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# Composition and Properties of Non-Fired Fly Ash Gravel and Concrete on Its Basis

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**Abstract.** Non-fired fly ash gravel was obtained on the basis of fly ash of thermal power plant № 5 of JSC "SIBEKO", 15 % of Portland cement and the hardening accelerator. The gravel of 5-20 mm fraction and 6 months' air-moist curing is 900 density grade, P300 strength grade, frost-resistance grade – F35. The compositions of cement concretes of strength class from B10 to B25 were established and their physical and mechanical properties were determined using obtained non-fired fly ash gravel. They belong to the lightweight concrete according to the density (1817-1857 kg/m<sup>3</sup>). The introduction of superplasticizer SP-1 reduces water demand of concrete mixture and increases strength of concrete on fly ash gravel.

## 1. Introduction

Construction of modern buildings and structures requires the use of concrete and reinforced concrete structures based on high-strength concrete with low density. To increase their strength highly active cements and hardening accelerators are used. These accelerators reduce water consumption for the preparation of concrete mixture and increase the density of concrete [1-3]. The decrease of concrete density is achieved mostly with use of lightweight aggregate and cement stone porosity. It is recommended to use keramzite, agloporite, fired fly ash and non-fired fly ash gravels [4-7] as aggregates in the composition of lightweight high-strength concrete. The physical and mechanical properties of aggregates mentioned above are presented in the table 1.

**Table 1.** Properties of artificial aggregates based on fly ash and slag wastes.

| Parameter  | Keramzite gravel | Fired fly ash gravel | Agloporite gravel | Non-fired fly ash gravel |              |
|--|------------------|----------------------|-------------------|--------------------------|--------------|
|  |                  |                      |                   | Dense                    | Light-weight |
| Bulk density (kg/m <sup>3</sup> )                  | 250-800          | 450-900              | 450-900           | 800-950                  | 450-600      |
| Water absorption (mass %)                          | 8-20             | 14-20                | 8-20              | 5-9                      | 7-15         |
| The strength when compressed in the cylinder (MPa) | 0.5-6.5          | 1-5                  | 0.5-3.5           | 5-8                      | 1-3          |

Non-fired fly ash gravel (NFFYG) is an artificial porous aggregate obtained in the form of granules from a pre-moistened mixture of fly ash from the coal combustion and Portland cement followed by



hardening during steaming or in natural conditions. For the NFFYG manufacturing Portland-slag cement and lime can also be used as binders, ash-slag mixture from the dumps of thermal power plants and ground metallurgical slag can be used as fillers and calcium chloride, sodium silicate, sodium sulfate, nitrite-nitrate calcium chloride and others can be used as cement hardening accelerators. In Russia about 30 million tons of ash and slag waste are generated annually during the burning of hard and brown coals at thermal and electric power plants, up to 40 % of their total volume is produced in Siberia.

These wastes pollute the environment and only less than 10 % of their current output are utilized, mainly in the production of construction materials. Power plant № 5 of JSC "SIBEKO" (Novosibirsk) more than 100 thousand tons of ash and slag are produced annually, then they are stored in dumps hydraulically. One of the most effective fields of application of ashes and slags can be production of artificial aggregates for concrete, in the concrete composition ashes occupy 70-85 % of volume. Feasibility study of obtaining and using of high-strength NFFYG based on fly ash of Reftinskaya district power plant in concretes is considered in [8, 9].

## 2. Raw materials and methodology

To obtain NFFYG and concrete based on it the following materials were used:

- the fly ash from the combustion of stone coal at thermal power plant № 5 of JSC "SIBEKO";
- Portland cement CEM I 42,5 N, Russian Standard 31108-2016 [10] by JSC "Sukholozhskcement" (Sverdlovsk region);
- technical sodium sulfate ( $\text{Na}_2\text{SO}_4$ ) A class, second grade according to Russian Standard 6318-77 [11].

