Brickwork Chemical Corrosion Features

D Yu Zheldakov

1Research Institute of Building Physics of RAACS, 21, Lokomotivny Passage, 127238, Moscow, Russian Federation

E-mail: djeld@mail.ru

Abstract. The use of multilayer enclosing structures in modern construction poses a new task of studying the mutual influence of all materials of multilayer structures on the durability of the structure as a whole. Masonry is the oldest and most representative multi-component envelopes. This work is devoted to the study of the processes of chemical destruction, taking into account the mutual influence of building ceramics (clay bricks) and cement-sand mortar.

The article deals with the main process of destruction of materials, based on the destruction of the amorphous part of the brick under the influence of calcium hydroxide, penetrating into the brick of cement-sand mortar, where it is produced in the process of dehydration of calcium silicates and aluminosilicates (leaching reaction). We consider the side processes of the first type, taking into account the presence in the amorphous phase of brick oxides of alkali and alkali-earth metals.

1. Introduction

The [1] shows the results of field studies of the brickwork destruction in different climate regions: in Moscow, Russia with a severely continental climate and cold winters and in Siena and Bologna, Tuscany and Emilia-Romagna regions (Italy) of mild Mediterranean climate with 365 days without frost (below zero degrees). The research data analysis led to the following conclusions:

1. The traditional approach to determine the material durability basing on the freeze-thaw number limit does not explain such phenomena as point destruction in equal positive temperature conditions of some masonry bricks, when their neighbors remain intact. The durability of any material, especially of the walling one, used with other materials, is determined by the principles of physical chemistry, describing the material chemical corrosion. At the same time, the influence of the freeze-thaw, as well as the climatic effect on the walling, is not completely denied, but these processes should be considered as secondary, accelerating or slowing the material destruction.

2. The traditional design of walling durability basing on material frost resistance grade compliance is not correct, since it is mainly based on the visual control of the test sample.

It happens that some experts calculate the service life of bricks, concrete, and even mineral wool, using the material frost resistance grade. Fully supporting the need of the material frost resistance study, I fully believe that using of material frost resistance grade to determine its durability cannot give any reliable results [2].

3. The global energy saving policy urges the construction industry to use multi-layer walling requiring strategic review of walling materials durability calculating. This is primarily due to the need to take into account the materials interaction during the chemical corrosion. All materials used for the
construction and contacting interact at the level of ion-exchange chemical reactions and sorption processes. The wet interface is a prerequisite for building materials interaction.

2. **Analytical Investigation**

Brickwork, as a system of "ceramics – cement-sand mortar" is the most typical case of two walling materials interaction. Processes similar to those described in the present work also take place, or even to a greater extent, in multi-layer walling, such as gas-concrete or LECA blocks with an outer layer of facing brick and other walling.

Let us consider the main reactions in the system of two building materials: cement-sand mortar with portland cement as binder and red solid loam brick. Let us assume that the initial condition is water presence in brickwork. Water can be in any state.

The starting reaction in the system in question will be the dissolution of calcium oxide and its transition to calcium hydroxide.

The calcium hydroxide in the system under study will be formed via three different schemes:

I. With hydration of free calcium oxide in cement-sand mortar [3-6];

II. With hydration of free calcium oxide present in the amorphous part of the brick.

This process is described by the simplest reaction.

\[ \text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \quad (1) \]

Calcium hydroxide is strong alkali. Its solubility in water at a temperature of 25°C is 1.18 g/l.

Firstly, the free calcium oxide contained in the hardened cement stone migrates into the solution, and then the associated CaO from hydrosilicates and calcium hydroaluminates forming the structure of portland cement.

III. According to scheme (I), the calcium hydroxide is formed in the cement-sand mortar in the first place. Further, after reducing the concentration of Ca(OH)_2 in the solution, with hydrolysis the calcium hydroxide is released from hydrosilicates, hydroaluminates and calcium hydroaluminoferrites, which form the core of the cement stone. These reactions are named “leaching of cement stone”, and the conditions of these reactions are well studied and described in the fundamental works of leading Soviet and Russian scientists [3]. The least resistant are hydrosilicates, hydroaluminates and calcium hydroaluminoferrites with a high content of calcium oxide in the molecule, which dehydrate when the concentration of calcium hydroxide in solution decreases, thereby maintaining the maximum concentration of Ca(OH)_2 in the solution.

At the second stage of the brickwork destruction, calcium hydroxide formed according to schemes I to III will react with substances of the brick amorphous part, and firstly with silicon, aluminum oxides and metakaolin [7-10]. The author carried out thermodynamic calculations of the probability of 42 reactions involving calcium hydroxide.

