**Evaluation of the Pozzolanic Activity of Expanded Clay Aggregate**

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**Abstract.** This article discusses pozzolanic activity. Methods for determining the pozzolanic activity of materials are presented, and the properties of expanded clay aggregate are examined. The works of researchers who have studied its pozzolanic activity are reviewed. Based on the reviewed studies, the pozzolanic activity of expanded clay aggregates produced by local manufacturers has been determined. The obtained results have been analyzed.

**Keywords:** pozzolan activity, expanded clay filler, titration, mineral additives, express method

### INTRODUCTION

### In the construction industry, reducing environmentally harmful emissions and optimizing production costs remain pressing tasks, making the use of active mineral additives that partially or completely replace Portland cement highly relevant [1, 2]. Pozzolanic additives react with lime to form secondary calcium silicate hydrates (C-S-H), which increase the strength, water resistance, and service life of concrete [3, 4].

### Although traditional active additives such as metakaolin, fly ash, silica fume, and ground granulated blast-furnace slag are widely used, some of them are considered regionally limited or expensive resources [5, 6]. Therefore, developing new, low-cost pozzolanic additives from industrial waste and locally available resources is also one of today’s important challenges [7].

### The production process of expanded clay is based on the bloating of clay fired at high temperatures. During this process, amorphous phases and microscopic gas bubbles are formed [8]. The dust and fine fractions generated during production are often stored as waste or used as low-value filler materials [9]. At the same time, studies show that the high content of silicon and aluminum oxides and the amorphous structure of this dust ensure its pozzolanic activity [10].

### Subsequent studies emphasize the need for thermal treatment, chemical activation, and control of particle size distribution to enhance pozzolanic activity [11, 12]. Additionally, the technological parameters of expanded clay production from clay particularly firing temperature and cooling rate strongly determine the proportion and reactivity of amorphous phases [10, 8].

**MATERIALS USED AND RESEARCH METHODS**

***Expanded Clay Aggregate*.** In our research, we examined the physical and mechanical properties of expanded clay aggregates produced in various regions of our country. These include products from “Navoi Keramzit” LLC in Navoi Region, “Qarshi Keramzit” JSC in Kashkadarya Region, and “Ghazalkent Expanded Clay Plant” LLC in Tashkent Region. The designations used for the expanded clay samples in our study are provided in Table 1.

**TABLE 1.** Conditional designation of expanded clay aggregates

|  |  |  |
| --- | --- | --- |
| № | Name of the expanded clay manufacturing company | Conditional name |
| 1 | “Navoiy Keramzit” LLC | K 1 |
| 2 | "Karshi Keramzit" OJSC | K 2 |
| 3 | "Gazalkent Expanded Clay Plant" LLC | K 3 |

The physical and physico-mechanical properties of the selected 5–10 mm fraction expanded clay samples were determined in accordance with applicable standards [13].

Based on bulk density, the expanded clay samples were classified as grade M450 for K1, M600 for K2, and M700 for K3 (see Table 2). In addition, the particle densities for K1, K2, and K3 were determined to be 2.388, 2.475, and 2.525 g/cm³, respectively, while their average particle (grain) densities were found to be 654, 832, and 851 kg/m³, respectively [14].

Considering that the bulk density grades for expanded clay used in lightweight concrete range from M150 to M1000, it can be concluded that the studied expanded clay samples meet the ГОСТ requirements for bulk density.

**TABLE 2.** Physical parameters of expanded clay samples

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| According to Table 1 | Bulk density, kg/m3 | Average density of grains, kg/m3 | Density,  g/sm3 | Porosity of expanded clay grains, % | Space between grains, % |
| GOST |
| K 1 | 435 | 654 | 2,388 | 73 | 33 |
| M450 |
| K 2 | 590 | 832 | 2,475 | 66 | 29 |
| M600 |
| K 3 | 682 | 851 | 2,525 | 66 | 20 |
| M700 |

The results obtained for water absorption (see Table 3) also showed that these samples fully meet the requirements of GOST. Considering that the bulk and average density grades are in the range of M150-M1000, it was found that the bulk and average densities of the studied expanded clay samples also meet the specified requirements.

