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Water Resistant High Strength Concrete

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Abstract

The article presents the water resistance research of a group of highly functional concrete, namely high strength. In connection with the increase in the production volume of such concrete, a comprehensive study of all the properties, including water resistance, is extremely important.

Keywords: *Water, Resistant, Strength, Concrete*

1. INTRODUCTION

The term “highly functional concrete” was first used in the early 90s of the last century, and although there was no regulatory regulation at that time, it was clear that the combination of properties characterizing this concrete is of great interest, primarily in the field of durability manufactured designs.

The concept of highly functional two-part concrete. It connects the areas of high operational properties of hardened concrete (high durability and/or high mechanical strength, low abrasion, etc.) and the areas of high technological properties of concrete mix (high mobility, self-sealing, non-delamination, long shelf life, etc.). The production of highly functional concrete is due to the use of highly effective water-reducing and mineral additives such as microsilica, fly ash, fine slag, metakaolin, as well as high-quality aggregates and cements.

The increased cement content and the integrated use of chemical and mineral additives leads to the fact that the water-binder (W/B) Value of highly functional concrete approaches stoichiometric boundaries (W/B = 0.20-0.25), and in some cases it can be lower. As a result, highly functional concrete is characterized by an extremely dense microstructure, respectively, high water resistance, frost resistance and corrosion resistance.

Since the W/B ratio of these concretes is low, there is no capillary porosity in the volume and the main flow of water or other fluid occurs by the molecular diffusion mechanism, therefore the absolute value of permeability is low.

The main constraint on the widespread use of highly functional concrete in the construction of waterproof structures is the high value of autogenous shrinkage and an increased risk of early cracking of concrete.

The family of highly functional concrete can be divided into 3 large groups:

1. High strength concrete

2. Self-compacting concrete,

3. Reaction powder concretes.

In the framework of this work, the water resistance of only one group of highly functional concrete, namely high strength, is considered.

Concrete with strength class B60 and higher are considered to be high strength. The use of high strength concrete is not limited to cases when the structures operate under increased compressive loads (lower columns of high-rise buildings, bridge supports, oil wells, etc.), their use is also rational in cases where concrete has high demands on durability.

Since the strength of these concretes is characterized by a wide interval, we have conventionally divided them into concretes with strength up to 80 MPa and concretes from 80 MPa and higher. This

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separation is due to a different approach to achieve such strengths. So, high strength concrete up to 80 MPa is obtained mainly through the use of highly effective water-reducing additives and the right choice of materials. To obtain concrete above 80 MPa, along with water-reducing, the use of active mineral additives is necessary.

2. High strength concrete up to 80 MPa

The production of such concretes is based on the use of highly active cements with high consumption and high-quality washed and fractioned aggregates. In the concretes of this strength range, polycarboxylate or melaminesulfoformaldehyde (as unlike naphthalenesulfoformaldehyde, can be used in large doses) superplasticizers are used as water-reducing additives.

To study the water resistance of these concretes, we used the following materials: washed basalt gravel 5-25 mm from the Kilikyskoye deposit with a strength grade of 800, river sands washed with Mkr = 3.2 and Mkr = 2.2, Portland cement CEMII/AP 52.5N (Ararat plant), Sikament FFN (MSF-based superplasticizer).

The composition of the base concrete: G = 1000 kg/m^3, S = 835 kg/m^3, C = 460 kg/m^3, Sikament FFN-3% = 13.8 kg/m^3, W/C = 0.44. Since the water resistance of concrete with different amounts of cement from 460 kg/m^3 to 550 kg/m^3 was considered, the composition of concrete changed accordingly. The dosage of superplasticizer and the amount of added water remained unchanged. The water resistance of concrete was estimated by the water permeability depth on cylindrical samples of 150x150mm, and the strength of concrete on cubic samples of 100x100x100mm after 28 days of hardening in a normal hardening chamber. The test results are shown in table 1.

Table 1. High strength concrete test results.

