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Fly Ash-based Geopolymer Binders: Perspective Materials for Sustainable Building

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Abstract. The possibility of obtaining a geopolymer binder on the basis of fly ash of the Reft thermal power station and fine-grained concrete on its basis is investigated. It is shown that the chemical-mineral composition and properties of this fly ash allow it to be used as an aluminosilicate component without additional grinding and introduction of mineral additives. In this case, the alkaline activator is an industrial sodium liquid glass diluted to a density of 1200 kg/m^3. The dependences of the strength of geopolymer binder and fine-grained concrete on its basis on the conditions of hardening, aggregate consumption and the sequence of mixing of components are established. Based on the fly-ash geopolimer and the screenings crushing granite dropout picked up the fine-grained concrete class B35.

Key words: geopolymer binder, fly ash, fine-grained concrete, alkaline activator, strength, water resistance, conditions of hardening

1. Introduction
Features of the life cycle of any building and/or structure are largely determined by the materials chosen for its construction. They affect the speed of construction and performance of the construction site, its maintainability and durability, the possibility and manufacturability of recycling after dismantling structures. Therefore, ensuring the construction of economically and environmentally efficient materials that meet the requirements of Sustainable development is an urgent task. The question of alternative binders that can compete with Portland cement, the production technology of which is resource-intensive and dangerous for the environment, is especially acute today [1-5]. Binders obtained by alkaline activation of mineral raw materials without the use of energy-intensive firing processes (characteristic of Portland cement technology) are considered as the most promising. There are several names of this class of binders: alkali-activated cements, slag-alkaline binders, alkaline cements and others; most often they are called "geopolymers". The validity of the use of this term is based on the fact that during their hardening the synthesis of high-molecular structures occurs by polymerization or polycondensation of monomer silicate and aluminate groups. The latter can be formed by the action of alkaline activators on the materials of aluminosilicate composition [6-8]. Aluminosilicate components are usually crushed rocks, mineral industrial waste or a combination thereof; solutions of sodium silicates, sodium or potassium hydroxides and other chemical compounds having an alkaline character are used as activators [9-18].

The literature describes numerous positive examples of the use of geopolymer binders in the composition of heavy and light concretes, mortars [19-21]. Despite this, to date, they have not been widely used in construction. One of the reasons is the complexity of the technology for producing geopolymer composites. It involves the combination of technology for the preparation of the binder and building material, based on it (for example, concrete). At the same time, the technology of obtaining the majority of composites using traditional binder analogues (cement, gypsum, etc.) provides for the use of the finished binder as a raw component [22]. Therefore, in each case for each type of aluminosilicate component, alkaline activator and type of reinforcing element (crushed stone, sand, fibrous materials, etc.) it is necessary to select the optimal technological parameters that provide the necessary properties of the building composite.

In this study, fly ash from the Reft thermal power plant (FARTP) located in the Sverdlovsk region was used as an aluminosilicate component. The chemical composition of ash is comparable with clays, and the phase composition is dominated by glass phase [23]. This suggests its high potential for the creation of alkali-activated binders. The aim of the study was to select the optimal technological parameters for the production of geopolymer ash binder and fine-grained concrete (FGC) based on it.

2. Initial materials and research methods characteristic

A representative sample of FARTP with the following characteristics: the specific surface 260 m^2/kg, bulk density 790 kg/m^3, true density 1900 kg/m^3 was used in this research. Chemical composition of FARTP, % (by weight): 58.70 SiO_2, 25.60 Al_2O_3, 7.21 Fe_2O_3, 5.59 CaO, 0.80 MgO, 2.10 loss on ignition. As an alkaline activator, industrial liquid sodium silicate glass with a density of 1450 kg/m^3, a silicate module 3.2 (manufactured by LLC «Himreaktivy», Yekaterinburg), and a water solution of sodium hydroxide were used. To obtain a liquid glass of the required density, it was mixed with distilled water. Density was controlled by the areometer with a range of measurement of 1000-1500 kg/m^3.

