

# EFFLORESCENCE

## WHAT IS EFFLORESCENCE?

Efflorescence is the formation of salt deposits, usually white, on or near the surface of concrete causing a change in appearance. Apart from the discolouration, efflorescence is generally harmless. This is best described as being 'a skin trouble and not a deep-seated disease'.

Primary efflorescence is efflorescence occurring during hardening of the concrete. Secondary efflorescence is the efflorescence resulting from the weathering of the hardened concrete. Cryptoflorescence is the deposition of salt within the pores of concrete below the exposed surface. The force of crystallisation growth may cause some fretting.

Light coloured concrete shows the deposit much less than darker coloured concrete. With time, efflorescence becomes less extensive. Efflorescence is most obvious in the winter but may be observed throughout the year after a heavy rain and a drop in temperature.



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## HOW EFFLORESCENCE OCCURS

Efflorescence occurs through one or a combination of the following processes.

### Chemical processes

Formation of efflorescence can be the result of a reaction of concrete constituents with carbon dioxide and/or sulphurous gases.

**Carbon dioxide** – Alkalies in the concrete react with carbon dioxide to produce two forms of salts in concrete: sodium and potassium carbonate and calcium carbonate.

Alkalies and calcium hydroxide in solution in the pores migrate to the surface, this migration depends on the permeability, voids and moisture content of the concrete. At the water-air interface, atmospheric carbon dioxide reacts with these hydroxides to form calcium, sodium and potassium carbonate. Penetration of water can cause efflorescence in the same way.

Sodium and potassium carbonates appear on the concrete as a soft white fluff that can be easily removed (although it may appear again). This type of efflorescence usually appears if the concrete has been exposed to wetting and slow drying.

Calcium carbonate appears usually as a white 'bloom' diffused over certain areas. In worst cases it appears as a hard white crust. It is the most troublesome and is difficult to remove. Calcium carbonate efflorescence is likely to form on concrete in which hydration is interrupted by premature drying and which is subsequently wetted.

**Sulphurous gases** – Sulphur dioxide and hydrogen sulphide, under damp conditions, react with the surface layer of the concrete and/or mortar joints in masonry construction forming calcium sulphate crystals. This white insoluble salt is washed onto the concrete or masonry facing after it rains.

In industrial areas, the  $\text{SO}_2$  concentration in the atmosphere could be ten times the average value. Under such high sulphurous atmospheric concentration, it is doubtful that this type of efflorescence can be avoided even with concrete or masonry that is least susceptible.

### Physical processes

The formation of efflorescence depends on a number of physical processes involving both salt and water transfer in and out of concrete or masonry. Specific conditions may dictate the extent to which any of the many processes involved take place and hence may dictate the extent of occurrence of efflorescence.

Various physical processes are described separately although in practice, these are inter-related, thus creating a rather complex mechanism.

**Solubility of salts** – Solubility of a salt (the mass of a given salt that can be dissolved in a fixed mass of water) depends on the properties of the salt and on temperature. The degree of saturation of salts contained in the concrete or masonry at the time of drying out will influence the occurrence of efflorescence.

In some instances when concrete absorbs enough water that the salt is not saturated, efflorescence will not occur. For the same amount of salt, if saturation is reached, efflorescence will occur on drying out.

Also, efflorescence may occur following a drop in temperature, eg as between summer and winter.

Warm water will usually dissolve more of a given salt. If we consider sodium sulphate, 100 parts of water will dissolve nine parts of sodium sulphate crystals at 10°C and more than double this amount (19.4 parts) at 20°C.

Saturation occurs when no more salts can be dissolved in the water. Once saturated, cooling of a given solution will result in some of the salts being deposited in a solid form. On the other hand, at the same temperature, loss of water through evaporation will result in some of the salt being deposited.

**Hygroscopicity (or affinity to water)** – Salts that are hygroscopic are not likely to form efflorescence.

Salts having greater affinity for water can pick up water from the air and therefore, at normal outdoor temperature, they are unlikely to dry and appear as efflorescence. Examples of these are sodium and potassium hydroxide present in portland cement. After carbonation, however, sodium carbonate may appear as efflorescence if not mixed with potassium carbonate which is also hygroscopic.