The ash used in the work is acidic by chemical composition, it is fine by the grain composition (average particle diameter of 8.8 microns), it is characterized with a high specific surface which is 358  $\text{m}^2/\text{kg}$ , has a true density of 2.36  $\text{g}/\text{cm}^3$  and it has no ability to self-hardening. The phase composition of ash is mainly represented by glass, quartz, mullite and magnetite minerals. According to the basic properties of ash meets the requirements of Russian Standard 25818-91 [12] (table 2), refers to the 3 type and can be used in the concrete production.

**Table 2.** Accordance of dispersion and chemical composition of fly ash of thermal power plant № 5 of JSC "SIBEKO" to requirements of Russian Standard 25818-91.

| Parameter                     | Sieve residue № 008 (%) | Oxides content (mass %) |                       |                         |                  |               |           | Weight loss on ignition (mass %) |
|-------------------------------|-------------------------|-------------------------|-----------------------|-------------------------|------------------|---------------|-----------|----------------------------------|
|                               |                         | $\text{SiO}_2$          | $\text{Na}_2\text{O}$ | $\text{Fe}_2\text{O}_3$ | MgO              | $\text{SO}_3$ | CaO       |                                  |
| Actual                        | 19.40                   | 55.70                   | 1.29                  | 5.38                    | 2.23             | 0.27          | 4.93      | 3.25                             |
| Russian Standard requirements | $\leq 20$               | $\geq 45$               | $\leq 3$              | $\leq 10$               | Not standardized | $\leq 3$      | $\leq 10$ | $\leq 10$                        |

NFFYG was obtained as follows: fly ash and Portland cement were mixed in a certain amount in a drum mixer, then it moistened with an water solution of sodium sulfate (calculated as 2 %  $\text{Na}_2\text{SO}_4$  by cement weight) heated to a temperature of 80-90 °C; the mixture was granulated on a laboratory plate granulator with a plate diameter of 0.7 m and a rotation speed of 24 rpm; the obtained raw granules hardened in air-wet conditions for 6 months. Cement quantity was 15 % by weight of the ash-cement mixture, water for moisture was about 20 % and the duration of preparation and granulation of the mixture was 15 minutes.

Physical and mechanical properties of NFFYG were determined according to Russian Standard 9758-2012 [13] and compared with the requirements of Russian Standard 33928-2016 [14].

For establishing the concrete composition. NFFYG, Portland cement (CEM I 42,5 N), natural quartz sand and sand screenings from granite crushing (class 2, moderate) and superplasticizer SP-1 were used.

Selection of the composition of natural hardening concrete was performed by calculation and experimental method. After testing the aggregates it was determined:

- the optimal water consumption which provides the required workability of the concrete mixture and the cement-water ratio;
- cement consumption per 1 m<sup>3</sup> of the mixture which is providing the required strength of concrete in a given period under certain conditions of compaction and hardening;
- the consumption of aggregates per 1 m<sup>3</sup> of the placed and compacted mixture.

According to the results of determining the concrete strength the experimental composition of the mixture was refined [15].

### 3. Results and discussion

For the disposal and storage of ash and slag wastes so-called "dry" ash and slag removal technologies are developed and used at thermal power plants, for example, their granulation and storage in a stack [16, 17]. This technology of removal of granulated ash is close to the production of natural hardening NFFYG and can be implemented at the thermal power plants with the production of artificial aggregate for construction concretes. The NFFYG of 5-20 mm fraction, P300 strength grade and 900 density grade was used for preparation of concrete mix (table 3). The appearance of NFFYG is shown in figure 1.

**Table 3.** Comparative characteristics of NFFYG of fraction 5-20 mm.

| Parameter  | The test results after<br>(days) |      | Requirements of<br>Russian Standard<br>33928-2016 |
|--|----------------------------------|------|---|
|  | 28                               | 180  |   |
| Bulk density (kg/m <sup>3</sup> )                  | 846                              | 865  | 800-900   |
| Average density (kg/m <sup>3</sup> )               | 1532                             | 1545 | Not standardized                                  |
| Grain composition:                                 |                                  |      |   |
| - content of grains of $\geq 5$ mm (%)             | 99.7                             |      | 85-100  |
| - content of grains of $\geq 20$ mm (%)            | 0.3                              |      | up to 10  |
| - content of grains of $\geq 40$ mm (%)            | -                                |      | not allowed                                       |
| Water absorption (mass %)                          | 13.7                             | 12.5 | $\leq 20$   |
| Humidity (mass %)                                  | 11.1                             | 1.4  | $\leq 5$  |
| Frost resistance                                   | F15                              | F35  | $\geq F15$  |
| Content of split grains (%)                        | -                                | 3    | $\leq 15$   |
| Weight loss in silicate decomposition (mass %)     | -                                | 0    | $\leq 5$  |
| Weight loss on ignition (mass %)                   | -                                | 8.9  | $\leq 5$  |
| The strength when compressed in the cylinder (MPa) | 4.4                              | 6.8  | 6.5-8   |