With silicon oxide, reaction (2) with the formation of wollastonite is the most probable from the thermodynamic point of view.

\[ \text{Ca(OH)}_2 + \text{SiO}_2 \rightarrow \text{CaSiO}_3 + \text{H}_2\text{O} \quad (2) \]

Between the considered reactions of calcium hydroxide with aluminum oxide, the most thermodynamically probable reaction is (3) with the formation of calcium meta-aluminate.

\[ \text{Ca(OH)}_2 + \text{Al}_2\text{O}_3 \rightarrow \text{CaO*Al}_2\text{O}_3 + \text{H}_2\text{O} \quad (3) \]

In metakaolin, aluminum acts as cation of the silicic acid salt (aluminum pyrosilicate) [10-13]. The most probable reaction from a thermodynamic point of view is the wollastonite formation

\[ 2\text{Ca(OH)}_2 + \text{Al}_2\text{Si}_3\text{O}_7 + \text{H}_2\text{O} \rightarrow 2\text{CaSiO}_3 + 2\text{Al(OH)}_3 \quad (4) \]

The same is true to the xonotlite formation

\[ 6\text{Ca(OH)}_2 + \text{Al}_2\text{Si}_2\text{O}_7 \rightarrow 2\text{Ca}_3\text{SiO}_5 + 2\text{Al(OH)}_3 + 3\text{H}_2\text{O} \quad (5) \]
Further, aluminum hydroxide can dehydrate to aluminum oxide through the following reactions.

$$\text{Al(OH)}_3 \rightarrow \text{AlO(OH)} + \text{H}_2\text{O} \quad (6)$$

$$\text{AlO(OH)} \rightarrow \text{Al}_2\text{O}_3 + \text{H}_2\text{O} \quad (7)$$

The aluminum hydrates formation is also possible: bauxites (8) and gibbsites (9)

$$\text{Al}_2\text{O}_3 + 2\text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3\,*2\text{H}_2\text{O} \quad (8)$$

$$\text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3\,*3\text{H}_2\text{O} \quad (9)$$

Thus, a schematic diagram of the main process of chemical destruction of building ceramics in a brick-mortar system will be described at the first stage by calcium hydroxide formation via three possible schemes and at the second stage by reactions (2) to (5).

For a more complete study of the chemical decomposition of building ceramics, it is necessary to consider possible side reactions [14-18]. In accordance with the classification of chemical processes in multilayer walling described in [1], side reactions of the first type (not the main reactions) are possible between two materials only with impurities presence in one of them.

Such impurities, in the first place, are impurities of alkaline metals K$^+$ and Na$^+$ and alkali-earth metal Mg$^{2+}$. These metals can be contained in the brick crystal part, or as oxides - in the amorphous part.

The alkalies are formed with reactions similar to (1). Further, the formed alkalies will react with silicon oxides and aluminum of the amorphous part of the brick, as well as with metakaolin. At present, thermodynamic calculations of 50 possible reactions of potassium, sodium and magnesium alkalies with oxides of aluminum, silicon and metakaolin were performed. Calculations show that the following reactions are thermodynamically most probable:

$$2\text{NaOH} + 3\text{SiO}_2 \rightarrow \text{Na}_2\text{Si}_3\text{O}_7 + \text{H}_2\text{O} \quad (10)$$

$$4\text{NaOH} + 3\text{Al}_2\text{Si}_3\text{O}_7 + 7\text{H}_2\text{O} \rightarrow 2\text{Na}_2\text{Si}_3\text{O}_7 + 6\text{Al(OH)}_3 \quad (11)$$

Alkalies reactions with aluminum oxide are less thermodynamically probable than with silicon oxide. Some reactions were not considered due to the lack of standard thermodynamic characteristics.

Thermodynamic methods of chemical physics are evaluative for general process understanding. To confirm the correctness of the thermodynamic evaluation, numerous instrumental studies of the process were performed. The experiment results will be briefly described in this article.

The phase and elemental composition of the initial sample satisfied the experimental conditions: The amorphous phase was 20% of the sample; the elemental composition included calcium, sodium and magnesium in addition to silicon, aluminum, iron and calcium.

According to the results of the study of the prepared systems, before and after interaction with calcium hydroxide, a change in the phase composition of the system was recorded. These changes were recorded only in systems with a high concentration of calcium hydroxide. It can be seen that the new substances are formed when calcium hydroxide interacts with the amorphous part of the brick sample. The crystalline part composition change is negligible.

According to the results of differential thermal analysis of systems before and after interaction with calcium hydroxide, the following conclusions can be drawn:

1. As a result of the interaction of the brick sample with calcium hydroxide, a new substance is formed. This fully confirms the scientific hypothesis on the interaction of calcium hydroxide with the amorphous part of the brick structure, and also completely correlates with the results of the structural analysis of the system.

2. The new substance is formed as a result of an endothermic reaction at temperatures of 720°C to 780°C. When comparing with standard thermal effects of reactions, it can be determined that the resulting reaction substance can be gyrolite, hydrosilicates and calcium hydroaluminates.
3. Summary and Conclusions
1. The brick chemical destruction schema was developed when considering a chemical system “loam brick - cement-sand mortar” as a whole. This schema allows us to explain the brick destruction at positive temperatures, as well as other destruction processes, which cannot be explained by the frost impact.

2. Chemical reactions involved in the destruction are supported by calculations using the methods of chemical thermodynamics. Experimental destruction studies have fully confirmed the conclusions based on the thermodynamic calculations.

3. The main conclusion of this study is that the durability of modern multilayer walling should be evaluated taking into account the chemical destruction versus all walling materials interaction, but not via item-by-item approach.

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