New Composites in Cementless Concrete from Secondary Mineral Resources

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Abstract: The objective of the research was to obtain fine concrete composed of secondary mineral resources only on the basis of the created composite cementless binder (patent № 2196749) with its properties being equivalent to those of traditional heavy concretes made from natural resources and the energy – consuming portland cement. The mixture proportions of the concrete were as follows: 900 to 1000 kg/m^3 cementless binder; slag sand of thermal power plants or granulated slag from metallurgical plants (blast – furnace or steelmaking production) of 0 to 5 grading fractions; 250 to 300 kg/m^3 water. The slump, average density and compressive strength of the concrete were 7 to 10 cm, 2000 to 2100 kg/m^3 and 50 to 60 MPa respectively. Physico-mechanical and deformation characteristics of concrete versus time, frost – resistance and waterproofhess have been investigated. The results are in accordance with the requirements of the CIS countries interstate standards.

Keywords: cementless binder, slag sand, optimal composition, new cementless concrete, strength, physico-mechanical properties, five years period, frost resistance, waterproofness.

1. Introduction

The objective of the investigation was to obtain a new cementless fine concrete on the basis of the created cementless binder patented in 2003 with higher characteristics as compared to those for conventional concretes made of natural components and the concretes developed by us earlier in the 20 th century (certificate) of the Government of Russia [1, 2, 3].

2. Experimental investigations on the development of a new composition for cementless fine concrete

The investigations made in this section of work included:

1. Study of the initial materials.

2. Development of the optimum mixture proportions.

2.1. Materials

The following materials were used:

– a new cementless binder synthesized by us;

– slag sand (furnace bottom ash) from the Abakan thermal power station (TPS).

Cementless binder (patent № 2196749) has been developed by mechanochemical synthesis at planetary mills designed by the ICS&M SB RAS using the following materials: 60 to 80% high-calcium fly ash from the Abakan thermal power station, 10 to 30% used up moulding sand ("burnt sand") from the foundry production of the "Abakanvagonmash" (HAP), wastes of the abrasion works.

The methods of its production and its properties are given elsewhere [4, 5, 6, 7].

Table 1 shows the chemical (oxide) analysis of a binder used in this work. After treatment at a planetary current mill, the binder was a uniform fine material; the degree of dispersity (specific surface) and an X-ray amorphous phase were 600 to 750 m^2/kg and 30%, respectively. The concentration of heavy metals in the mixture was low (up to 100 g/t).

Table 1. Chemical Analysis of Cementless Binder and Slag Sand from the Abakan TPS

Materials	Compound										
	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	Na_2O	K_2O	TiO_2	MnO	Ba	LOI
Cementless composite binder	28.62	28.89	14.27	9.92	9.94	0.81	0.37	0.39	0.14	0.61	5.43
Slag sand from the Abakan TPS	56.47	29.92	3.50	8.16	9.63	–	–	–	0.17	–	–

2.2 Granulated Furnace Bottom Ash (Slag) up to 5 mm Size Fraction from the Abakan TPS

The bulk density and the absolute density of the slag are 1580 and 2430 kg/m^3, respectively. It is referred to as a dense slag. The chemical analysis of the slag sand is given in Table 1. It is characterized by the absence of free CaO and loss on ignition; according to the State Standard 25589-91 [8], it can be used in concretes as an aggregate as replacement for natural rubble and sand.

2.3. Development of the Optimum Mixture Proportions of Concrete

First, proportions of components for the concrete to be developed have been determined experimentally, namely:

- the optimum water-to-binder ratio;
- the maximum possible introduction of an aggregate (slag sand) into concrete;
- the effect of the heat-moisture treatment regime on the compressive strength of concrete.

The optimum water-to-binder ratio was determined by casting the 2x2x2 cm specimens with water at room temperature. The results of the experiment are in Fig. 1.

As can be seen from Fig. 1, the best water-to-binder ratio was 1/3. Then, the correlation between the compressive strength of a binder and the temperature of a mixing water was determined. The best results were obtained at the water temperature of 20–40 ^{0}C.

