Fibrous Concrete with Reduced Permeability to Protect the Home Against the Fumes of Expanded Polystyrene

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Abstract. Designed the composition of the fiber-reinforced concrete on composite binder with high gas-, water- and steam impermeability. With 1.6% of reinforcing steel anchoring a fiber can be obtained in terms of the maximum physical and mechanical properties ($R_{\text{comp}} = 100.9$ MPa). It was found that the combined effect of mechanical and chemical activation (the presence of limestone particles) increases the pozzolanic activity of the acidic environment. It has a catalytic effect on the reaction activity of the surface of ash and sand during machining in a vario-planetary mill. Furthermore, the introduction of limestone increases the alkalinity of the concrete, which leads to the formation of greater hydration products of cement per unit of time. Theoretical and experimental results can be recommended for enhanced implementation of the construction in various regions of the World, taking into account the availability of raw materials.

1. Introduction

In modern construction one of the most commonly used construction materials are concrete and reinforced concrete, and from heat-insulating materials - the expanded polystyrene. At the same time, a well-known fact that the foamed polymers materials have ecologically and fire hazard, and, in the absence of adequate protection, also have short time of exploitation. Undoubtedly, that is not allowed contact of polystyrene to the interior and from the exterior climatic conditions. The problem can be solved by the internal arrangement of insulation between two structural concrete (reinforced concrete) layers. At the same time, concrete - a porous material, and the evaporation of styrene from polystyrene occurs continuously, and when the temperature rises, significantly accelerated. Adequately, only the injection of special additives, bridging the pores in concrete and sealing the structure is able to neutralize the environmental and fire hazard of polystyrene, as well as to increase its durability by preventing the penetration of atmospheric moisture (which is very important for the monsoon climate of Asian-Pacific area). Thereby, the engineering of concrete, having high gas, water and steam impermeability, able to protect from moisture as expanded polystyrene, and styrene vapors from the room is an urgent task [1,2].
2. Materials and methods

Analysis of the literature suggests the possibility of producing concrete with high density. Note, however, that the implementation of the potential of concrete is only possible by creating the optimum structure of the material, the formation of which is determined by such parameters as:

- types and quality of raw materials;
- technology preparation of concrete mixtures, etc.

The main factors determining the efficiency of designing of concrete and its construction units are technical features:

- obtaining the desired properties (strength, workability, and etc.) At the lowest possible consumption of costly and energy-intensive components;
- reducing the complexity of operations related to the selection of optimum compositions;
- verification of quality control samples and testing at the factory.

The properties of fine-grained concrete are characterized by the same factors as the conventional heavy concrete, but the lack of coarse aggregate leads to increased water demand in concrete, and in equally strength concrete cement consumption increased by 20...40%. To reduce the consumption of cement is advisable to use high-quality fillers, plasticizers, mixtures to produce a good seal [2,3,4].

In the manufacture of fine-grained concrete it is advisable to use natural and enriched sand, crushed and granulated slag and fly ash, waste industry, which also includes screenings of crushed granite. The properties of fine-grained concrete are highly dependent on the properties of the binder component in the concrete and aggregate used, grain structure, surface quality and water demand which determine the basic physical and mechanical properties of concrete. When receives a fine concrete aggregate used smaller size and higher surface area compared to conventional heavy concrete, the presence of these factors leads to an increase in cement consumption, which negatively affects the physical and mechanical characteristics of fine-grained concrete.

To achieve this goal have been developed composite binders obtained by co-grinding in the varioplanetary mill cement, fly ash limestone, and superplasticizer. It is advisable to use local raw materials, which are characterized by high activity silica-containing phases of man-made sand (in particular, elimination of crushed granite), obtained from crushing rocks.

Fine-grained structure, in addition to high homogeneity is also characterized by reduction of specific stress in the contact area and an increase of the integrated strength of adhesion between cement stone and aggregate.

Structure-forming role of filler is most developed with increasing surface of interaction, these conditions are realized in the fine-grained concrete with screenings of crushing of granite rubble of Wrangel field (Russian Federation) based on composite binders that due to the high surface intensify and accelerate the process of structure formation of concrete strength and seal structure.

