Method for Calculating the Durability of Bricklaying Materials Based on Chemical Corrosion Processes

D Zheldakov¹, N Sosnovskiy²
1NIISF RAASN, 127238 Moscow, Russia
2NRU MGSU, 129337 Moscow, Russia
E-mail: djeld@mail.ru

Abstract. Estimation of the durability of building ceramics is an important applied task. Especially difficult is an analysis of multi-layer building enclosures because of potential interactions of their component parts. Durability of building ceramics is in need of additional research. In this article, the method of evaluation of chemical resistance of a ceramic brick is reviewed. The research was conducted to determine the error of the method with the use of sodium hydroxide as a destructive agent. The results have shown a minor standard deviation of 2.74% with a confidence interval of 3.11%. The comparative analysis of alkalis activity interacting with ceramic materials was conducted: an experiment with sodium hydroxide and potassium hydroxide were made and chemical degradation coefficients are included. The results has demonstrated different degree of alkali effect in the same experiment conditions that confirmed thermodynamic calculation of chemical reaction’s trends. The methods of corrosion research of building ceramics with use of calcium hydroxide and magnesium hydroxide were reviewed and completed and mass-spectrometric analysis of these solutions were conducted. Conducted analysis and completion of the research methods that evaluate degradation of building ceramics creating a vector for the following researches with a goal to create a broader picture of corrosion process of building materials.

1. Introduction
Freeze-thaw resistance of a material gives only qualitative assessment about material’s durability [1, 2, 15, 16]. Furthermore, this assessment is exclusively subjective because it is based mostly on researcher’s technical erudition that can’t be used as a measurement of life span of construction.

The use of multi-layered building’s enclosure in modern construction industry makes the evaluation of durability even harder because the materials in multi-layered constructions can interact with each other on ion-exchange processes’ level.

The questions of concrete’s chemical corrosion and evaluation methods of concrete’s construction durability based on processes of chemical degradation are actively researched since the 70s of last century to this day [3-6, 18].

The research of material’s corrosion of building ceramics based on empirical researches with a description of technical parameters of ceramic’s interaction with acids with salification that leads to ceramic degradation, ceramic material’s structure parameter or causing salt efflorescence on brickwork’s surface [7-10, 17]. The low amount of researches in brickwork degradation field mostly caused by high corrosion resistance of this material’s class.
[11, 12] describes a method of durability evaluation of building ceramic’s material based on chemical corrosion process. It’s classification of chemical corrosion’s processes allows to correctly describe processes between materials of the single construction. Developed method allows to evaluate the time of material’s degradation based on experimental data. Additionally, [13, 20] introduces the term “critical durability of the material” – parameter, which units are hours or years, and it is defined as time while material changes it’s physical, chemical and other parameters at given conditions until specific critical values.

Calculation method of critical durability of the material of building ceramics based on acquiring experimental parameters of the material in accordance with developed research methods: reaction’s speed in the alkali formation process (measurement of humidity’s corrosion activity) and alkali effect on brick’s material (measurement of chemical resistance). These methods allows to implement a new performance parameter of building ceramics: chemical degradation coefficient. This parameter’s units are [%/hour] that allows it’s use in calculations of the material durability. These methods described in details in [14].

2. Method

2.1. Error evaluation of chemical resistance calculation method

The method of conducting laboratory experiment to evaluate chemical resistance of the building ceramic’s material includes multiple weighing of the sample, preparation of reagents, control of experiment’s time. Significant amount of controlled parameters can lead to significant errors of the experiment. Thereby, a task to determine an experiment’s error was made.

For the error evaluation there were used 5 samples of the single brick M100, fractions of 0.45-0.5 mm, mass of 2.0 g, prepared in accordance to experiment’s method. In experiment, potassium hydroxide with concentration of 0.5 n was used. Experiment was conducted with solution temperature of 100 °C. Sample was weighed every hour after the contact with alkali.

Figure 1 shows the results of the experiment as layered on each other charts with dependency of sample’s mass to time of effect on it with potassium hydroxide solution.

![Figure 1. Degradation chart of ceramic brick in potassium hydroxide (KOH) with concentration of 0.5 n and at temperature of 100 °C.](image)
Chemical degradation coefficient evaluated in accordance to the method in [14].