**TABLE 3.** Water absorption, thermal conductivity coefficient, and compressive strength of expanded clay samples

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| According to Table 1 | Water absorption by mass,% | Water absorption by volume, % | Thermal conductivity, W/m‧K | Compressive strength in cylinder, MPa | strength mark according to GOST 32496-2013 |
| GOST 32496-2013 |
| K 1 | 23,46  ≤25 | 15,3 | 0,197 | 2,86 | П125 |
| K 2 | 16,9  ≤25 | 14,05 | 0,2744 | 4,43 | П150 |
| K 3 | 16,8  ≤20 | 14,2 | 0,2825 | 5,07 | П200 |

The chemical composition of the selected expanded clay filler is presented in Table 4 below.

**TABLE 4.** Chemical composition of Gazalkent expanded clay filler

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SiO2 | Al2O3+TiO2 | Fe2O3 | CaO | MgO | SO3 | l.d.i.p. |
| 58,96 | 11,64 | 8,73 | 12,82 | 2,12 | 1,35 | 2,38 |

*Methods of determining pozzolanic activity of expanded clay aggregate.* The following three methods were used to determine the pozzolanic activity of the expanded clay aggregate:

the first method is based on determining the absorption of a saturated lime solution by silica contained in expanded clay [15]. The determinations were carried out every 2 days for 30 days;

the second method involves heating 1 g of mineral additive in a 30% NaOH solution at 90°C for 2 hours to determine the pozzolanic activity of expanded clay [16].

The activity coefficient (Ka, %) of the mineral additive determined by this rapid method was calculated using the following formula:

(1)

where: m1 - is the mass of the initial mineral additive, g; m2 - is the mass of the dried mineral residue, g.

The use of the developed rapid method makes it possible to classify the activity coefficient of expanded clay aggregate as follows: high activity (Kₐ from 51% to 100% and above), active (Kₐ from 21% to 50%), and low activity (Kₐ from 5% to 20%) [15].

The third method also involves determining the ability of the silicon oxide in expanded clay to absorb saturated lime solution [15]. Taking into account the temperature-dependent solubility of calcium hydroxide, the amount of CaO absorbed from the saturated calcium hydroxide solution by 1 g of active mineral additive (AMA) was calculated using the following formula:

(2)

where: 1.4 — the titer (differential correction) of 0.05 mol/L hydrochloric acid solution for CaO, mg/mL·g; V₀ — the volume of hydrochloric acid (in mL) required to titrate 50 mL of saturated calcium hydroxide solution at (20 ± 2) °C without added expanded clay powder; V₁ — the volume of hydrochloric acid (in mL) consumed in titrating the test solution containing expanded clay powder at 85–90 °C; V₂ — the volume of hydrochloric acid (in mL) required to titrate 50 mL of saturated calcium hydroxide solution without expanded clay powder at 85–90 °C [16].

As the test result, the amount of CaO absorbed from the saturated calcium hydroxide solution by 1 gram of expanded clay powder is measured twice, and the average value is taken. The result is accepted if the difference between the two measurements does not exceed 1% of the average value [16].

**EVALUATION OF THE POZZOLANIC ACTIVITY OF EXPANDED CLAY AGGREGATE**

Based on the above, we decided to investigate the potential pozzolanic activity of expanded clay gravel in our study. It should be noted that, since in expanded clay concrete the cement paste is in direct contact with the aggregate, samples were prepared by scraping the surfaces of expanded clay granules and passing them through a No. 008 sieve. In the second case, considering that crushed expanded clay aggregate is used in concrete and the cement paste is assumed to be in direct contact with the fractured surfaces of the aggregate, the internal structure of the expanded clay was also examined.

Three methods were selected to determine pozzolanic activity:

* absorption of lime by the tested active material under natural conditions;
* absorption of lime by the active material determined by maintaining the lime aqueous solution with the tested material at 80 °C for 8 hours followed by titration;
* the express method.