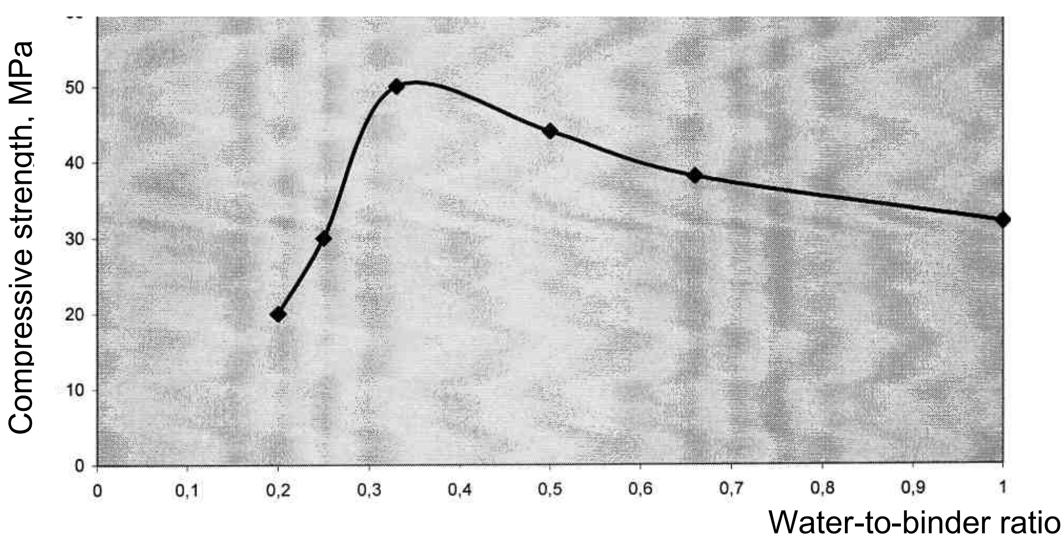

Fig. 1. Compressive strength of cementless binder versus water-to-binder ratio

The maximum possible introduction of a binder was determined using the 7x7x7 cm specimens cast at the water temperature of 30 ^{0}C with further hardening for 28 days. The test results are given in Fig. 2.

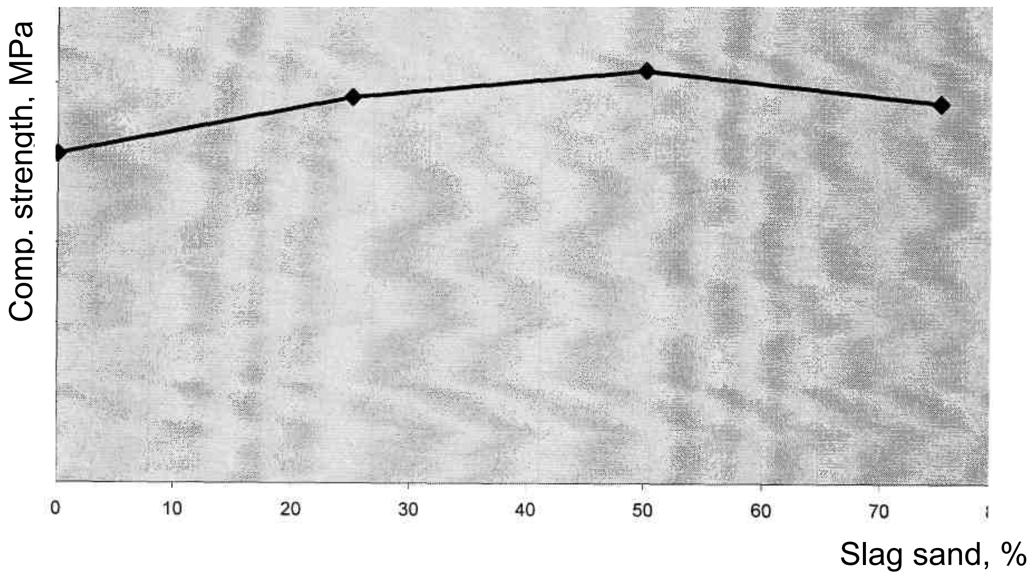

Fig. 2. Compressive strength of cementless fine composite concrete versus the amount of the slag incorporated

The analysis of the date of Fig. 2 shows that to increase the compressive strength of a fine concrete it is necessary to incorporate 50% slag sand. As a result of the investigations, the optimum mixture proportions for a fine concrete on the basis of the created cementless binder have been determined; they are as follows:

binder, kg/m^3	– 900–1000
slag sand, kg/m^3	– 850–1000
water, kg/m^3	– 250–300
slump, cm	– 7–10
the average density of concrete, kg/m^3	– 2085
compressive strength, MPa	– 45–55

3. Physico-mechanical and deformation properties of a new cementless fine concrete

3.1. Drying Shrinkage Creep for a 5-Year Period

For the determination of the drying shrinkage and creep strains of cementless ash-slag concrete, the 10x10x40 cm prisms were tested using the methods of NIIZhB [9]. Prisms were cured at 18 to 22 ^{0}C and 50 to 75% relative humidity. Shrinkage strains were measured by a dial type indicator with a scale of 0.001 mm.