Concretes based on NFFYG are characterized by relatively low consumption of cement, its resistance to tension as well as the adhesion strength of gravel to the mixture is much higher compared to concretes based on other types of aggregates (heavy concrete, keramzite concrete, etc.), ranging from B25 class and above. NFFYG is an effective aggregate on the basis of which it is possible to produce lightweight structural concretes with compressive strength of 10-40 MPa and above, density of 1700-2100 kg/m<sup>3</sup> [18-21].

Concrete compositions with a design strength class of B10 and B25 were established on the basis of NFFYG from fly ash of thermal power plant № 5 of JSC "SIBEKO". Concrete mixtures had a PK2 brand of mobility. The actual consumption of materials of the selected concrete is presented in table 4, their physical and mechanical properties is presented table 5. Concretes are lightweight with density

from 1817 to 1857 kg/m<sup>3</sup>. Concrete based on sand screenings from granite crushing as fine aggregate (composition 3) has a compressive strength after 28 days of normal hardening by 25 % more in comparison with strength of concrete based on natural quartz sand (composition 1) and respectively belongs to the B10 strength class (table 5). The concrete of 2 and 4 compositions with the compressive strength to 36.7 and 17.8 MPa belong to classes B25 and B12,5 respectively. It was found that the introduction of a superplasticizer SP-1 in the amount of 1.7 kg/m<sup>3</sup> in the concrete mix the water consumption decreased by 8.7 % and the concrete strength increased from 14.9 to 17.8 MPa.



**Figure 1.** Non-fired fly ash gravel appearance.

**Table 4.** Component composition of concrete mix.

| Composition number | Material consumption (kg/m <sup>3</sup> ) |       |              |                 |       |      | Density of concrete mix (kg/m <sup>3</sup> ) | Design strength class |
|--------------------|---|-------|--------------|-----------------|-------|------|--|-----------------------|
|                    | Cement                                    | NFFYG | Natural sand | Sand screenings | Water | SP-1 |  |                       |
| 1                  | 177                                       | 708   | 840          | -               | 236   | -    | 1961   | B10                   |
| 2                  | 367                                       | 716   | 664          | -               | 250   | -    | 1997   | B25                   |
| 3                  | 178                                       | 704   | -            | 859             | 249   | -    | 1990   | B10                   |
| 4                  | 179                                       | 708   | -            | 865             | 230   | 1.7  | 1984   | B10                   |

**Table 5.** Physical and mechanical properties of concrete.

| Composition number according to table 4 | Dry concrete density (kg/m <sup>3</sup> ) | Compression strength (MPa) |               | Actual strength class of concrete |
|---|---|----------------------------|---------------|-----------------------------------|
|   |   | after curing               | after 28 days |                                   |
| 1                                       | 1843                                      | 7.9                        | 11.9          | B10                               |
| 2                                       | 1857                                      | 24.0                       | 36.7          | B25                               |
| 3                                       | 1817                                      | 7.8                        | 14.9          | B10                               |
| 4                                       | 1834                                      | 12.2                       | 17.8          | B12.5                             |

#### 4. Conclusion

On the basis of fly ash of thermal power plant № 5 of JSC "SIBEKO", 15 % of Portland cement and 2 % of sodium sulfate as the hardening accelerator the 5-20 mm fraction NFFYG was obtained which after 6 months of air-moist curing had the 900 density brand, P300 strength brand and F35 frost-resistance brand. Lightweight concrete compositions of strength classes from B10 to B25 were established using the obtained gravel.

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