The geopolymer binder was prepared by thoroughly mixing FARTP with an alkaline solution. The resulting paste was formed in the form of samples of a cubic shape measuring 20 × 20 mm, which were hardened under normal conditions and under heat treatment conditions: in an autoclave (autoclave mode: 1 hour rise in temperature, 4 hours at 123 °C and 2.2 atm pressure, 1 hour temperature release), in a drying oven (drying for 8 hours at 100 °C), in the curing room (curing room mode: 1 hour temperature rise, 4 hours at 85 °C, 1 hour temperature release). For the production of FGC, the screenings crushing granite fraction of 1.25-2.5 mm with a bulk density of 1320 kg/m^3 was used. The content of pulverized and clay particles was 3 % by mass. 2 methods of preparation of molding mass were used. Method 1 (suspension): the beginning of fly ash was closed with sodium liquid glass, then mixed with granite screenings. Method 2 (dry mix): first, fly ash and granite screenings were mixed in a dry state, then the mixture was closed with sodium liquid glass (Fig.1). The ratio of the solid (ash-removal and screening) and liquid (sodium silicate solution) component did not change and was 0.48.

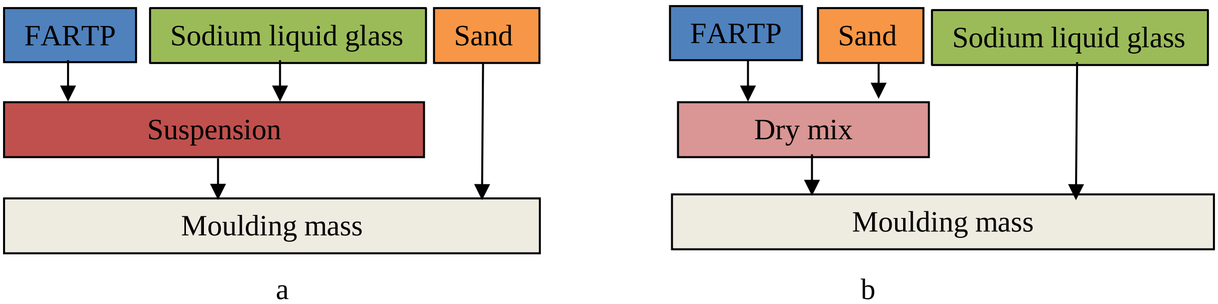

Figure 1. Methods of preparation of molding mass: a – method 1 (suspension); b – method 2 (dry mix)

The compression strength test was carried out on a PRG-1 benchtop press after a predetermined hardening time. To determine water absorption, the samples were placed in water for 24 hours, after measuring their mass. The water resistance of the hardened stone was evaluated by the softening coefficient:

$$Cs = R_{sat}/R_{dry}$$

where R_{sat} is the strength of a stone saturated with water; R_{dry} – the strength of the stone in a dry state.

3. Experiment results and discussion

The influence of some technological parameters (type and concentration of alkaline activator, hardening conditionson) the strength and water resistance of fly ash-based geopolymer binder and fine-grained concrete based on it was investigated.

Industrial liquid sodium silicate glass provides 5 times more high-strength artificial fly ash-stone than an aqueous solution of NaOH (Table 1).

Table 1. The influence of alkali activator on properties of fly ash geopolimer.

Alkaline activator	The ratio of the liquid and solid component (*L*/*S*)	Water Resistance (*Cs*)	Compressive strength, MPa, at the age of days (normal hardening conditions)	
			3	7
Liquid sodium silicate glass	0.48	0.57	5.5	15.1
Water solution of sodium hydroxide	0.48	0.30	1.1	2.9

The optimal density of the liquid glass solution in this case was 1200 kg/m^3 (Table 2).

Table 2. Effect of liquid glass density on compressive strength of fly ash geopolimer.

Density, kg/m^3	Compressive strength, MPa, at the age of days (normal hardening conditions)	
	3	7
1350	6.5	14.6
1300	6.9	15.4
1250	7.2	18.8
1200	7.5	22.1
1150	7.4	21.5

Heat treatment accelerates chemical reactions and improves the strength characteristics of the ash geopolymer. After it, when samples reached 1 and 3 days, they were tested for strength and water resistance. Regardless of the type of treatment, the softening coefficient of the ash geopolymer was 0.9. The maximum compressive strength had samples subjected to steaming, the minimum – after autoclaving heat treatment (Figure 2).

