating the spalling problem.



There are many acidic chemicals in our atmosphere

WHY REINFORCE CONCRETE WITH STEEL?

There are several reasons for reinforcing concrete with steel:

- Concrete has very high compressive strength, but very poor flexural strength. Therefore, concrete will immediately crack with the slightest flexural pressure exerted by normal stresses such as thermal changes or ground movement (such as earth tremors, foundation settling or soil volume changes due to seasonal moisture level fluctuations). Steel provides the essential flexural strength required to support a building or structure though such pressures.
- Concrete and steel are fully compatible with each other as they have the same coefficients of expansion – that is, they expand and contract with changes in temperature at the same rates. Using a reinforcing material of differing thermal expansion and contraction rates would readily result in stress fractures.
- Steel can be quickly fabricated to accommodate a wide range of architectural designs.
- Steel is readily available and cost-effective.

Steel and concrete expand and contract at the same rate – perfect partners!

WHAT CONTRIBUTES TO CONCRETE SPALLING?

Issues that can contribute to concrete spalling are:

- Faulty concrete specification or design
- Incorrect placement of rebar and/or mesh, resulting in inadequate concrete cover[ii]
- Poor site supervision during pouring, when the rebar is pushed too close to the surface of the concrete[iii]
- Lack of a protective "anti-carbonation" surface coating to prevent ingress of acidic chemicals

Low concrete cover and no protective coatings gave the rebars no protection from atmospheric acid attack

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IS RUST STAINING ALWAYS A SIGN OF SPALLING?

No. Small steel bits such as tie wires and chair legs are often embedded near the surface of the concrete, and whilst corrosion of these small steel bits do not affect the integrity of the structure, they do look unsightly and rust stains can bleed through most applied finishes. They can be gouged out and the gouge filled with a cementitious repair mortar.

Spots of rust are no reason to panic! They are likely to be due to isolated steel impirities such as chair legs and tie wires, used to space out the steel rebars before the concrete is poured

HOW CAN I PREVENT SPALLING?

There are several measures that can be followed to reduce and prevent concrete spalling.

1. Specify a minimum concrete cover according to the exposure classification of the structure as per Australian Standard AS3600[iv].
2. Arrange adequate site supervision to ensure that specified concrete coverage is achieved or exceeded.
3. Ensure that good concrete curing techniques are followed to achieve the maximum concrete design strength.
4. Specify and ensure the use of a certified and effective anti-carbonation and chloride ion resistant coating system.

HOW DOES A PROTECTIVE COATING WORK?

An applied protective coating that is certified as **anti-carbonation** and **chloride ion resistant** prevents the ingress of **carbon dioxide**, **chloride ions** and **moisture** into concrete and is therefore essential to protect your building from concrete spalling. This type of coating can stop both the **carbonation** of the concrete, and the formation of **incipient anodes** on the surface of the reinforcing steel.

The bonus is that the right choice of coating can also greatly enhance the aesthetics of the building or structure, adding to its market value.

Vicroads specifies anti carbonation coatings for bridges, overpasses, sound barriers, and other steel-reinforced concrete structures

DOES DULUX SUPPLY ANTI CARBONATION COATINGS?

Dulux supplies both water based acrylic coatings and heavy duty two pack protective coatings.

AcraTex 955 AcraShield, when applied in two coats at 180 microns over AcraPrime 501 offers outstanding anticarbonation and chloride ion resistance.

Dulux Weathermax HBR, when applied at 80 microns over **Dulux Durebild STE** at 125 microns, not only offers exceptional anticarbonation and chloride ion resistance, but also provides resistance to defacement by spray can graffiti. This offers a total protection system for all public areas, and is the reason many Vicroads projects are now protected by the **Durebild STE – Weathermax HBR** coating system.

For more information, please contact the Dulux Protective Coatings Technical Consultant in your state.

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[i] "Guide to Concrete Repair and Protection", a joint publication of ACRA, CSIRO and Standards Australia.
[ii] Inadequate concrete cover means that the rebar is placed too close to the surface of the concrete. The lower the concrete cover, the quicker the carbonation front can reach the rebar and the sooner the spalling occurs. Even when a high concrete coverage is specified, it is rarely achieved throughout a building, as the resultant concrete cover can appear perfectly fine unless the steel is actually protruding from the concrete!
[iii] Ibid
[iv] Australian Standard™ AS 3600—2001, "Concrete Structures"