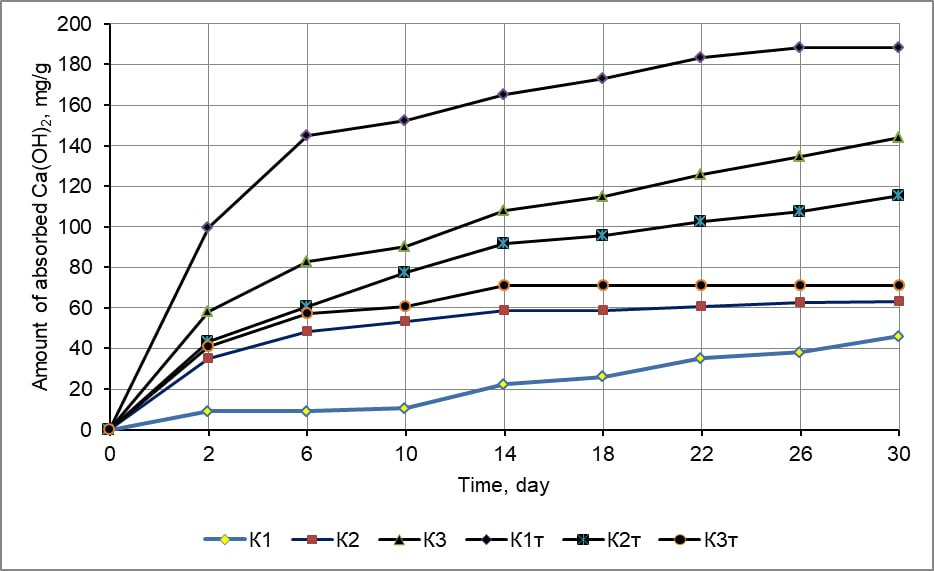
Expanded clay is characterized by its high content of SiO₂ and Al₂O₃ (aluminosilicates) and its ability to react with alkalis under certain conditions. In most cases, the interaction of lime with active mineral additives is based on the binding of lime into calcium silicate hydrates in the presence of water through the action of reactive silica [24]:

*mCa(OH)2 + SiO2·nH2O → (0,8–1,5)CaO·SiO2·pH2O,* (3)

*mCa(OH)2 + SiO2akt+ nH2O → (0,8–1,5)CaO·SiO2·pH2O* (4)

The results of the study on the pozzolanic activity of the surfaces of expanded clay granules are presented in Figure 1.

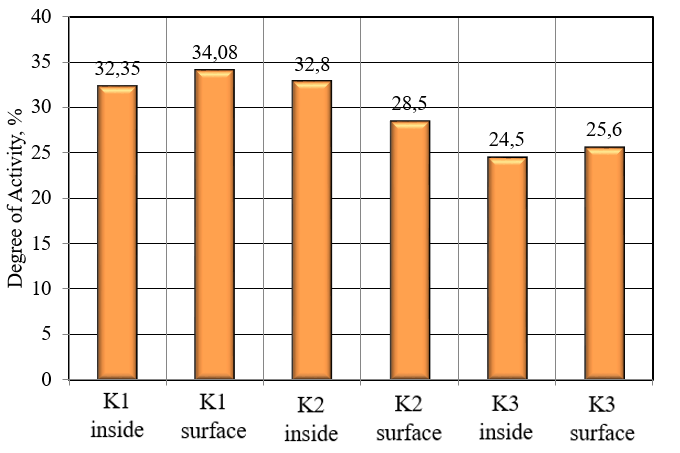
It was found that the pozzolanic activity of the untreated expanded clay powder, determined by the lime absorption method, is 53 mg/g. The ability of mineral additives to bind calcium hydroxide in the presence of water at normal temperature depends on the content of chemically reactive forms of substances they contain.



**FIGURE 1.** **Lime uptake kinetics from saturated solution:** sample numbers correspond to Table 1; K1, K2, K3 – samples stored under natural conditions in saturated Ca(OH)₂ solution; K1t, K2t, K3t – samples heated in saturated Ca(OH)₂ solution at 80 °C for 8 hours and then stored under natural conditions for 30 days.

***Express method for determining the pozzolanic activity of expanded clay samples.*** In this study, a rapid method was used to determine the activity coefficient of various mineral additives. This method is based on assessing the activity of mineral additives by monitoring changes in the mass of the initial material after drying.

When the activity of the expanded clay aggregates was determined using the express method, their activity levels were found to correspond to the values shown in Figure 2.



**FIGURE 2.** **Activity level of expanded clay determined by the express method (designations according to table 1)**

**CONCLUSION**

It was found [10] that when expanded clay is air-cooled, the following types of glassy-phase regions can be observed under the microscope: small melted and single large prismatic quartz crystals, large platy anorthite crystals, and tablet-shaped hematite crystals. Crystallization of tetragonal cristobalite along cracks and edges of the quartz grains was also recorded.