The results of the research shows that chemical degradation coefficients for 5 material’s samples of a single brick are within 17.409 %/hour and 18.698 %/hour with a standard deviation of 2.74% with a confidence interval of 3.11%. Thereby, developed method to determine the chemical resistance of the material of building ceramics has a high accuracy of the experiment’s results.

Additionally conducted researches has shown:
- decreasing the time step to 0.5 hour doesn’t lead to more accurate results and lays in the same confidence interval;
- increase of the experiment’s steps (e.g. using alkalis with less concentration) doesn’t lead to increase of experiment’s error because of potential losses at intermediate control of sample’s mass.

2.2. Research of the alkali activity when interacting with ceramic’s material

The method to determine humidity’s corrosion activity, also described in [14, 21], allows to evaluate the amount of alkaline and alkaline-earth ions in the materials that form alkalis in the brick’s material when humidified. The amount of forming alkalis depends on the brick’s material and it’s an important parameter when determining it’s durability when chemical corrosion process proceeds. Hydroxides in brick’s material form all the alkaline and alkaline-earth metals when humidified. Concentration of ions in solution evaluated by mass-spectrometric analysis with inductively coupled plasma and atomic-emission analysis with inductively coupled plasma. The results of some researches are shown in Table 1.

| Brick’s material | Concentration, (mg/l) / % |
|-----------------|--------------------------|
|                 | K⁺  | KOH | Na⁺ | NaOH | Ca²⁺ | Ca(OH)₂ | Mg²⁺ | Mg(OH)₂ | Sum    |
| Plinfa          | 4,22 | 6,05 | 0,49 | 0,85 | 5,11 | 9,44    | 0,45 | 1,08    | 10,27 | 17,42 |
| Brick 1835 y.  | 41,1 | 34,7 | 4,8  | 4,9  | 49,7 | 54,2    | 4,4  | 6,2     | 100,0 | 100,0 |
| Brick M100     | 0,61 | 0,88 | 0,26 | 0,45 | 0,55 | 1,02    | 0,023| 0,055   | 1,443 | 2,405 |
| Large-block ceramic | 42,3 | 36,6 | 18,0 | 18,7 | 38,1 | 42,4    | 1,6  | 2,3     | 100,0 | 100,0 |
| Hollow brick 1957 y. | 0,64 | 0,92 | 0,40 | 0,70 | 3,30 | 6,10    | 0,46 | 1,10    | 4,80  | 8,82  |
| Brick M100     | 13,3 | 10,4 | 8,3  | 7,9  | 68,7 | 69,2    | 9,7  | 12,5    | 100,0 | 100,0 |
| Large-block ceramic | 1,27 | 1,82 | 0,77 | 1,34 | 0,14 | 0,26    | 0,026| 0,06    | 2,206 | 3,48  |
| Hollow brick 1957 y. | 57,6 | 52,3 | 34,9 | 38,5 | 6,3  | 6,3     | 7,5  | 1,2     | 1,7   | 100,0 |
|                 | 0,95 | 1,36 | 0,21 | 0,37 | 1,83 | 3,38    | 0,103| 0,25    | 3,093 | 5,36  |
|                 | 30,7 | 25,4 | 6,8  | 6,9  | 59,2 | 63,1    | 3,3  | 4,6     | 100,0 | 100,0 |

It should be noted that even relatively low amount of researches shown in Table 1 of brick’s material with the method of humidity’s corrosion activity shows that, firstly, the amount of formed alkalis in brick’s material varies in a wide range within 2.405 mg/l to 17.42 mg/l; secondly, percent ratio of alkalis is different for each sample. For example, the amount of potassium hydroxide in large-block ceramic is 52.3% while solid brick M100 has only 10.4%.

Authors conducted a significant amount of researches based on chemical thermodynamic theory with a goal to study the possibility of reaction’s processes of alkali’s chemical interaction with silicon and aluminum oxides in amorphous part of brick’s material. Calculations were made by Gibbs thermodynamic potential. Based on these researches following conclusion was made – reaction’s interactions of all alkalis with silicon oxide theoretically possible. At the same time, thermodynamic possibility of reaction’s interaction of silicon oxide with different alkalis vary in a wide range.
Theoretical possibility of reaction’s interaction of alkalis with aluminum oxide is significantly lower.