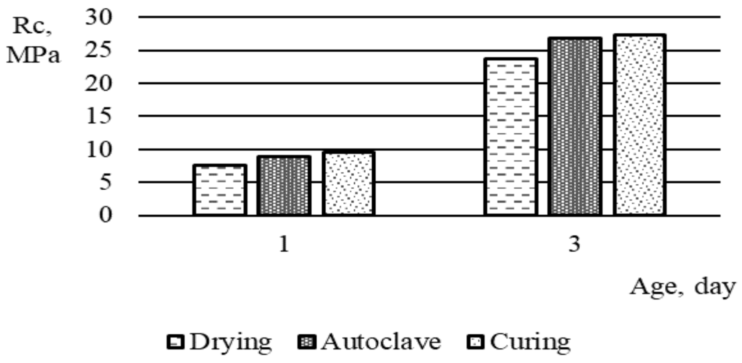

Figure 2. Influence of the type of heat treatment on the strength of the ash geopolymer.

It was found that the optimal ratio of the aluminosilicate component (fly ash) and the fine aggregate (granite screenings) was 2.0 (Figure 3).

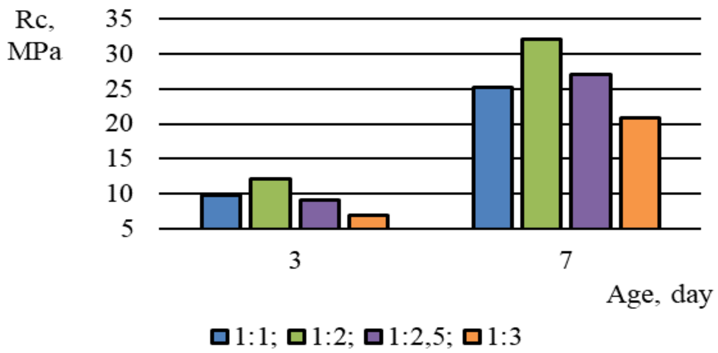

Figure 3. Effect of addition of fine aggregate on the strength of the geopolymeric composite.

When organizing the technological process of obtaining building composites based on ash geopolymers, it is important to observe the sequence of mixing components. it is advisable to pre-mix the fly ash with the reinforcing element, and then mixing them with an aqueous solution of an alkaline activator. The strength of FGC samples produced by method 2 (dry mixture) was 14 % higher than that obtained by method 1, all other things being equal.

As a result of the studies, a high water resistance fly ash-based geopolymer FGC was obtained, the strength of which corresponded to class B 35 (Table 3).

Table 3. est results of geopolymer fine-grained concrete.

Property	Value
Density, kg/m^3 (dried condition)	1870
Tensile strength, MPa, at the age of 28 days	4,8
Compressive strength, MPa, at the age of 28 days	47,3
Coefficient of softening (water resistance)	1

4. Conclusion

Studies have shown that it is possible to obtain geopolymer binder at the fly ash of the Reft TPP without additional grinding and introduction of mineral additives. In this case, the alkaline activator is an industrial sodium liquid glass diluted to a density of 1200 kg/m^3. The dependences of the strength of geopolymer binder and fine-grained concrete on its basis on the conditions of hardening, aggregate consumption and the sequence of mixing of components are established. Based on the fly-ash geopolimer and the screenings crushing granite dropout picked up the fine-grained concrete class B35. After further studies of durability, this material can be recommended for implementation in production as cost-effective, environmentally friendly and promising to replace cement concrete of appropriate quality.