As a component of the composite binder used the fly ashes of Russian largest thermal power plants: Vladivostok TPP and Artem TPP, Primorye TPP and Partizansk TPP. An important factor is the ability to separate the dry ash that is currently implemented in these power plants. The use of man-made products in the manufacture of building materials contributes to the solution of the following main objectives: saving energy and raw resources; waste utilization; improvement the environmental situation in the regions. It should be noted that revenues in the seaside ash dumps are one of the largest in the Far Eastern Federal District of Russian Federation. In particular, the annual flow of ash in the ash dumps of the Primorsky Territory from 2.5 to 3.0 mln. tons per year, Khabarovsk Territory - to 1.0 mln. tons. Fly ash thermal power plants it is an effective material for the production of fine and active mineral additives. These residues do not require special preparation when injected into the concrete. Was applied mineral powder from limestone Dinnogorsk deposit (Russian Federation) production of "Spasskcement".

To study the effect of composition on the binding properties of fine-grained concrete samples of concrete slump were produced in the range of 10-12 cm in the developed binder, which were further investigated by standard methods for various technological parameters.
The properties of composite materials largely depend on the structure of disperse systems of which they are obtained. The structural strength of the dispersed system, its stability and the behaviour in the time, the rate of destruction and restoration of the structure are interconnected. Conglomerate building material - concrete refers to a class of composites. As a concrete matrix substance, successively ambitious outline levels are the cement-sand stone, cement stone (micro concrete), cementing substance, neoplasms cementing substance, solid phase neoplasms, essence single structural element of neoplasms, which corresponds to a large-scale order from the macro- to the nanoscale structure. Ordered structure of the composites due to the proportionality of scale levels of the structure - the corresponding properties of the composite at each scale level. The achievement of high strength concrete contributes to a combination of factors: increasing density of systems by optimizing the composition of the grain; reducing the number of long cement matrix by reducing the water-cement ratio; filling the pores between the cement particles and to improve the rheology due to the effect of lubrication; formation of secondary products of hydration in the pozzolanic reaction with Ca(OH)$_2$ for the introduction of concrete additives microfill effect.

To select the optimal method of grinding tests were carried out in a ball, vibration and vario planetary mill. The grinding in vario-planetary mill is more energy-efficient compared to the ball and vibration mills. In addition due to the combined action of the drum and centrifugal drum and abrasive efforts, it is possible to achieve a highly dispersed powders.

3. Results and discussion
A composition of ash and slag waste is determined by the quantitative ratio of contained in the material minerals that are dependent on initial mineralogical composition of fuel used.

Process optimization of structure by hydration composite binder components creates a dense structure of the matrix, it is necessary to solve the problem - the creation of a composite for the production of high-strength concrete. This can be realized by co-grinding of Portland cement, mineral admixtures and polyfunctional reducing the water-cement ratio of the concrete mix through use the hyper plasticizer.

To reduce the water demand of concrete mix produced powder hyper plasticizer selection of the six most common in the Far East market for construction materials. cement paste broke was measured using Hagermann cone. For grout used Spassky cement CEM I 42,5N. Water-cement ratio - 0.3. Dosage plasticizer - 0.3%. Time of measurement face breaking cone was recorded after the end of mixing the cement paste.

Achieving high values of cone face breaking noted on raw binder mixture using hyper plasticizer PANTARHIT PC160 Plv (FM) (Table 1).

| Time measurements, min | Melflux 1641 F, Germany | Melflux 5581 F, Germany | PANTARHIT PC160 Plv (FM), Russian Federation | FOX$^\text{TM}$-8H (Pwd), Russian Federation | PC-1030, China | JK-04 PPM, China |
|------------------------|-------------------------|-------------------------|---------------------------------------------|---------------------------------------------|----------------|----------------|
| 0                      | 290                     | 350                     | 370                                         | 250                                         | 240            | 130            |
| 5                      | 380                     | 390                     | 400                                         | 260                                         | 280            | 120            |
| 30                     | 390                     | 350                     | 390                                         | 240                                         | 190            | 98             |