The shrinkage strains were 0.4 and up to 0.6 mm at 24 hours and 28 days, respectively. Between 28 and 180 days, the shrinkage strain increased to 0.65 mm/m and ceased beyond this period. At 5 years it was 0.07 mm/m versus 0.75 mm/m according to the Building Regulations 2.03.01–84 for fine concretes.

Besides, the drying shrinkage of the concrete developed was smoother than that of a sand concrete (Fig. 3) which was attributable to a lower bleeding of the first. Due to a lower bleeding and higher strength gain as compared to the cement sand concrete, it obtained a higher crack resistance.

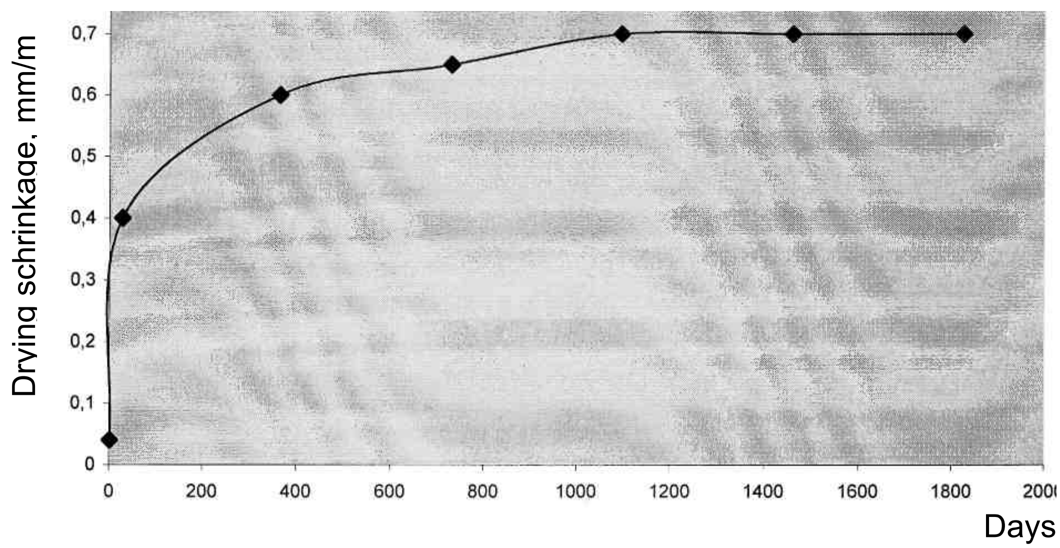

Fig. 3. Relative shrinkage of fine cementless concrete

Creep tests were performed on spring devices beginning at the age 28 days. Prisms, 10x10x10 cm in size, were subjected to a long-term loading at the applied stress constituting 50% of the prism strength (0.5R prism) (Fig. 4).