**Crystal form** – The readiness with which efflorescence forms depends on the shape of the salt crystals that are deposited from solution. This is a complex and difficult field which has not been fully explored. However, it is known that sodium and magnesium salts form efflorescence much more readily than potassium salts.

**Pore structure** – Pore structure of concrete or masonry containing saturated salt solutions influences the drying out and location of salt deposits on evaporation of water. The pore structure as a whole will influence the rate of water transfer



(fast for fine pores and slower for coarse pores). The pore structure at the surface is particularly significant regarding the location in which salts will be deposited. The effect of pore size may explain the appearance of efflorescence on certain areas. These areas are probably fine-pored.

Two distinctly different types of pore structures are considered, fine-pored and coarse-pored. In the case of a fine-pored structure near the face exposed to the evaporating environment the capillary action will draw water towards the surface. Visible deposits of salt crystals tend to occur at the exposed face as evaporation takes place. With a coarse-pored structure (eg open textured masonry), the larger dimension of the pores cause free water to fall below the exposed surface. However, evaporation by diffusion and pore ventilation could take place resulting in crystallisation occurring below the exposed surface, ie crypto efflorescence.

**Water movement** – The degree of water saturation influences the formation of calcium carbonate, on the surface or within the pores of the concrete. Saturated or nearly saturated pores cause carbon dioxide and calcium hydroxide to meet at the surface and calcium carbonate is formed there (visible efflorescence).

When pores are partly saturated with water, the air containing carbon dioxide penetrates the concrete and carbonation takes place within the pores under the surface (visible to a limited degree).

In dried up pores, no carbonation takes place. If water is added later and pores are filled there will be a considerable risk of efflorescence.

## CAUSES OF EFFLORESCENCE

While there is virtual agreement that efflorescence is caused by multiple factors in combination (usually catalyzed by climatic and environmental conditions), views are quite discordant on which factors are the major culprits.

*It is usually impossible to deduce the exact causes of a specific case with absolute certainty.*

### Concrete

Factors related to concrete are:

#### Constituents

- **Cement** – The choice of cement type/make influences efflorescence only in exceptional cases. Pigments in coloured cement and other admixtures added to concrete or mortar may contribute to the potential to efflorescence through their salt content. The inclusion of fly ash and slag can be effective in reducing the occurrence of efflorescence, unless they are high in alkalis and sulphates.
- **Aggregates** – Aggregates contribute to efflorescence if they contain soluble salts. Sand contaminated with salt is a major factor. Sands occurring in close proximity to the sea are an obvious risk. Aggregates containing soluble sulphates, eg some expanded clay and shale and blast furnace slag, can cause efflorescence.
- **Salts** – Soluble salts available in the materials used to make concrete or masonry are capable of being transported and deposited on the surface as efflorescence. The salts are mainly calcium, magnesium, iron and metal sulphates, and chlorides. The typical presence of water-soluble salts in the major constituents is: pigment 0.3%, aggregate 0.3%, water 0.2%, lime (for masonry mortar) 0.7%, cement 2%.
- **Water/Cement** – Generally, a high water-cement ratio results in porous blocks with micro voids becoming interconnected. Such micro structure encourages the movement of water and salt solutions through the block giving rise to the potential to efflorescence.

### Quality

- **Pore Structure** – The higher the absorption capacity of the concrete the higher the potential to effloresce. The absorption capacity is related to the permeability and the porosity of the concrete which, in turn, are functions of the internal pore structure.  
Greater permeability results in water more readily penetrating the concrete. When humidity in the surrounding atmosphere drops, water comes to the surface bringing with it soluble salts from within the concrete pores. Permeability and porosity of the concrete are both related to the internal pore structure. This, in turn, is related to the materials and their proportion and to the effectiveness of the curing of the concrete.  
Moisture content of the concrete influences calcium hydroxide efflorescence. When the concrete is close to saturation, calcium carbonate efflorescence appears on the surface. When the concrete is dry, no efflorescence occurs. Subsequent wetting and drying increases the risk of efflorescence.
- **Variability** – Variability in the quality of the concrete causes localised occurrences of efflorescence. Differences in compaction or curing of the concrete can result in variation in water absorption capacity. At the points where water permeates more easily, salts will be carried to the surface.

