Avoiding efflorescence through design and construction practices

Colin Cass sets out the two main principles for avoiding staining from calcium build-up on external tiling.

It is unfortunate when a finished tile or stone work project becomes disfigured by a build-up of efflorescence. These ugly stains are usually a calcium-based deposit arising from soluble salts within the bedding mortar and elsewhere in the tiling system, which become insoluble when they react with the atmosphere.

The manufacturing, transport and installation of a ceramic tiling or stone system require significant capital investment, technical expertise, design and installation skill. The whole process from raw materials to finished installed product also has a significant environmental output. It is therefore a responsibility of those involved to ensure that their work results in a long-lasting, low-maintenance and serviceable finish. It is a loss to all concerned when what could have been a fine example of finished tile or stone work is disfigured by unsightly efflorescence. Yet this calcification can be almost completely avoided if minor alterations are made in design, workmanship and the use of materials.

"In time, and with water, everything changes."

- Leonardo da Vinci

To help architects, designers, builders, and tile and stone installers understand how to work together to minimise the possibility of efflorescence, this article concentrates on the most common type of soluble salt, where it comes from, and how to prevent it from forming ugly stains on the surface of external tiling.

This paper is not meant to be a scientific exploration of the chemistry behind the formation of various types of efflorescence; rather it aims to be an easy to understand but technically valid guide. It also details procedures for the removal of existing efflorescence. To begin, it is helpful to understand how and why it forms.

Photo 1. *Secondary efflorescence with calcium carbonate forming on the surface of external stair tiling.*

Efflorescence: definition and formation

In the study of chemistry, efflorescence is defined as the process of losing water of hydration from a hydrate; in the construction sector, it is characterised as an accumulation of calcium crystals and/or salts that disfigures the top, edges or underside of masonry structures.

Efflorescence cannot form without water, so the problem is almost always limited to external tiles and bricks exposed to rain. However, salts that cause efflorescence can also come from moisture leaching into the tiling system from elsewhere, such as groundwater, planter boxes, the mixing water or the aggregate. Occasionally, a small amount can emanate from ceramic tiles themselves.

Efflorescence has two main types: primary and secondary. Primary efflorescence occurs as part of the hydration process of cement setting, and tends to appears as a bloom on the surface of newly finished construction work. It is usually easily removed by brushing, or with a weak 5:1 mix of water to phosphoric acid, and tends not to return.

Secondary efflorescence – also known as leaching – occurs only when continuous or cyclical saturation of a cementitious material allows free lime or other salts within the masonry to be dissolved and to migrate to the surface (**Photo 1**). Secondary efflorescence can be very difficult to stop, and may continue to leach out of the masonry for many years. The avoidance tactics described here concern secondary efflorescence.

Efflorescence relating to installation procedures

Most tiles installed around the world are now laid using adhesive. Very often, the adhesive is applied to a cementitious layer of mortar (render or screed) which is used to make the background flat enough for accurate tile installation. The substrate behind this intervening layer is usually masonry or concrete. A relatively high percentage of stone tiles or paving materials are 'wet fixed' directly into a mortar bed. These cementitious bedding materials contain large volumes of a soluble salt, calcium hydroxide (up to 20 per cent of the weight of the cement content), which forms during the manufacture and hydration of the cement.

When exposure conditions are conducive, the calcium hydroxide can be carried by regular but usually intermittent volumes of water to the surface of the tile work, where it reacts with carbon dioxide from the atmosphere to form calcium carbonate when the water evaporates. Calcium hydroxide is not the only soluble salt that causes efflorescence on external ceramic and stone surfaces, but it is the most abundant.

Movement of water through masonry materials

Any entry of rainwater to a building system will obviously follow the path of gravity, finding its way to the lowest point or exit. In walls, water may simply exit at the face or travel down to the floor. If a flooring substrate has a gradient down to an area where there is no outlet, then this area of the tiling screed will become saturated and act as the reservoir for this now salt-laden water. The salt solution will then rise to the surface of the tiling through a process of equilibration, because it is attracted to warmer or dryer atmospheric conditions. As the water evaporates, a calcium build-up will remain. If the tiled area is exposed to sunlight or warm conditions, it can act like a layer of plastic sheeting over an area of damp but seemingly dry concrete. Condensation will form on the undersides of the tiles and the natural movement of the moisture upwards through the tile joints will encourage efflorescence crystal growth along the tile joints and on the surface of the tiles (**Photo 2**).