Based on the results of thermodynamic calculations, the method to determine kinetic parameters of the reaction’s interaction of alkalis with brick’s material was developed. The method to determine humidity’s corrosion activity was taken as a base [14].

The method of research for sodium hydroxide was applied the same as for the research of kinetic process of interaction between brick’s material and potassium hydroxide: sample’s mass 2.0 g, temperatures of the process 100 °C, 60 °C and 22 °C and alkaline concentrations 0.05 n, 0.5 n, 5.0 n.

Sample of ceramic brick were fractured in advance, fractions 0.45–0.5 mm, dried up and weighed on the scales with an error of 0.001 g. Solution of sodium hydroxide is being prepared in required concentration and then it is poured into 250 ml flask and heated to the temperature of the process. Prepared solution is being poured into flask with fractured brick’s sample in the vent hood. Then, flask is fixed in the thermostat and connects to refrigerator. Single experiment is 1 hour.

Solution is drained without losing the solid fractions of sample. Sample is washed with distilled water, carefully decanting roiled water. This operation carried through until water stays clean after stirring.

Then, 250 ml of hydrochloric acid was poured into flask with the same concentration and temperature. Solution interacted with the sample for 30 minutes.

Cleaned samples placed in the drying chamber with temperature of 110 °C. Dried out samples weighed on electronic scales with an error of 0.001 g. Obtained results are written in protocol and chart was drawn. Experiment was conducted until sample’s mass is lower than 0.5% of initial mass

Figure 2 shows the charts of brick sample’s material degradation when affected by the solutions of sodium hydroxide (NaOH) and potassium hydroxide (KOH) with the concentration of 0.5 n and temperature of 100 °C.

**Figure 2.** Degradation chart of ceramic brick in sodium hydroxide (NaOH) and potassium hydroxide (KOH) with the concentration of 0.5 n and at temperature of 100 °C.
Obtained results of the research shows a high intensity of chemical reaction’s process that leads to corrosion of ceramic brick when interacted with sodium hydroxide. Chemical degradation coefficient for sodium hydroxide is 25.9 %/hour which is 1.44 times higher than chemical degradation coefficient of potassium hydroxide (18.9 %/hour) that correlates with the thermodynamic calculation’s results. Thereby proven that effect of different alkalis on the brick’s material with the same conditions is different. Researches of chemical degradation coefficient dependency from temperature and concentration continues.

When researching the interactions of brick’s material with calcium and magnesium hydroxides, the difficulty of conducting the experiment is their low solubility in water. Solubility of alkaline and alkaline-earth metals in water from [19] shown in Table 2.

| Hydroxide   | Molecular Weight | Temperature, °C | Solubility, g/l | Temperature, °C | Solubility, g/l |
|-------------|------------------|-----------------|-----------------|-----------------|-----------------|
| KOH         | 56.11            | 0               | 953.0           | 100             | 1780.0          |
| NaOH        | 40.00            | 20              | 1070            | 100             | 3370.0          |
| Ca(OH)₂     | 74.09            | 25              | 1.48            | 100             | 0.77            |
| Mg(OH)₂     | 58.32            | 25              | 0.00642         | 100             | 0.04            |

Here, solubility of calcium hydroxide is three orders lower than solubility of potassium or sodium hydroxides. Significant difference of solubility led to corrections in the research method.

Due to the fact that solubility of calcium hydroxide lowers with the increase of temperature (Table 2), in order to derive degradation’s speed to temperature and concentration dependency, it was conducted at 100 °C with the maximum possible concentration of calcium hydroxide. At 22 °C suggested to conduct the experiment with two concentrations: maximum possible with consideration of solubility of calcium hydroxide at 22 °C and maximum possible concentration at 100 °C.

With the case of magnesium hydroxide, solubility increases with temperature increase that’s why experiment should be conducted at 22 °C with maximum possible concentration to get the dependency. At 100 °C it should be conducted at maximum possible concentration at 100 °C and maximum possible at 22 °C.

Flasks of 2 L were used in the researches. Sample’s mass lowered by 1.0 g.

Conducted analysis of possible effect of active interaction between calcium hydroxide and air’s carbon dioxide that can be present in refrigerator and flask. The results of calculations shown that despite low concentration of active agent in solution the amount of air present in unfilled part of the flask and in refrigerator is not enough to shift an error of the experiment greater than 0.03%.