When determining the pozzolanic activity of expanded clay aggregates using the express method, the activities of the internal and surface parts were studied separately. This was done because the surface of the aggregates receives more heat compared to the interior, which could result in differences in activity—a fact confirmed by the research findings. As a result, it was found that the surface of the K1 sample exhibited 5.34% higher activity than its interior, the K2 sample showed 13.1% lower activity, and the K3 sample had 4.49% higher activity than its interior part.

According to the results determined by the express method, the K3 sample exhibited the lowest pozzolanic activity, being 1.32 times less active than the K1 sample and 1.34 times less active than the K2 sample. Nevertheless, it was found that all expanded clay samples fall within the category of moderate pozzolanic activity based on their activity levels.

**REFERENCES**

* 1. Kh. Kh. Kamilov, T. T. Shakirov, N. A. Muminova, and D. R. Abdazov, "Porous aggregate developed with the use of coal-containing clays of the Angren field," *Bull. Tomsk. Polytech. Univ. Geo Assest Eng.*, **335**, 87–103 (2024). doi:10.18799/24131830/2024/11/4476.
  2. K. L. Scrivener, V. M. John, and E. M. Gartner, "Eco-efficient cements: Potential economically viable solutions for a low-CO₂ cement-based materials industry," *Cem. Concr. Res.*, **114**, 2–26 (2018).
  3. H. F. W. Taylor, *Cement Chemistry*, 2nd ed. (Thomas Telford, London, 1997), p. 459.
  4. P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*, 4th ed. (McGraw-Hill, New York, 2014), p. 671.
  5. M. C. G. Juenger, F. Winnefeld, J. L. Provis, and J. H. Ideker, "Advances in alternative cementitious binders," *Cem. Concr. Res.*, **41**, 1232–1243 (2011).
  6. R. Siddique, *Waste Materials and By-Products in Concrete* (Springer-Verlag, Berlin, 2008), p. 416.
  7. Cement Sustainability Initiative, *The Cement CO₂ Protocol* (WBCSD, Geneva, 2009), p. 32.
  8. Kh. Kamilov, A. Zaitov, and A. Tulaganov, "On a formula finding fractal dimension," *Arch. Mater. Sci. Eng.*, **104**(1), 19–22 (2020). doi:10.5604/01.3001.0014.3865.
  9. R. Z. Rakhimov, M. I. Khaliullin, A. R. Gaifullin, and O. V. Stoyanov, "Keramzit dust as an active additive in mineral binders – composition and pozzolanic properties," *Vestn. Kazan. Technol. Univ.*, **16**(19), 57–61 (2013). (In Russian).
  10. V. Z. Abdrakhimov, V. A. Kulikov, I. V. Kovkov, and E. S. Abdrakhimova, "Phase composition kinetics at different cooling rates of expanded clay based on montmorillonite clay," *Izv. Samarsk. Nauchn. Cent. Ross. Akad. Nauk*, **12**(4), 311–315 (2010). (In Russian).
  11. H. Mola Abasi, M. R. Maheri, and M. Shabanian, "Effect of thermal activation on pozzolanic activity of clay-rich sediments," *Constr. Build. Mater.*, **243**, 118278 (2020).
  12. Y. Li, J. Zhang, J. Wang, and J. Huang, "Reactivity enhancement of calcined clay using alkaline activation: Mineralogical and microstructural evolution," *Cem. Concr. Compos.*, **139**, 105406 (2023).
  13. GOST 9758–2012, *Porous inorganic aggregates for construction work – Test methods* (Federal Agency for Technical Regulation and Metrology, Russia, 2012). (In Russian).
  14. S. I. Torakhonov, Kh. Kh. Kamilov, and D. R. Abdazov, "Physical and mechanical properties of expanded clay produced in Uzbekistan," in *Proc. Int. Sci.-Tech. Conf. “Modern solutions for improving integration of science, education and production in manufacturing of building materials and products”*, SamDAQI, October 27–28, 2022, pp. 198–201. (In Uzbek).
  15. Yu. M. Butt and V. V. Timoshev, *Workshop on Chemical Technology of Binders* (Vysshaya Shkola, Moscow, 1973), pp. 268–272. (In Russian).
  16. V. V. Strokova, I. V. Zhernovskiy, A. V. Maksakov *et al.*, "Rapid method for determining the activity of silica raw materials for granulated nanostructured aggregate," *Stroit. Mater.*, **1**, 38–39 (2013). (In Russian).