For further research 7 composite binders were developed. In each superplasticizer PANTARHIT PC160 Plv (FM) was added in an amount of 0.3%, the ratio of binder: sand - 1: 3. To determine the optimal number of components in the "cement-lime-ash" system carried them grind to a specific surface of 600 m$^2$/kg at various ratios (Table 2).
Table 2 - The compositions and properties of composite binders

| No | Content cement, wt. % | Fly ash, wt. % | Limestone, wt. % | Compressive strength, MPa |
|----|-----------------------|----------------|-----------------|---------------------------|
|    |                       | Vladivostok TPP | Artem TPP | 3 d | 7 d | 28 d |
| 1  | 100 (without grinding) | –              | –             | 17  | 32.5 | 47.5 |
| 2  | 30                    | –              | 50            | 20  | 30.2 | 40.1 | 50.4 |
| 3  | 35                    | 45             | –             | 20  | 34.2 | 43.1 | 53.2 |
| 4  | 40                    | –              | 45            | 15  | 36.6 | 48.2 | 56.6 |
| 5  | 45                    | 45             | –             | 10  | 39.2 | 50.1 | 59.2 |
| 6  | 50                    | –              | 40            | 10  | 45.1 | 54.9 | 65.8 |
| 7  | 55                    | 40             | –             | 5   | 47.2 | 54.1 | 70.2 |
| 8  | 100                   | –              | –             | 5   | 60.3 | 81   | 103.2 |

Note: The control formulation No 1 (without final grinding); number 2-8 compositions milled to $S_{sp} = 600 \text{ m}^2/\text{kg}$

The resulting composite powder had a specific surface area equal to 600 $\text{ m}^2/\text{kg}$ (determinations were performed on surface meter PSH-11), 0.15-500 micron particle size, the average particle diameter is shifted to 0.65-11.2 mm, density 930 kg/m$^3$ (Figure 1).

Co-grinding of cement with ash and limestone can increase the activity of binding to 70.2 MPa. The increase in strength is due to the improvement of co-grinding of cement stone structure.

This is due to the presence the mill ground active mineral components that contribute to an earlier binding portlandite, intensify the process of hydration of clinker minerals.

At the same time, the larger particles act as nucleation sites and act as microfiller reducing shrinkage deformation, improve performance of the composite. A characteristic feature of the structure of cement stone on designed binders ground with additives is substantially smaller number of microcracks.

The structure of the cement paste on the composite binder denser than conventional Portland cement, it is a very dense packing of the grains in the total mass of neoplasms. Co-grinding of components leads not only to increase the ultimate compressive strength, but also increases the rate of curing of the samples with additives.

In order to determine the optimum particle size were produced co-grinding of cement, hyper plastisizer, ash and limestone (in a ratio of composition number 7) to different specific surface: 500, 550, 600, 700, 800, 900 $\text{ m}^2/\text{kg}$.

The results of determination of compressive strength of cement specimens are shown in Table 3.
Table 3 - The results of determination of compressive strength (MPa) cement stone samples

| Age of sample, d. | The specific surface area of the composite binder, m²/kg |
|------------------|--------------------------------------------------------|
| 500              | 46.1                                                   |
| 550              | 47.4                                                   |
| 600              | 47.2                                                   |
| 700              | 46.0                                                   |
| 800              | 45.6                                                   |
| 900              | 45.5                                                   |
| 3                | 50.3                                                   |
| 7                | 54.2                                                   |
| 28               | 68.1                                                   |

The optimal activity of the binder is 550-600 m²/kg. The increase activity in excess of these values has a negative effect on the structure. Using a binder with increased activity significantly speeds up the process of "setting" - "setting the end" of the mixture ends after 35-40 min., while the developing temperature 95-97°C. Fast setting prevents the formation of raw uniformly distributed spherical particles in the macrostructure of cement stone. Electron microscopy revealed the presence of heterogeneity macrostructure and irregularly shaped cells.

Calculation of the composition produced in accordance with the recommendations on the selection of compounds and heavy fine-grained concrete.

Baseline data for the design of the composition:
- the desired strength - 100 MPa;
- the mobility of the concrete mix slump - 10-12 cm;
- activity composite binder - 77.3 MPa;
- screening of crushed granite with water demand 7% and the true density of 2.6 kg/l and a bulk density of 1.37 kg/l;
- sand true density of 2.63 kg/l.

\[
W/C = \frac{AR_w}{R_w - A_i \cdot 0.5R_{cm}},
\]

coefficient A_i is accepted by the reference literature [5].

\[
W/C = \frac{0.43 \cdot 77.3}{100 - 0.43 \cdot 0.5 \cdot 77.3} = 0.40
\]

According to the schedule in reference [5] water flow turned 220 l/m³.

\[
CB = \frac{220}{0.4} = 550 \text{kg/m}^3
\]

Emptiness dropping out of granite rubble:

\[
E_{gr} = 1 - \frac{1.37}{2.6} = 0.47
\]

According to the handbook [5] extendable coefficient α = 1.5.