Preventing efflorescence

It is unlikely that all primary efflorescence can be completely eliminated; this is why it is often regarded as an aesthetic problem and treated as a building maintenance issue. Although secondary efflorescence cannot be completely prevented either, its occurrence can be dramatically reduced through good design and construction practices.

The two key principles for minimising efflorescence are to minimise the entry of water into the tiling system, and to direct water that penetrates the tiling system to a designed outlet.

To minimise efflorescence on external paving, it is necessary to have a positive gradient to designated outlets in the substrate before any membrane and overlaying screed is applied. If the gradient is incorrect, water that finds its way into the mortar will pond on the membrane surface and encourage the formation of efflorescence at that spot.

Principle 1: Minimising entry of water

The entry of water into the tile screed can be minimised by one of three methods: treating the cured tile screed with a liquid waterproofing penetrant that is compatible with both the membrane and the tile adhesive (**Photo 3**); applying a waterproofing membrane both under and over the screed; and/or sealing the surface of the tiles and grout joints with a penetrating water repellent (**Photo 4**).

Liquid waterproofing penetrants are usually a type of methyl silicate or nano-sized mortar additive; such pre-sealers can provide good protection from efflorescence that forms inside some granitic-type stone products without greatly reducing the bond of the stone to mortar or adhesive.

The advantages of treating the screed with a penetrant are that water is prevented from entering the tile bed (unless it cracks); the penetrant is at the underside of the tiles where it is protected from the environment; and its application is quicker and cheaper than a secondary membrane system (detailed below).

Photo 2. *Efflorescence forming where moisture below the impervious tiles rises through cracks in the grout.*

Photo 3. *Concrete treated with a nanotechnology-based sealer repels water. Efficacy with friable mortars such as paving beds is not yet known.*

Photo 4. *The application of a penetrating sealer prevents or minimises water penetration through the tiles and grout.*

The disadvantages are that the system is rigid (so if the screed cracks, water will enter and be re-drawn to the surface by capillary and thermal action, resulting in the formation of efflorescence near the cracks); the porous nature of most tiling screeds limits the effectiveness of penetrating methyl silicate-type products; the process will slow down the tiling process due to the curing time required for the screed and the penetrant; and wet-bed fixing of tiles cannot be undertaken with this method.

The advantages of a waterproofing membrane both under and over the screed (**Figure 1**) are that it excludes moisture from the tile screed, and it is better able to withstand movement and any cracking of the screed (the top membrane act as a crack suppression membrane).

One of the disadvantages is that a double membrane effectively doubles the cost of waterproofing, and the added work will slow down the tiling process because the screed has to be sufficiently dry to avoid failure of the secondary membrane. (Although rapid-curing, low-moisture toppings can overcome this problem). Another disadvantage is that the essential bond breaker/fillet joints in the secondary membrane at the wall/floor junction may interfere with the tiling process and be difficult to install properly, and so tiling may have to finish 5 mm or more from walls. Also, some of the chemicals used may not be compatible with the tile adhesive and the membrane (because of tile adhesive bonding issues, solvent-based polyurethane membranes should not be used as a secondary membrane system). Finally, wet-bed fixing of tiles cannot be used with this method.

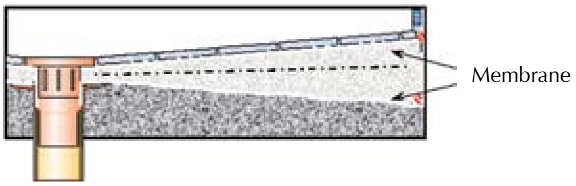
Using only one membrane on top of the screed is acceptable, and will reduce the cost and some of the time delay. However, detailing the bond breaker/fillet joints is critical and difficult because it must occur at the junction of walls and floors and be contained within the thickness of the tile.

The advantages of sealing the surface of the finished tiling and grout joints with a water repellent are that it does not delay the tiling process; it is possible to wet-bed tiles; and it makes the tile and grout more stain-resistant.

The disadvantages are that minor cracks in the grouting will lead to water penetration; water will bead on the surface, which may lessen the slip resistance of the finished surface; and the surface sealer will require periodic re-application.