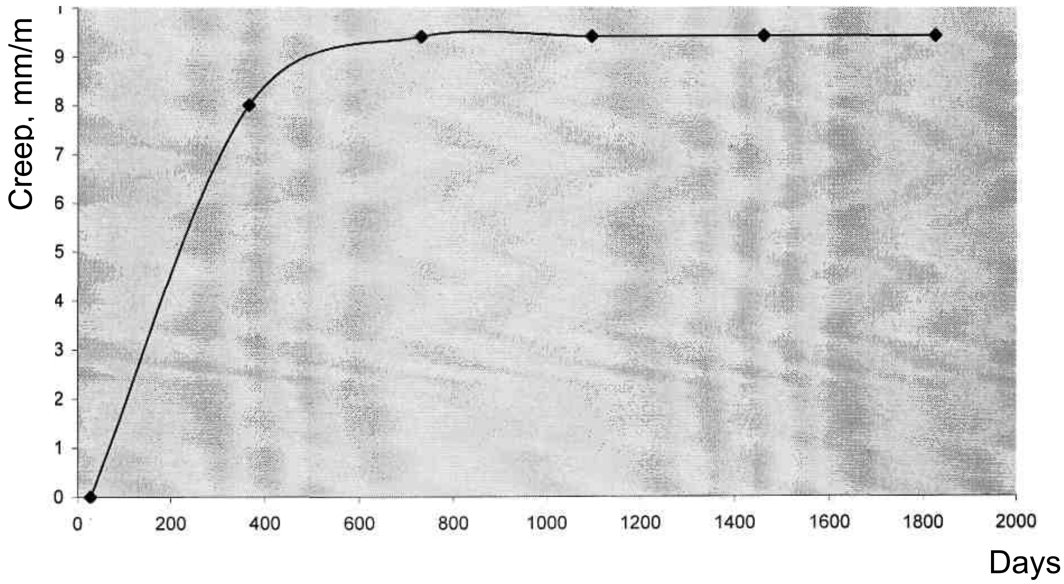

Fig. 4. Creep fine cementless concrete

The creep strain developed noticeably in the early of loading and then slowed down. As can be seen from the diagram, the relative creep strain of the fine cementless ash-slag concrete achieved 0.8 mm/m at 20 days, and the magnitude of the creep increased insignificantly between 20 and 180 days (up to 0.94 mm/m) ceasing beyond this period.

The concrete showed 12 to 15% less creep than the data reported for a fine sand concrete.

The main physico-mechanical and deformation properties of a new concrete have also been studied for 5 years (Table 2). It is evident from the data that concrete increased its compressive and prism strengths by 53 and 58%, respectively, over a 5-year period, the strength gain decreasing with time. The maximum compressive strength and prism gain was achieved at 28 days (18 and 26% respectively) with only 5 and less per cent gain at later periods. For comparison: the conventional concrete increases its strength up to 10 and 15–18% at 1-year and 5-years, respectively.

Modulus of elasticity of the concrete was determined using the NIIZhB methods [10]. It increased by 54% over a 5-year period versus 15 to 20% for fine cement concretes according to the Building Regulations 2.03.01.–84. Compressibility and extensibility increased by 23 and 50%, respectively, which exceeded the Building Regulations by 10 to 12%. During the last three years, these properties stabilized.

Table 2. Physico-Mechanochemical and Deformation Characteristics of Cementless Concrete

Properties of Concrete	Age of Testing, days						
	1	28	365	730	1095	1460	1825
Compressive strength, MPa	45.9	51.5	57.3	58.9	59.4	61.3	62.1
Prism strength, MPa	34.4	40.7	45.8	48.3	49.9	51.5	52.2
Prism-to-Cube strength ratio	0.75	0.79	0.80	0.82	0.84	0.84	0.84
Modulus of elasticity, MPa	15.5	19.7	28.7	28.9	29.3	29.4	30.4
Compressibility, mm/m	0.84	0.86	1.02	1.03	1.04	1.05	1.07
Extensibility, mm/m	0.08	0.1	0.14	0.15	0.16	0.18	0.18
Relative shrinkage, mm/m	0.04	0.4	0.6	0.65	0.7	0.7	0.7
Relative creep, mm/m	–	–	0.8	0.94	0.94	0.94	0.94

3.2. Frost Resistance of a New Composite Concrete

10-cm cube specimens were tested for frost resistance in the corrosion laboratory of NIIZhB in the accelerated mode developed by the NIIZhB [11]. Frost resistance was investigated in the altitude chamber “Nema TBV 800” (Figs. 5 and 6) according to the 3-d method of the State Standard 10060-95 [12].