The amount of filler:

\[
F = \frac{1000}{0.47 \cdot 1.5 \cdot 1.37 + 1/2.6} = 1623 \text{kg/m}^3
\]

Thus, an exemplary structure of a concrete mixture: composite binder - 550 kg/m³, a filler - 1623 kg/m³, water - 220 l/m³. The optimal composition will be selected by experimental verification.

Research of physic-mechanical properties of fine-grained concrete showed that the use of the composite binder prepared by co-grinding of cement, fly ash and limestone, and hyper plasticizer allows to improve the characteristics of concrete, as compared to similar compositions made with other binding materials. This fact is explained more dense structure of cement stone developed composite binder lesser porosity due to the smaller amount of water in the concrete (Table 4).
Table 4 - Physical and mechanical properties of fine-grained concrete depending on the composition of the binder

| Composition | Binder, kg | Material consumption per 1 m³ | Slump | The compressive strength R, MPa | Prism strength R, MPa | Elastic modulus |
|-------------|-----------|-------------------------------|-------|--------------------------------|----------------------|-----------------|
|             | Cement    | Fly ash | Limestone | Hyper plasticizer | Screenings crushing of granite, kg | Sand, kg | Water, l | Slump | 10-12 | 10-12 | 10-12 | 10-12 | 10-12 |
| 1*          | 550       | -      | -         | -                | 220                   | -                | 107.5          | 86.3          | 61.2          |
| 2           | 288       | 235    | 27        | -                | 240                   | 241              | 83.7           | 59.5          | 43.8          |
| 3           | 275       | 246    | 29        | 1.2              | 1000                  | 242              | 84.2           | 60.3          | 44.5          |
| 4           | 257       | 257    | 36        | 1.2              | 1000                  | 242              | 76.3           | 55.2          | 40.9          |
| 5           | 244       | 268    | 38        | 1.2              | 1000                  | 243              | 75.2           | 55.0          | 40.8          |
| 6           | 230       | 278    | 42        | 1.2              | 1000                  | 244              | 75.0           | 54.9          | 40.8          |
| 7**         | 550       | -      | -         | -                | 215                   | -                | 63.1           | 42.3          | 36.2          |

* binder of low water with a specific surface 550 m² / kg.
** binder based on Portland cement produced by JSC "Spasskement".

The best physical and mechanical properties of the compositions showed No1 and No2: (cement - 48-51%, acidic ash - 43-45%, limestone - 4-9%).

It should be noted that with increasing amounts of ash and reducing the amount of cement to ensure equal mobility formulations (slump = 10-12), it is necessary to increase the amount of mixture introduced into the concrete mixing water [6,7,8].

Despite a number of advantages compared, for example, conventional heavy concrete, fine concrete has high shrinkage and reduced by 20-25% modulus [9,10].

Great opportunities to improve the performance opens disperse fine concrete reinforcing polymer and metal fibers.

In order to obtain high-density fiber-reinforced concrete was studied the effect of the introduction of the concrete matrix of reinforcing fibers. As a basis for the concrete matrix was adopted composition No 3 from Table 4.

To determine the optimal percentage of reinforcement were fine steel fiber concrete formed concrete samples of the same composition with different steel fiber content (Table 5).

Table 5 - The dependence of the strength of the fine steel fiber concrete reinforcement ratio

| Composition | Material consumption per 1 m³ | Reinforcement, Fiber % | R_compr, MPa |
|-------------|-------------------------------|------------------------|--------------|
| 3-1         | 550 240 1623 - -            | 0                      | 94.2         |
| 3-2         | 550 240 1623 - -            | 1                      | 96.1         |
| 3-3         | 550 240 1623 - -            | 1.2                    | 97.3         |
| 3-4         | 550 240 1623 - -            | 1.4                    | 99.8         |
| 3-5         | 550 240 1623 - -            | 1.6                    | 100.9        |
| 3-6         | 550 240 1623 - -            | 1.8                    | 99.5         |
| 3-7         | 550 240 1623 - -            | 2                      | 99.6         |

For further optimization of structure and prevent crack initiation, increase strength and durability of the structure was used basalt fiber by domestic production (Table 6). It was found that by
reinforcement 1.4-1.6% by volume is possible to obtain the maximum physical and mechanical properties. A further increase in the percentage of reinforcement is not advisable as it causes a decrease in strength and performance steel fiber concrete.