Due to the low concentrations of calcium hydroxide solution, it was controlled (checked) by mass-spectrometric analysis with inductively coupled plasma and atomic-emission analysis with inductively coupled plasma. The results of the research shown constant proportional lowering of concentrations in the solution by 9.4% compared to preset one.

3. Conclusions

Conducted researches has shown a high precision of chemical degradation coefficient evaluation method developed for critical durability of the material of brick’s material calculations. This method can be recommended already for the precise comparative evaluation of brick material’s durability.

The results of laboratory experiments has proven the regularities obtained in theoretical thermodynamic calculations. The results of the researches shows the dependency between values of chemical degradation’s coefficient and alkali chemical activity and ceramic brick’s material. Therefore, more precise method of evaluation of building ceramic material’s durability requires
calculations to include degradation speed with the consideration of activity and concentration of each alkali.

Conducted analysis and correction of the experiment’s method to evaluate building ceramic’s degradation allows to obtain data for calculations of chemical reaction’s degradation speed when concentration and temperature of building material’s corrosion processes changes.

4. References

[1] Belelyubskij N A 1884 Uniform testing of building materials
[2] Podval'nyj A M 1996 About concrete frost test Stroit'nye materialy 4
[3] Moskvin V M 1980 Corrosion of concrete and reinforced concrete, methods for their protection p 536
[4] Podval'nyj A M 2004 On the classification of concrete corrosion Beton i zhelezobeton 2 pp 23-27
[5] Rimshin V I 2005 Longevity problems Beton i zhelezobeton 2 p 27
[6] Stepanova V F, Falikman V R 2014 Modern problems of ensuring the durability of reinforced concrete structures Beton i zhelezobeton Conference May 12 pp 275-302
[7] Inchik V V 2007 Physic-chemical aspects of the destruction of brickwork Problems of the durability of buildings and structures in modern construction pp 79-85
[8] Anan’ev A I 2018 Durability, humidity and heat-shielding properties of hollow brick exterior walls of buildings AVOK pp 70-73

[9] Salahov A M, Morozov V P, Najmark D V, Eskin A A 2016 Optimization of the regime of firing the front brick of light tones at the factory «Kerma» Stroit'nye Materialy 8 pp 32-37
[10] Minas A I 1961 The salt form of physical corrosion of building materials and methods of dealing with it Abstract of dissertation for the degree of Doctor of Technical Sciences p 37
[11] Zheldakov D Yu 2018 Chemical corrosion of bricklaying Problem definition Stroit'nye Materialy 6 pp 29-32
[12] Zheldakov D Yu 2019 Chemical corrosion of masonry The course of the main process Stroit'nye Materialy 4 pp 36-43
[13] Zheldakov D Yu 2017 Terminology and General Theory of Prediction of Ultimate Durability of Structures Izvestiya vysshikh uchebnyh zavedenij. Tekhnologiya tekstil'noj promyshlennosti 2 pp 114-118
[14] Zheldakov D Yu 2019 Methods for studying the kinetics of the process of chemical corrosion of masonry materials Izvestiya vysshikh uchebnyh zavedenij. Stroit'stvo 11 pp 74-86
[15] Fagerlund G 1977 The international cooperative test of the critical degree of saturation method of assessing the freeze/thaw resistance of concrete Materials and Structures 58 pp 231-253
[16] Fagerlund G 1996 Assessment of the service life of materials exposed to frost Durability of Building Materials and Components 1
[17] Litvan G 1975 Testing the frost susceptibility of bricks (In Masonry: Past and Present) pp 123-132
[18] Litvan G 1988 The mechanism of frost action in concrete Theory and practical implications Proceedings of Workshop on Low Temperature Effects on Concrete IRC/NRCC pp 116-127
[19] 1963 Spravochnik himika Tom 2 Handbook of a chemist Vol 2 The main properties of inorganic and organic compounds p 1168
[20] Zheldakov D Yu 2018 Prediction of ultimate durability of building envelopes Izvestiya vysshikh uchebnyh zavedenij. Tekhnologiya tekstil'noj promyshlennosti 3 pp 247-252
[21] Zheldakov D Y 2020 Brickwork chemical corrosion features IOP Conference Series: Earth and Environmental Science