Construction Materials

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Formation of lime efflorescence on concrete and concrete products

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Summary

Many specialists from all over the world occupied themselves with the problem of efflorescence formation on concrete and on concrete products. This problem is nearly as old as the concrete itself. The fact that to this very day, the problems of efflorescence formation course and of formed efflorescence elimination is not yet clearly defined up to now, shows how extensive and difficult is this task. This paper concerns the problems of efflorescence formation on concrete and concrete products depending on some conditions to which the concrete is exposed.

KEY WORDS: concrete, concrete product, lime efflorescence, primary, secondary

1. INTRODUCTION

Is the efflorescence on the surface of concrete the demonstration of its degradation? This form of degradation is in contrast with the sulphate corrosion or with other forms of corrosion not dangerous in light of structural properties and the efflorescence has not major effect on the durability of concrete structures. Nevertheless the efflorescence which occurs on the surface of concrete products mostly in the form of white "spots" or layers is an aesthetic defect which can significantly influence the quality of concrete soffit products.

The efflorescence consists from inorganic salts or hydroxides which are leached out from concrete (from the cement stone or from the aggregate). The hydrous solution of these salts is transported by the system of capillary tubes in concrete. It evaporates on the surface of the concrete and reacts with atmospheric CO_2 or SO_2 (produced in a high degree by the industrial production). The efflorescence is formed largely in the form of salts (chiefly as sodium, potassium and mainly as calcium sulphates or carbonates). The main component is as a rule $CaCO_3$. The occurrence of efflorescence is typical on the surface of concrete alternately soaked and dried or exposed to the action of pressure water. Less frequent factors of efflorescence formation on concrete surface are:

- The proportion of individual concrete components and their total concentration in the bearing hydrous solution,
- The relative air humidity in the surrounding atmosphere (φ [%]). It depends on the solubility degree of individual components and on RH whether the given

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salts crystallize in the pores or on the surface of the material. The crystallization in pores is one of the building materials significant destruction factors [1, 2, 3].

2. LIME EFFLORESCENCE

It is formed by calcium carbonate ($CaCO_3$) which is formed by the action of atmospheric carbon dioxide (CO_2) in humid medium on calcium hydroxide ($Ca[OH]_2$) liberated during maturing (hydration) of concrete [3].

2.1. Primary lime efflorescence

The primary lime efflorescence is formed only for a limited period from the concrete or concrete products production by the reaction of calcium hydroxide (this is the component of both, the hardened concrete and the hardened lime mortar) with the atmospheric CO_2 under moisture, in the surface layers of concrete products.

2.2. Secondary lime efflorescence

The secondary lime efflorescence is formed during the whole service life of concrete by reaction of the calcium hydroxide leached out on the surface of products with the atmospheric carbon dioxide under presence of moisture. By the effect of atmospheric CO_2 the in water insoluble calcium carbonate is transformed after a longer period in the in water soluble calcium hydrogen carbonate $Ca[HCO_3]_2$. The secondary efflorescence does not in contrast to the primary efflorescence form only lighter spots on the surface of concrete but it constitutes on the surface crystalline substance, which dusts off as removable dust.

Consequently, after this transformation of the calcium carbonate the lime efflorescence disappears. The time of calcium carbonate conversion into calcium hydrogen carbonate is approximately 1,5 till 3 years (in dependence on internal and outer conditions, first of all on climatic effects) [2, 3].

3. MECHANISMS INFLUENCING FORMATION OF LIME EFFLUESCENCE

The frequency of lime efflorescence formation on concrete depends on many variables. These are first of all the water content (w and φ) and the content of the atmospheric CO_2 [3]. It is necessary to mention that no less than from 75 % the formation of all efflorescence on concrete is caused by the "lack of technological discipline" in the production and the remaining 25 % is the result of the concrete components chemistry.

3.1. The main conditions supporting the formation of lime efflorescence on concrete:

- The high w/c ratio,
- Temperature,
- Porosity,
- Improper admixtures,
- Mixing and compacting conditions,
- Additives,
- Water tightness,
- Treatment conditions,
- Capillarity,
- Content of free lime,
- Proportion of cement and aggregate in concrete,
- CO_2 content in the atmosphere,
- Time of products storing,
- Type of construction,
- The storing of products [1,2,3].

4. MEASURES ELIMINATING THE FORMATION OF LIME EFFLORESCENCE IN THE PRODUCTION

4.1. Measures and methods limiting the efflorescence formation used in production

- Elimination or limiting of causes mentioned in chapter 3.1,
- Utilization of additives which contribute to following possible effects:
  - Interruption of capillary tubes and on this way the undesirable mass transfer,
  - Increase of water tightness, waterproofing of capillary pores,
  - Chemical fixing of lime to insoluble product [3].