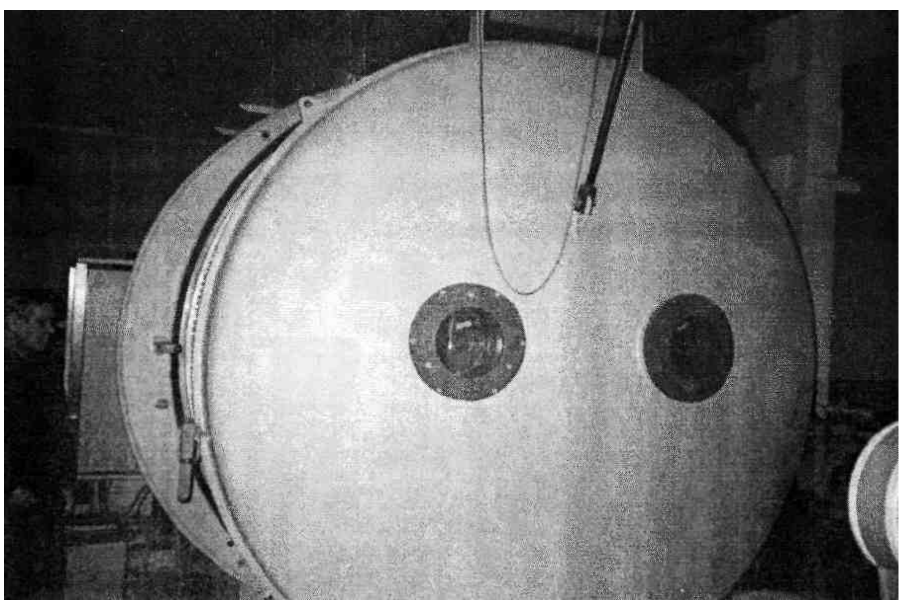

Fig. 5. Thermal altitude chamber “Nema”

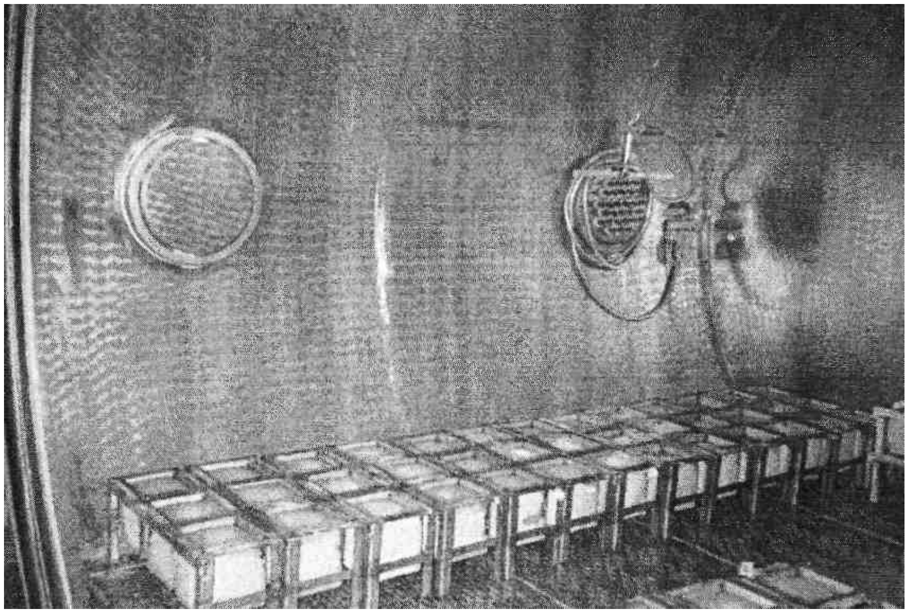

Fig. 6. The interior of the thermal altitude chamber “Nema”

Specimens previously saturated with a 5% NaCl solution were placed in a bath at 20^0C for 4 days.

Two hours after extraction from the bath, the control specimens were tested for compressive strength while the others were weighed and placed into a refrigerating chamber where they were frozen to -50 ^{0}C. After freezing, the specimens were exposed to thawing in the same baths. Charging the specimens into the refrigerating chamber, their freezing and thawing took 24 hours.

At the end of a definite number of cycles, the specimens were weighed again and tested for compressive strength. Testing was terminated when the strength of the specimens was reduced by more than 15% of the initial strength. After 5 cycles, which correspond to 30 cycles according to State Standard (F50), the compressive strength of specimens was reduced by 6%. After 10 cycles (F100), the surface of the specimens began to scale off, ribs crumbled but the strength of concrete increased by 12%, the coefficient of frost resistance being 1.2.

Up to 20 cycles (F200), the increase in the weight of specimens was observed which was attributable to the continuation of the reaction of hydration. After 20 cycles, concrete began to fail.

3.3. Waterproofness of Composite Fine Concrete

The waterproofness tests of cylinder specimens were performed on a standard installation (Fig. 7 and 8).