Most external tiling systems will benefit from the application of a penetrating sealer, but that should not be relied upon as the sole method of minimising efflorescence; it is likely that water will eventually enter through small cracks in the system. To determine when a sealer needs to be reapplied, a few drops of water can be sprinkled on the tile joint; if it is absorbed, it is time to re-seal.

Figure 1. *Waterproofing membrane on top of screed as well as on the substrate.*



Expensive and slow but efflorescence is unlikely. Screed must be dry (< 12% moisture. Do the car mat sweat test) Screed must be reinforced over sheet flooring. Not suitable for polyurethane membranes.

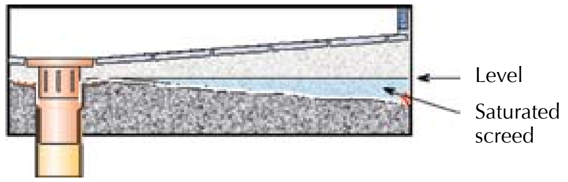
Principle 2: Directing water to an outlet

The second principle for minimising efflorescence is to ensure that any water that penetrates the tiling system is directed to a designed outlet. To enable this, it is imperative that there are positive falls in the substrate before any waterproofing membrane or overlaying screed is applied (**Figures 2** and **3**).

The best method of removing (salt-laden) water that has found its way into the mortar is to allow it to escape at the neck of any drainage grate or sump. In other words, do not seal the grate to the membrane without ensuring that there are weep holes in the side of the grate (**Photo 5**). The capacity of the drain must also be sufficient to allow easy evacuation of surface water, or water may re-enter the bedding system through the weep holes. Be aware that the diameter of the drain may decrease as salts build up in the pipe; this may require periodic maintenance.

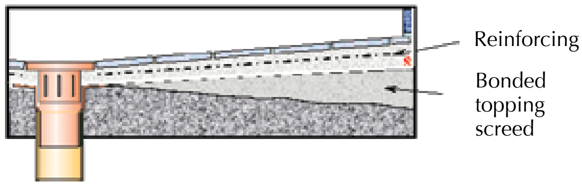
>

Figure 2. *Installing a membrane over a negative gradient in the substrate should be avoided, as efflorescence will almost certainly occur.*



Waterproofing over a substrate that does not drain to the floor waste can cause efflorescence. Constant saturation is to be avoided when using acrylic membranes.

Figure 3. *Tile bedding is drained. The membrane acts as a slip sheet, so a reinforced screed is required.*



Slight chance of efflorescence. Suitable for all membranes.

Photo 5. *When the drain is open at the neck, and there is a gradient in the substrate to the drain, the efflorescence forms down the drain pipe and not on the tiles.*

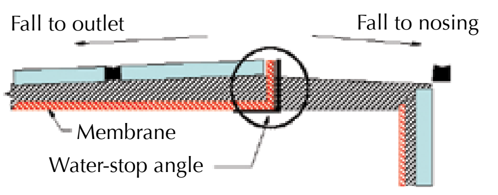
Substrate falls must not be allowed to go to a free edge (**Photo 6**) unless the salt-laden water is collected by a gutter, or the area is not going to be adversely affected by the appearance of efflorescence (such as in a garden bed).

A water-stop angle – usually 90 degree extrusions of metal or plastic, sealed to the surface or incorporated into the waterproofing system – should be fitted at free edges and behind the nosing at the top of stairs, ensuring a positive fall in the substrate from the water stop to the drainage outlet on the deck. The vertical leg of the water-stop angle should finish flush with the surface of the tiling (**Figure 4**) to prevent water that enters the bedding on the deck from escaping over the free edge.

Often on stairs, it is advisable to have a surface gutter run down the side with a drainage cell beneath it. This ensures that the only efflorescence that can form on the risers and treads is from the limited amount of calcium hydroxide available in the stair tiling (**Photo 7**). The drainage cell should be about 200 mm wide and should be laid plastic side up, with no joins at nosings.

Photo 6. *Where the gradient in the substrate leads to a free edge, efflorescence will form on the riser. To avoid this problem, seal a water-stop angle to the floor at the edge or one tile in from the edge, and grade the substrate behind the angle to a drain.*

Figure 4. *Angles can stop the bulk of water in the screed of a deck from exiting over a free edge or down a flight of stairs.*



Waterstop detail for balcony edge or stair top.

