Problems with Concrete - Spalling 1.3.8

What is Spalling?

Spalling is the deterioration of steel reinforced concrete, and is generally 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?

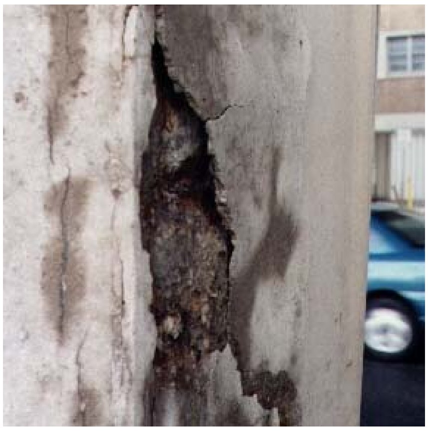
According to the Weekend Australian (July 11-12, 1998) the Institute of Engineers Australia said that this "insidious structural affliction cost Australians over $100 million per year. Given the increase in atmospheric carbon dioxide since then, and recent building design trends towards unpainted concrete,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

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

What Causes Spalling?

There are two unrelated mechanisms that cause concrete spalling, **carbonation** and **incipient anode formation**.[i]

1. Carbonation of Concrete



Mild steel rapidly **oxidises** (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. This corrosion protection lasts as long as the concrete maintains its high alkalinity, which (with diligent building maintenance) can be virtually indefinite.

Unfortunately, concrete is also quite **porous** (even "high strength" concrete), and readily absorbs moisture (H_2O), carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and many other airborne chemicals. These chemicals act as **acids** and **neutralise** the calcium hydroxide, ($Ca(OH)_2$) present in the Portland cement. (In fact, "acid rain" is rainwater in which these acids are dissolved.)

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

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.

As soon as the carbonation front reaches the rebar, the alkalinity at the rebar drops, and the rebar loses its **only protection against oxidation**.

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.

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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 complex molecule of greater molecular weight and volume than the original iron material.

$4Fe$	+	$3O_2$	+	nH_2O	$\rightarrow$	$2Fe_2O_3 \cdot nH_2O$
(Iron)		(Oxygen)		(Water)		(Hydrated iron oxides - "rust")

2. Incipient Anode Formation

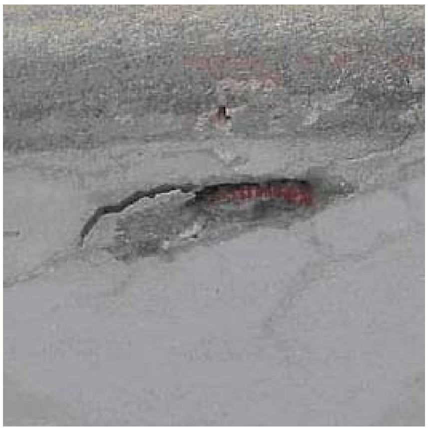
A totally different cause of concrete spalling is often found along the Australian coastline. Coastal air is laden with chloride ions (from seawater salt). As concrete is porous, it readily allows chloride ions to move easily through the concrete matrix and form **incipient anodes** on the surface of 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.

Why reinforce concrete with steel in the first place?

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; they expand and contract with changes in temperature at almost exactly 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.

What Are The Contributors To Concrete Spalling?



Issues that can contribute to concrete cancer 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 surface coating to prevent ingress of carbonation-causing chemicals

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Is All Rust Staining a Sign of Spalling?

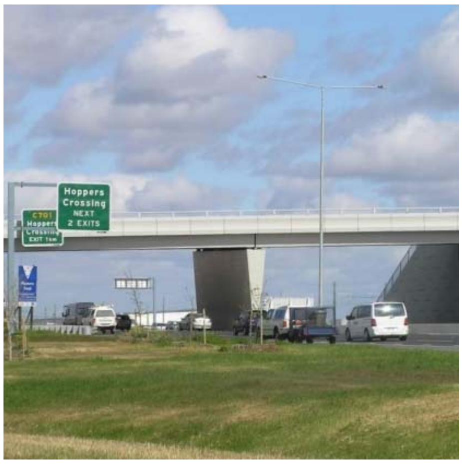
No. Tie wires often find their way to the surface of the concrete, and whilst corrosion of these tie wires do not affect the integrity of the structure, they do look unsightly and rust stains can bleed through most applied finishes.

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 An Applied Coating Work?



An applied 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.

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"