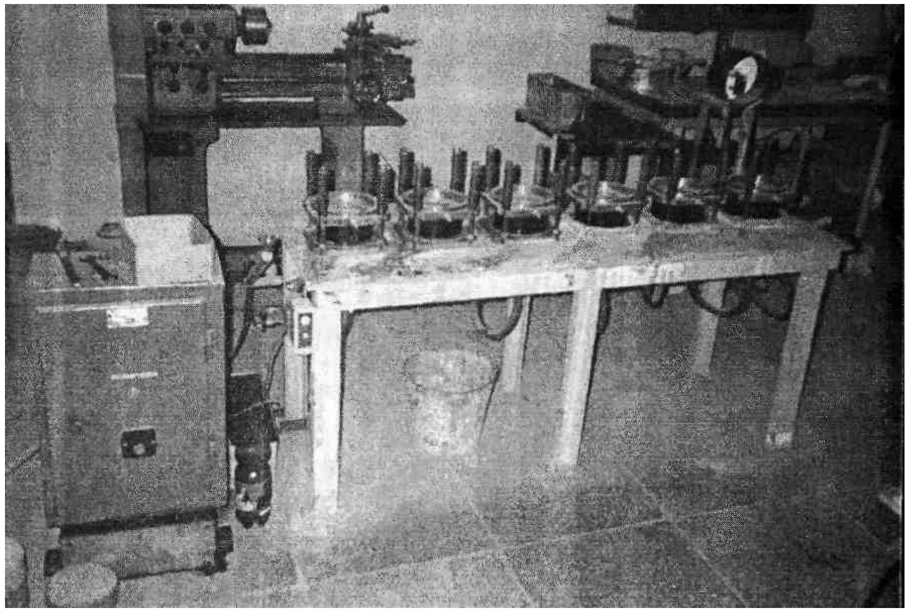

Fig. 7. The installation for testing specimens for water sorptivity

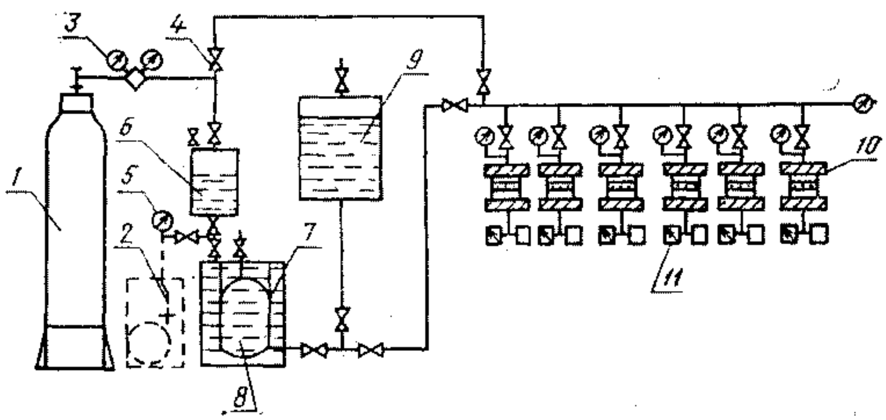

Fig. 8. Thematic diagram of the installation for testing specimens for waterproofness.
1 – gas balloon; 2 – pump; 3 – redactor; 4 – valve; 5 – manometer; 6 – pressure transmitter; 7 – water reservoir; 8 – elastic reservoir with deaerated water; 9 – spare reservoir with deaerated water; 10 – test pocket; 11 – the filtrate weight measurer

Waterproofness was determined in accordance with the State Standard 12730.5-84 [13] using the method of “wet spot”. Water was supplied to a lower base of cylinders under the pressure of 2 atmospheres (W2) and kept there for 6 hours. Then the pressure increased by 2 atm. The process continued until the sings of water filtration in the form of drops or wet spot appeared on the upper base of specimens. Waterproofness for the series of specimens was evaluated by a maximum water pressure at which on four out of six specimens infiltration was not observed.

Sides of the specimens were previously painted with three layers of paint so that water penetrated through the cylinder bases only. The waterproofness grade of concrete was referred to as W10.

3.4. Water Sorptivity

The water sorptivity tests were carried out on 70-mm cubes. They were placed in water at 20^{0}C and weighed every 24 h until the difference between the last and previous weighing was 0.1%

It was found that the water sorptivity of a new fine concrete according to mass and according to volume was 9.3% (W_m = 9.3%) and 19.8% (W_v = 19.8%), respectively. These values meet the requirements of the Building Regulations for fine concretes.