Photo 7. *A gutter down the left edge of the stairs, which contains drainage cell material under the stone, will ensure that water from the landing takes that pathway and does not emerge through the stair risers.*

As subterranean water will take the easiest path, in large areas or where large volumes of subterranean water are expected, strips of drainage cell material can be placed on the waterproofing, beneath the screed, to provide for easy movement of the water to the designated outlet (**Photo 8**).

Most of the procedures set out for paving can apply equally to cladding, but the bond strength of multi-layer systems must be satisfactory for the mass of the tiles being used, and it is recommended that tiling above about 3 metres should be on an engineered system. The most important single factor for preventing efflorescence in wall tiling is the prevention of water ingress, usually through a capping system at the top and exposed edges.

Limiting water ingress into both wall and floor tiling systems through properly designed and installed movement control joints is essential. This usually involves surface preparation, priming the edges of the joint, the use of joint backing materials, the provision of recommended width-to-depth ratios for the sealant, and the use of suitable exterior grade

Photo 8. *Drainage cell fabric under the tiling screed makes it easy to direct subterranean water to designated outlets.*

Photo 9. *Efflorescence has formed inside this granitic stone and it is now irremovable. Pre-sealing the back of the stone with a specialist solution could have avoided this problem.*

sealants that do not 'bleed' plasticiser into stone materials. A maintenance schedule for the sealant joints should also be provided.

Removing efflorescence

The following procedure is recommended for removing efflorescence: physically scrape off any build-up by mechanical means (ensure wire brushes have stainless steel bristles); sweep up and dispose of residues; check that acids will not negatively affect the stone or surrounding materials (use a chelating cleaner rather than acid on calcareous stone); if the surface is unaffected by acid, wash it with phosphoric acid mixed with five parts water (more aggressive acids, such as hydrochloric/muriatic, should be used with great care); repeat washing until the stains have dissolved; flush the surface liberally with water, and neutralise with a mild solution of ammonia and water; and then allow to dry and check results.

After cleaning, try to establish how the water entered the mortar behind the tiling, and implement the methods set out above to reduce water ingress. Generally, the minimum treatment required after cleaning is sealing with a penetrating hydrophobic (water-repelling) sealer.

Chelating cleaners, such as those containing ethylenediamine tetra acetic acid (EDTA, which has a pH of 7.4) – although not very aggressive when treating efflorescence on calcareous stone, such as limestone and marble – can render some soluble salts insoluble, thereby limiting the calcium hydroxide available for future release. In cases of severe efflorescence, chelating cleaners will not convert enough salts to make a great difference. In all cases, sealers and cleaning agents should be tried on a small and inconspicuous area first.

It has been reported that the incorporation of Class F fly ash or metakaolin in concrete mixes can lock up significant amounts of calcium hydroxide. This would also be true for friable cement mortars such as those used for floor tiling. Although the use of builder's cement is likely to reduce efflorescence, its slower development of early-age strength must be considered.

The use of non-cementitious, non-efflorescing grouts is considered best practice if efflorescence is likely to occur.

Efflorescence inside the stone

Some igneous stone, particularly absorbent granitic products, can become permanently discoloured when efflorescence crystals form inside voids in the stone (**Photo 9**). The best method to prevent this discolouration is to pre-seal the back and edges of the stone 24 hours before laying. Pre-sealers usually have a potassium methylene siliconate base, which is very different to the silane siloxane base of common penetrating sealers. Unlike normal sealers, pre-sealers will not interfere with the bonding of cement or adhesive to the back of the stone.

Summary

Efflorescence from calcium hydroxide – the main form that disfigures tile work – can be stopped from causing significant and recurring disfigurement by following two easily achievable design and construction rules: limit water entry and control water egress. Water entry to the tiling system can be minimised by binding, waterproofing and sealing, among other options. Without water, the efflorescence cannot form. If some water does penetrate the tiling system, it must be directed to an outlet to ensure that any efflorescence which does form will do so in a predetermined inconspicuous location. This redirection of subterranean water can be achieved by introducing gradients in the substrate, subterranean flow paths through drainage cells in the bedding, and water-stop angles at or near free edges. If these rules are followed, efflorescence can be all but eliminated from the face of finished exterior tile and stone. DS

Colin Cass is a consultant on tiles, stone, waterproofing and efflorescence control through Techtile Consulting Pty Ltd (techtile@gmail.com).

This article is adapted from a paper delivered at Qualicer 2008, the 10th World Congress on Ceramic Tile Quality, in Castellón, Spain, on 11 February.