### Curing

Curing and curing procedure can be critical to the control of efflorescence. The pre-set period following demoulding and prior to curing is very important. Poorly controlled presetting conditions, eg dry windy conditions will increase the potential of the concrete to effloresce.

Factors related to curing are:

- **Humidity** – Curing in dry air (less than 65% RH) increases the risk of efflorescence.  
(Ref: Samuelsson, *Building Research and Practice*, Jan–Feb 1978.)
- **Temperature** – Temperature is of less significance than humidity. At the same relative humidity, curing at 20°C gives almost the same resistance to efflorescence as when cured at 60°C.

- **Carbon dioxide (concrete products)** – Curing in a carbon dioxide atmosphere may reduce calcium carbonate efflorescence. However, the conditions under which this type of curing is carried out will influence the effectiveness and extent of carbonation. Less than 1% by volume of carbon dioxide in the curing air has no influence on efflorescence. A 5% carbon dioxide content was found to have a remarkable positive effect.
- **Autoclaving (concrete products)** – Autoclaving reduces efflorescence provided that the materials used contain no soluble sulphates. Severe efflorescence may occur in autoclaved units due to soluble sulphates in the aggregates.

### Environment

- **Early exposure** – Exposure of newly-cast concrete to free water (from rain or other sources) increases the risk of efflorescence.
- **Temperature** – Temperature affects efflorescence through its effect on the rate of evaporation. A high rate of evaporation does not necessarily cause efflorescence. It is the slow rate of evaporation which allows migration of salts to the surface.
- **Moisture** – Moisture is the vehicle by which salts are transported to the surface where they accumulate as the water evaporates. Rain-water is the primary source of moisture, it enters concrete or masonry construction through:
  - Permeable concrete or masonry units
  - Partially filled joints
  - Inadequate flashing
  - Cracks and other openings in the wall (high rainfall is more likely to induce efflorescence than dry, arid conditions).Other sources of moisture are vapour from the interior of buildings which accumulates within the wall as it condenses.
- **Ambient conditions** – Efflorescence is usually a seasonal problem, being more intense in winter than in summer. The rate of evaporation under summer conditions may be very high so the moisture is evaporated within the concrete and the salts are deposited within rather than on the surface of the concrete. In cooler weather the evaporation rate is slower, allowing moisture to move to the surface before evaporating and leaving salt deposits on the surface.

- **External sources of salt** – Usually, occurrence of efflorescence is reduced and probably stopped with time unless there is an external source of salt.

- *In soils* – In general, soils are considered one of the most prolific external sources of salts. Salts can be found in soil and ground-water, naturally occurring or due to industrial effluents. Moisture rise and subsequent efflorescence can be seen in concrete in contact with soil or similar materials containing salts.
- *In service* – Many industrial processes are potential sources of salts which can be transferred to the concrete in water or water vapour. There is a greater risk of efflorescence if the polluted water vapour is condensing on or within the concrete. Storing of chemical materials in buildings can be a potential source of salts, eg fertilizers. Accidental (but a significant) source of salts is leakage from services, for example waste pipes.
- *External sources of salt in the atmosphere* – The two major acid gases, carbon dioxide and sulphur dioxide increase the risk of efflorescence. Industrial fumes are frequently laden with sulphurous gases which can cause efflorescence. Salts derived from fuel burning are also of significance. Salts derived from sea spray can cause efflorescence on facades of buildings close to sea.
- *In cleaning chemicals* – Certain chemical compositions used for daily or regular cleaning of buildings or during maintenance may constitute accidental sources of soluble salts. Cleaning agents regarded as potential sources of salts are caustic soda, washing soda, soda ash, household scouring powders and some organic detergents.

### **Mortar**

Efflorescence in mortar for masonry work is influenced by factors relating to:

- **Constituents** – The composition of mortar is of significance. The use of unhydrated or partly hydrated lime, the use of unwashed sand or sand contaminated with salt, the use of pigments containing soluble salts, the use of cement high in alkalies can contribute to efflorescence in masonry work.