4.2. Means and methods removing the already formed efflorescence

As a rule the lime efflorescence can be removed sufficiently mechanically, for instance by sweeping it up. Also special means can be used. The concentrated preparation is diluted with water and after the concrete surface was saturated with water and the superfluous water was removed, the diluted preparation is applied on the surface of the product by means of a brush or sponge.

After the efflorescence is dissolved the surface is washed down with water. If it is not possible to remove the lime efflorescence by one of readily available products, it is possible to apply a special procedure.

One can use for instance the 3% solution of hydrochloric acid, phosphoric acid or the solution of some organic acid (for instance acetic acid or oxalic acid etc.). It is necessary to take into account that in the case of lime efflorescence dissolution with acids the shade of concrete products colour and the structure of the surface can change, because the acids attack and disintegrate together with the efflorescence also the cement stone [1, 3].

5. EXPERIMENTAL MEASUREMENTS

5.1. Division of experimental works

Considering the fact, that the formation of efflorescence is influenced by quite a number of factors, the most important effects were selected for testing, namely the general effect of the surroundings and of the concrete composition.

5.1.1. Determination of efflorescence formation conditions

The aim was the laboratory testing of concrete samples of concrete with exactly defined variant composition, exposed to different types of surroundings.

5.1.2. Determination of concrete composition on the formation of the efflorescence

Test pieces with exactly defined proportion of concrete components were prepared in this phase. The test pieces were tested consequently for the dependence of lime efflorescence formation on the type of used concrete, on the method of concrete compacting during the production of these test pieces, on the proportion of cement and aggregate and on the value of w/c ratio.

5.1.3. Efflorescence formation conditions in relation to concrete composition

The aim was to make test pieces with the constant w/c ratio and with variable proportion between cement and aggregate and to expose it to different types of surroundings.

5.2. Methods of testing

5.2.1. Determination of the conditions for efflorescence formation

The made concrete prisms were stored in following surroundings:
- Water bath (t = 20 ± 2°C),
- Laboratory surroundings (t = 20 ± 2°C, RH = 40 – 60 %),
- Air tight chamber with 98 % of CO_2 concentration,
- Hot air drier (t = 50°C),

The influence of these surroundings was monitored on the formation of efflorescence. The extent of concrete surface coverage with efflorescence was determined and evaluated by optical microscopy and its mineralogical composition was detected by means of X-ray diffraction analysis.

5.2.2. Determination of the concrete composition influence on the formation of efflorescence

The made test pieces were exposed to surroundings in which the most efflorescence was formed during the preceding phase and the effect of the concrete composition was described on the efflorescence formation at varying:
- Kind of cement (locality),
- Way of concrete compacting,
- Proportion of cement and aggregate,
- Water-cement ratio.

5.2.3. Determination of efflorescence formation conditions in dependence on the concrete composition

The prepared concrete prisms with the cement and aggregate proportion 1:5 or 1:6 were placed into following surroundings:
- Climatic chamber – for 24 hours, temperature 28°C and RH 95 %,
- Normal atmospheric surroundings (outdoor) – for the period of 24 hours,
- Drier – for the period of 6 hours, temperature 60°C.

The effect of climatic conditions on the formation of efflorescence was subsequently monitored on these test pieces and the results were compared with results obtained in the phase I (article 5.2.1.)

5.3. Results of individual phases of work

5.3.1. Determination of efflorescence formation conditions

All efflorescence which arises on the test pieces during this work is so-called primary efflorescence. This is formed only during the limited period from the

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concrete or concrete products production by the reaction of calcium hydroxide with atmospheric CO_2 in humidity on surface layers of concrete products.

The secondary efflorescence is formed by the effect of atmospheric CO_2 and it is transferred after longer period from the in water insoluble $CaCO_3$ into in water soluble calcium hydrogen carbonate Ca $[HCO_3]_2$. This process lasts longer time.

The test pieces made from the cement CEM I 42,5 R from the cement plant Mokrá, and from the aggregate Bratčice with constant proportion of cement and aggregate 1:3 and with the water-cement ratio w = 0.5 with vibration and by manual stamping. The test pieces were exposed for 28 days to individual surroundings and we can state that:

- The formation of efflorescence does not take place in surroundings with fluctuating pressure and relative air humidity with the temperature 50°C and higher,
- In laboratory surroundings at t = 20 ± 2°C, constant atmospheric pressure and in relative air humidity varying from 40 to 60% the efflorescence is admittedly formed but not so quickly as in the water medium with the temperature t = 20 ± 2°C. On the other hand the efflorescence which was already on the surface of the test pieces before they were placed into this surroundings increased moderately their volume,
- In the chamber with constant atmospheric pressure and the temperature t=20±2°C with the content of 98% of CO_2 is the efflorescence formed only in small quantity, but when we have put into the chamber a sample which already contained on the surface efflorescence the efflorescence quantity increased (volumetrically, no the surface area),
- Unambiguously the most favourable conditions for the formation of efflorescence is the aqueous medium with the temperature of t = 20 ± 2°C. In this medium even after 14 days of storing always new efflorescence was formed while in other media the growth of it was stagnating,
- The most important factor influencing the formation of efflorescence is besides the temperature of surroundings the value of the relative humidity (RH) and the rate of air circulation,
- Quick overlapping of the surface with efflorescence takes place after placing the prisms in the chamber with elevated concentration of CO_2 but in a definite moment the formation of new efflorescence stops. The elevated CO_2 concentration in the atmosphere results in the closing of pores on the surface by the formed efflorescence and in the stagnation of its further formation,
- We observed the rapid increase of efflorescence after placing the concrete into water bath at the temperature t = 20 ± 2°C for the period of at least 28 days,
- When we have taken out the samples from the water storing after 28 days, have removed the efflorescence and placed the samples once more into this surroundings, the growth of efflorescence did not start again.

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5.3.2. Determination of the concrete composition influence on the formation of efflorescence

- We can state that the intensity of efflorescence formation is not direct proportional to the increasing value of water ratio, i.e. the value of water ratio doesn't affect the size of efflorescence formation,
- We can further state that with the increasing proportion of cement and aggregate the intensity of efflorescence growth increases,
- The type of cement has an effect on the formation of efflorescence. The intensity of concrete surface coating with efflorescence was in our case with both types of cements nearly identical but in some cases we observed still a higher intensity of efflorescence formation in the case of concrete made from cement CEM I 42.5 R from the cement plant Mokrá. The contributing case can be the higher content of CaO in the cement CEM I 42.5 R Mokrá in comparison with the cement CEM I 42.5 R from the cement plant Hranice,
- The way of compacting in the concrete manufacture can have a significant influence on the formation of efflorescence. The efflorescence during water storage was formed practically on all samples, naturally the concrete compacted by vibro-pressing was much more resistant against the formation of efflorescence in comparison with concrete made only by ramming.

5.3.3. Determination of efflorescence formation conditions in dependence on the concrete composition

The test was carried out in laboratory conditions to precise the hypothesis concerning the efflorescence formation in hot air driers which is connected with the velocity of surface desiccation and with the water vapour diffusion. Two sets of prisms with different ratio of cement and aggregate were placed into the hot air drier, in the damping box and in the laboratory surroundings.

- In the phase I more efflorescence was formed on the concrete surface in the case of the cement : aggregate proportion 1,5 contrary to the proportion 1:6,
- The main effort was of course to describe the processes in the hot air drier during the period of 24 hours since the placing of samples. The rapid desiccation of concrete during the first 8 hours caused intensive formation of efflorescence. Of course the surface of concrete is after 24 hours practically without efflorescence,
- The obtained efflorescence was submitted to X-ray diffraction analysis, which confirmed the similarity of efflorescence concerning the mineralogical composition. In cements of CEM I 42.5 R type from both the cement plant Mokrá and the cement plant Hranice the prevailing mineral component in efflorescence is calcite.

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6. CONCLUSION

We can state following the theoretical analyses and practical realized tests that the less favourable atmospheric conditions under which the formation of efflorescence takes place in a high degree are the temperatures 0 – 5°C in the morning hours of autumn months. The period of fresh concrete products storing has no effect on the quantity of efflorescence, it is rather the measure against their formation which can be easily realized in every manufacturing plant or during the production.

The first condition for the minimization of the lime efflorescence formation is the dosing of optimal batch water quantity for perfect hydration and for achieving of concrete high compactness with small rate of absorption. This can be achieved by the addition of adequate additives and admixtures.

It is further necessary to prevent during the hardening of concrete both its desiccation and the water condensation on its surface owing to the cold surrounding atmosphere. This can be achieved by the use of so-called maturing chambers during the hardening of concrete products. The type of the used cement with different chemical and mineralogical compositions can affect the formation of possible lime efflorescence. The tests which we have performed verified the influence of some variables on the possibility of lime efflorescence formation on concrete. It is necessary to remember that the efflorescence formation is influenced by a number of further factors which could not be included into this work.

The further development in this area should be directed towards the deeper understanding of the efflorescence formation reasons under the effect of further outer factors. This research should help to prevent or at least to minimize the formation of efflorescence on concrete and in this way to increase the esthetic value of concrete.

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