4. Conclusions

As a result of the 5-years investigations, a new cementless binder and a fine concrete on its basis have been created from secondary mineral resources only.

A new composite fine cementless concrete incorporating a cementless binder [5] and slag sand of 0 to 5 mm size fraction as an aggregate exhibited a higher performance than the concrete developed earlier [2, 14, 15].

Both furnace bottom ash sand from the burning of coal and granulated slags from the metallurgy production meet the standard requirements for use in concretes.

5. References

[1] Pavlenko, S.I., Aksenov, A.V., Merkulova, S.I. et al, Cementless fine mixture ready for use. “The experience of enterprises in utilization of industrial and domestic wastes”, Proceeding, the 2 nd scientific-practical seminar, Novokuznetsk, 23–25 November, 1999, Administration of Kemerovo region and Novokuznetsk, State committee for protection of the environment, Novokuznetsk: publishing house “Kuzbass Fair”, 1999, pp. 68–71

[2] Technical Certificate “On fitness of the product for use in construction at the territory of the Russian Federation” № TC-07-0175-99 (resolution of the Russian Federation government, 27.12.1977 № 1636) “Cementless ash-slag concrete fine mixture ready for use”, Register of the

Gosstroy Russia, 08.06.1995

[3] Pavlenko, S.I., Shmelkov, M.A., Phisico-Mechanical and Deformation Properties of Cementless Fine Ash-Slag Concrete over 5-year Period. Proceeding of “Fourth Canmet, ACI International Conference on Durability of Concrete”, Sydney, Australia, 1997, Supplementary papers, Published ACI, Farmington Hills, Michigan, USA, 1997, pp. 331–340

[4] Pavlenko, S.I., Bazhenov, Yu.M., Avvakumov, E.G., Aksenov, A.V., Mechanochemical Synthesis of New Composite Binder from Secondary Mineral Resources. 11th International Congress of the “CHEMISTRY OF CEMENT” Cement`s Contribution to Development in the 21th Century (ICCC 2003) Durban, South Africa, 11–16 May 2—3, Congress Proceeding, Volume 3, Alpha (Pty) Ltd. The Al Choice, Holcim Group, Volume 3, 2003, pp. 1217–1226

[5] Patent 2196749 Russia, C27C04D7/28 Cementless binder (S.I. Pavlenko, S.I. Merkulova, A.V. Aksenov et al), Inventions Bulletin № 2, 2003

[6] Diploma ans a silver medal of the VI International Saloon of Industrial Property “ARKHIMED” (Inventions, industrial samples, trade marks). Russia, Moscov, 18–21 Mach, 2003

[7] Pavlenko, S.I., Aksenov, A.V., A new composite binder and fine concrete with secondary mineral resources on its basis. Scientific edition-monograph, Moscow: Publishing house of International Association of the Construction higher education establishments, 2005

[8] State Standard 25589-91

[9] NIIZhB, Recommendations for Study of Creep and Shrinkage of Concrete. MR-1-75-Moscow, Stroyizdat, 1976

[10] NIIZhB, Recommendations for Determining Strength and Structural Characteristrics of Concrete Subjected to Short-Story-Long-Term Loading, pp. 10–76, Moscow, Stroyizdat, 1976

[11] Romanova, N.A., Ivanova, O.S., Hardening of the ash-containing concretes in winter conditions and their frost resistance. Proceedings, All-Union conference “Concretes on the basis of ash and slag from TPS and their use in construction”, Editor, S.I. Pavlenko, 1990, State education USSR, Minenergo USSR, Gosstroy USSR, SMI, Novokuznetsk, Publishing house, 1990, Volume 2, p. 84

[12] State Standard 10069-95

[13] State Standard 12730-84

[14] Pavlenko, S.I. Patent of Russia № 2065420. Concrete mixture, Moscow, Inventions Bulletin, 1996, № 23

[15] Pavlenko, S.I., Malyshkin, V.I., Bazhenov, Yu.M., Cementless fine composite concrete from secondary mineral resources. Scientific edition-monograph, Novokuznetsk, Publishing house of the Siberian branch of the Russian Academy of Sciences, 2000