- **Quality** – Porous mortars with high water absorption capacity are more prone to efflorescence. The use of mortars that are highly non-porous compared to the masonry units causes efflorescence to occur on the units.

### **Field practices**

The following practices may cause efflorescence:

- No protection from rain to unfinished concrete (particularly walls) during construction
- Masonry units piled at the building site with no protection from rain
- Inadequate roof flashing
- Lack of drips on cornices and sills
- Leaky gutters and down-pipes
- Poorly filled mortar joints (bad workmanship or unworkable mortar)
- No damp-proof courses.

### **PREVENTION OF EFFLORESCENCE**

Prevention and/or control of efflorescence can be achieved by one or more of the following:

#### **Selection of materials for making concrete or mortar**

Use of ingredients with least possible soluble salts.

Use of integral waterproofing agents may be of advantage. However, some types of waterproofing agents may cause efflorescence themselves, eg water-soluble soaps or water-soluble alkali silicates. Waterproofing agents based on esters of fatty acids can be effective without interfering with the hydration process.

A simple remedy appears to be making richer and denser concrete. However, this may increase the risk of shrinkage and would in case of masonry affect the texture.

Use of cement:lime:sand mixes to produce mortars no stronger or denser than necessary. Such mortar would have high plasticity, greater bond with masonry and possibly low soluble salt content. If the mortar is dense, drying out at the mortar joints will be either prevented or restricted. Drying out of the wall therefore takes place mostly through the masonry. Thus efflorescence tends to appear mostly on the masonry.

Use of ingredients free of or containing minimum quantities of salt. Lime used should be hydrated lime free from calcium sulphate.

Use of tools, mixers, and boards that are clean, free of rust, salt or other harmful materials.

### Curing of concrete

Premature drying should be avoided. Concrete should not be exposed to wind or high temperature immediately after casting.

To ensure good curing, the relative humidity of the concrete should be kept high. However, for masonry units if the relative humidity in the curing chambers reaches 100% and condensation occurs, problems with efflorescence may result. This could be in the form of a general lightening in colour or else occur as spots or runs corresponding to areas where condensation has taken place.

When units are in the steam-curing chambers awaiting steaming, the use of humidifying sprays or other means of keeping the chamber saturated should be considered.

Steam curing will help to reduce efflorescence, particularly if pozzolans are present in the mix because of the reduction in the amount of calcium hydroxide present in the hardened concrete. The temperature adopted will affect the results obtained. Experiments by CSIRO showed that the formation of calcium hydroxide during hydration of the cement is suppressed in steam at 185°C.

### Surface treatment

Treatment of newly finished concrete, before being subjected to wetting, with water-repellent materials will reduce the tendency to effloresce. Such application may prevent efflorescence for several years. The exact time will depend largely on the density of the concrete and the adequacy of curing.

Silicones may be suitable for this purpose. They are used either in solution in volatile organic solvents or dissolved in water as alkali silicates. When applied to the completed walls, they do not change the colour or the texture.

*WARNING: Use of a surface treatment may cause problems. Localised accumulation of salts and their crystallisation beneath the treated surface may cause surface spalling or flaking. Particularly in porous and soft masonry units.*



### Control of moisture

The golden rule is KEEP WATER OUT.

Masonry units delivered on building sites should be kept dry, eg covered by polythene sheeting. They should not be stored on wet soil where moisture movement could cause rising damp, especially if stored for a long time. When stacked, they should allow air circulation.

Proper attention should be given to design detailing for correct installation of waterstops, flashings and copings to prevent entry of water.

During construction, the top course of masonry should be covered at the completion of each day's work, particularly when rain is expected.

All mortar joints, especially those exposed to the weather, should be tooled with a V or concave-shaped joiner to compact the mortar at the exposed surface.

If architecturally acceptable, wide overhanging roofs should be used to protect the walls from rainfall.

Installation of lawn sprinklers, or any other water sources, should be planned so that walls are not subjected to unnecessary wetting.

## REMOVAL OF EFFLORESCENCE

When efflorescence is associated with abnormal wetting of the concrete, such as from faulty drains, it is necessary to correct those faults before attempting to remove efflorescence.