References

[1] Huntzingera D N and Eatmonb T D 2009 J of Cleaner Production 17 pp 668–75
[2] Gartner E M and MacPhee D E 2011 Cement and Concrete Research 41 (7) pp 736–49
[3] Khozin V G, Khokhryakov O V, Sibgatullin I R, Gizzatullin A R and Kharchenko I Y 2014 Carbonate cements low water demand – green alternative cement industry Russia Building materials 5 pp 76-82
[4] Tang S W, Yao Y, Andrade C and Li Z J 2015 Cement and Concrete Research 78 A pp 143–54
[5] Domanskaya I, Bednyagin S and Fisher H-B 2018 IOP Conf. Ser.: Earth Environ. Sci. 177 012029
[6] Loewenstein W 1954 The Distribution of Aluminum in the Tetrahedra of Silicates and Aluminates American Mineralogist 39 pp 92–96
[7] Khale D and Chaudhary R 2007 Mechanism of geopolymerization and factors influencing its development: a review J. of Materials Science 42 pp 729–46
[8] Rakhimov R Z, Rakhimova N R and Stoyanov O V 2014 Geopolymers Vestnik Kazanskogo tekhnologicheskogo universiteta 17 (23) pp 189–96
[9] Glukhovsky V D 1979 Alkaline and alkaline-earth hydraulic binders and concretes (Kyiv: Vyscha shkola) p 232
[10] Davidovits J 1993 Geopolymer Cements to minimize Carbon-Dioxide Greenhouse Warming Ceramic Transactions 37. Cement-Based Materials: Present, Future and Environmental Aspect. pp 165–182
[11] Barbosa V F F, MacKenzie K J D and Thaumaturgo C 2000 Synthesis and characterization of materials based on inorganic polymers of alumina and silica: sodium polysialate polymers Intern. Journal of Inorganic Materials 2 pp 309–17.
[12] Komnitsas K and Zaharaki D 2007 Geopolymerisation: a review and prospects for the minerals industry Miner. Eng. 20 pp 1261–77
[13] Rashad A M 2013 Alkali-activated metakaolin: A short guide for civil Engineer-An overview. Construction and Building Materials. https://doi.org/10.1016/j.conbuildmat.2012.12.030
[14] Robayo-Salazar R, Mejía-Arcila J, Mejía de Gutiérrez R and Martínez E 2018 Construction and Building Materials 176 pp 103–11
[15] Bernal S A, Provis J L, Fernández-Jiménez A, Krivenko P V, Kavalerova E, Palacios M and Shi C 2014 Binder chemistry – High-calcium alkali-activated materials. RILEM State-of-the-Art Reports, 13, pp 59–91
[16] Rodríguez E, Bernal S, Provis J, Paya J, Monzo J and Borrachero M 2013 Effect of nanosilica-based activators on the performance of an alkali-activated fly ash binder Cement and Concrete Composites 35 (1) pp 1-11
[17] Panizza M, Natali M, Garbin E, Tamburini S and Secco M 2018 Assessment of geopolymers with Construction and Demolition Waste (CDW) aggregates as a building material Construction and Building Materials 181 pp 119–33
[18] Marjanović N, M. Komljenović M, Baščarević Z, Nikolić V and Petrović R 2015 Physical-mechanical and microstructural properties of alkali-activated fly ash-blast furnace slag blends *Ceramics International* **41** pp 1421–35
[19] LI Z and LI S 2018 Carbonation resistance of fly ash and blast furnace slag based geopolymer concrete *Construction and Building Materials* **163** pp 668–80
[20] Kozhuhova N I, Zhernovski I V and Strokova V V 2012 Evaluation of biopositive geopolymeric binders on the basis of low calcium fly ash *Building Materials* **9** pp 84–86

[21] Kireety C H and Raghavarani Y 2016 Global Journal of Engineering Science and Researches, 3 (10) http://doi.org/10.5281/zenodo.163105
[22] Voitovich E V, Kozhukhova N I, Zhernovsky I V, Cherevatova A V and Niezvet D D 2013 The concept of quality control aluminosilicate binders degidrattingo hardening *Building Materials* **11** pp 68–70
[23] Potapov S O, Sviridova M N, Tanutrov I N and Toloknov D A 2016 Physico-chemical properties of fly ash from the combustion of coal Butlerov communications **45** (3) ROI: jbc-01/16-45-3-36