For further optimization of structure and prevent crack initiation, increase strength and durability of the structure was used basalt fiber domestic production (Table 6).

Table 6 - The dependence of the strength of the fine basalt fiber concrete reinforcement ratio

| Composition | Material consumption per 1 m³ | Reinforcement, % | R<sub>comp</sub>, MPa |
|-------------|-------------------------------|------------------|---------------------|
| 2-1         | Binder 550 Water 240 Filler 1623 Fiber - | 0 | 94.2 |
| 2-2         | 550 240 1623 1 | 0.0004 | 95.6 |
| 2-3         | 550 240 1623 1.2 | 0.0005 | 95.9 |
| 2-4         | 550 240 1623 1.4 | 0.0006 | 96.3 |
| 2-5         | 550 240 1623 1.6 | 0.0007 | 97.1 |
| 2-6         | 550 240 1623 1.8 | 0.0008 | 98.2 |
| 2-7         | 550 240 1623 2.0 | 0.0009 | 98.1 |

Comparing the experimental data on the Table 2 and Table 3 for further investigations take part steel fiber concrete No 5 (1.6% reinforcement).

The positive dynamics of growth of the strength of the composite binder under the joint influence of the fine constituents of ash, limestone crushing screenings and hyper plasticizers with the maximum increase in the activity of the binder is 62%.

Active mineral components of the composite binder contribute to the binding of Ca(OH)<sub>2</sub> produced during cement hydration additional amount hydrosilicate neoplasms. At the same time optimizing the process of structure formation is achieved by polydispersity composite components. Highly spherical ash particles act as nucleation sites and act as a nano- and micro- filler. In conjunction with the larger particles of the mineral component is more dense filling intergranular spaces cement concrete structure with a reduction in the number of pores and microcracks [11].

This is confirmed by micrographs of cement paste on the composite binder, the resulting joint grinding of clinker and industrial wastes of the Far Eastern region. Cement stone structure is a very dense packing of fine grains to the total weight of the crystalline neoplasms (Figure 2).

Figure 2 - The microstructure the cement stone: on CEM I 42,5 N (a) on the composite binder (composition No 7 in Table. 2) (b)

The additional amount of hydrated crystalline phases is contributing to filling the voids at the micro level in the crystalline matrix of calcium hydrosilicates on the boundary of the contact area, increasing the degree of adhesion binder with filler.
4. Conclusions
Designed the binder composite obtained by co-grinding of cement (55%) of acid composition of ash (40%) and limestone (5%) to a specific surface of 550 kg / m², the activity of 77.3 MPa.

It was found that the combined effect of mechanical activation increases pozzolanic activity of acidic sol, has a catalytic effect on the reaction activity of the surface of the ash and sand in the process of machining in the vario-planetary mill.

It was revealed that the additive ash and limestone crushing of waste composite binder for all dosages and reduce water permeability of concrete. Thus, it revealed a clear link between the properties of concrete and the characteristics of the cement stone structure - the increase in the number of neoplasms at the complex hydrosilicate reducing gel and capillary porosity, particularly at the molecular and submicroscopic levels that determine the growth and increasing strength of concrete impermeability.

Designed the fiber-reinforced concrete structure on the composite binder. At 1.6% of reinforcing steel anchoring a fiber can be obtained in terms of the maximum physical and mechanical properties (R_{compr} = 100.9 MPa).

It was found that the developed concrete provides an effective diffusion coefficient, it allows you to protect the premises from the toxic effects of expanded polystyrene. Enough material low water absorption and low water vapor permeability values - 0.021 mg / (m • h • Pa) explains the features of the pore structure of space the cement stone.

Reduced permeability (porosity) of fiber-reinforced concrete improves the corrosion resistance, including for concrete using incorporates acidic ashes.

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