### Soluble salt deposit

Many of these deposits can be removed by stiff-bristled brush, especially if this is undertaken soon after deposition. Brushed-off material should be totally removed by vacuum cleaning or other means.

If dry brushing is not effective, washing with water in conjunction with further brushing should be tried.

*WARNING: Washing with water may result in salt deposits appearing again as the washing water evaporates. Repeated dry brushing as the deposits appear is likely to be the most successful treatment.*

### Insoluble salt deposit

The hard, white, scaly or crusted deposits cannot be removed by water washing. High pressure water jet is effective, sometimes augmented with the addition of fine sand to the water. Light sand blasting, where it can be used with care may be quite effective.

*WARNING: Sand blasting may change the texture of the concrete, in the case of coloured concrete it may cause colour variation. It may therefore be necessary to treat the entire wall area.*

The controlled application of diluted acid is effective in most cases. In some cases such as calcium carbonate efflorescence, it may be the only way.

*WARNING: Washing with acid may alter the texture of the wall and/or cause discolouration. Treatment of the entire wall may be required to avoid such effects.*

The acid usually recommended is hydrochloric acid, diluted one part of acid to 10 or 20 parts of water. The normal procedure is to wash or brush the area affected with a diluted acid followed by good rinsing with water.

For coloured concrete, a more diluted acid solution may be required, 2% acid is suggested (1 part of acid to 50 parts of water).

If the surface is to be painted, it should be neutralised by washing with a 10% solution of ammonia or potassium hydroxide or allowed to weather for one month.

Precautions that should be taken when working with acid:

- The surface to be treated should be thoroughly wetted with water so that the acid does not penetrate too deeply.
- The acid solution should be tested on a part of the wall that is not readily seen, to make sure of no adverse effects.
- Acid should always be added to the water and not water to acid.
- Protective clothing should be worn by workers.
- Metal tools, brushes, or containers should not be used. Plastic containers and tools are suitable.
- Run-off into drains should be washed away completely by leaving fresh water running through the drains for about 10 minutes.

In general, washing with acid appears to be successful in most cases. Generally a 5% solution hydrochloric acid or a proprietary acid-based concrete cleaner is used. The acid concentration can be adjusted to suit individual cases. A less concentrated solution will require more applications to remove hard crusted salt deposits and will be less likely to result in an acid-etched appearance.

## TESTING FOR SUSCEPTIBILITY TO EFFLORESCENCE

Tests for assessing the tendency to effloresce include:

- A qualitative test, known as the puddle test, can be carried out on both fresh and hardened concrete. Discoloration appearing after water dries up gives an indication of the resistance to efflorescence. The test involves applying a puddle of distilled water to the surface of the concrete. After the water has evaporated the surface of the concrete is visually assessed for the formation of efflorescence. The length of time for which water stays on the surface will influence the conclusion drawn. The longer the time, the more calcium hydroxide can reach the surface. Water stays longer if the water-cement ratio is low or the test is carried out in humid air.
- Quantitative test involving extraction of lime by de-ionised water. This is an improvement on the puddle test as it is possible to control the extraction time. The test was developed by the R&D section of the Swedish firm Cements AB and reported by Samuelsson in *Building Research and Practice*, January-February 1978. The test involves controlled dripping of distilled water – 1 litre of water to drip for 16 h on the surface of the specimen. The run-off water is

collected at the end of a 24-hour period and was analysed chemically for calcium, sodium and potassium salts.

The effects of different factors on efflorescence were investigated using this method. It was found that the minimum quantity of lime (expressed as CaO) necessary to cause efflorescence (visible discolouration) was of the order of 1g/cm<sup>2</sup>.

- A Standard Test in ASTM C67 *Standard Methods of Sampling and Testing Brick and Structural Clay Tile*, the test for efflorescence involves partial immersion of representative samples (full sized samples) in distilled water for a period of 7 days in a drying room. At the end of this period the units are visually examined for efflorescence and compared to control samples that were in the same drying room but without contact with water.

#### **FURTHER INFORMATION**

Further information on good concreting practices can be downloaded from the Cement Concrete & Aggregates Australia website at [www.concrete.net.au](http://www.concrete.net.au).

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