	Cement content, kg/m^3	Sand fineness modulus	Concrete mixture			Concrete		
			W/C	Cone slump, sm	Density, kg/m^3	Density, kg/m^3	Strength, MPa	Water permeability depth, mm
1.	460	$M_{кр}$=3.2	0.39	22	2480	2465	70.7	20
		$M_{кр}$=2.2	0.44	26	2500	2449	65.8	21
2.	500	$M_{кр}$=2.2	0.42	26	2485	2457	67.3	24
3.	550	$M_{кр}$=2.2	0.38	26	2488	2465	77.5	26

As can be seen from the results of the table, the investigated high strength concretes are characterized by high relative density. The water permeability depth was 20-26 mm, which corresponds to the concrete brand for water resistance greater than W20.

When considering the results corresponding to composition N1 with a cement flow rate of 460 kg/m^3, we have that the use of sand with a smaller fineness modulus leads to an increase in the water demand of the concrete mix. The value of the W/C ratio increases from 0.39 to 0.44 for the same mobility class (A5). Accordingly, the strength of concrete decreases from 70.7 MPa to 65.8 MPa, however, this has no effect on the permeability of concrete: the water permeability depth remains at the same level and amounts to 21 mm. This is due to the blocking property of the fine-grained part of the sand, which is described in detail in Chapter 2. It follows that the positive effect of fine sand on the water resistance

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of concrete is greater than the negative effect of increasing the W / C ratio. That is why further experiments with high strength concrete in the framework of this study were carried out using sand with Mkr = 2.2.

An increase in cement content from 450 kg/m^3 to 500 kg/m^3 and 550 kg/m^3 leads to a decrease in the W/C ratio to 0.38 and an increase in concrete strength from 65.8 MPa to 77.5 MPa, however, in proportion to an increase in cement content, the permeability of concrete also increases. So, the water permeability depth increases by 23.8% from 21 mm to 26 mm for a composition with a cement content of 550 kg/m^3. Such an increase in permeability is associated with an increase in the volume of cement stone and, since the water transport mechanism in high strength concrete is mainly diffusion (capillary pores are absent here), its permeability also increases.

Therefore, for high strength concrete, as well as for ordinary, there is an optimal cement content, which ensures minimal permeability of concrete. In addition, an increase in the cement content above the optimum leads to an increase in shrinkage and the possibility of cracking and a decrease in the water resistance of the structure as a whole.

3. High strength concrete with a strength of more than 80 MPa.

The production of concrete with a strength of more than 80 MPa is based on the integrated use of water-reducing and chemically active mineral additives. To study this type of high strength concrete, we used a 3MB complex additive based on naphthalenesulfoformaldehyde dry superplasticizer and microsilica. The maximum consumption of the additive is 20% by weight of cement. In the study, the same materials were used as in the previous case with the difference that for all compositions sand with Mkr = 3.2 was used as a fine aggregate. For the basic composition was adopted above. As in the previous case, high strength concrete with different cement contents was considered: 450-600 kg/m^3, the curing of which took place under normal conditions.

The test results are shown in table 2.

Table 2. High strength concrete test results.

Binder consumption	Concrete mixture				Concrete			
	W/C	$\frac{W}{C+3MB}$	Cone slump, cm	Density, kg/m^3	Density, kg/m^3	Strength, MPa		Water permeability depth, mm
						7 days	28 days	
C=450 kg/m^3+3MB-20%	0.33	0.27	20	2550	2542	65.9	97.6	7
C=500 kg/m^3+3MB-20%	0.31	0.26	23	2548	2539	75.5	92.6	10
C=600 kg/m^3+3MB-20%	0.27	0.22	25	2560	2543	77.4	88.4	12

Note: the results are the average of 3 samples.

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From the results of the table it follows that these concretes with the addition of microsilica have a denser structure and are less permeable in comparison with the high strength concretes shown in Table 1. This is explained, firstly, by the filling effect. Since the average particle size of microsilica is about 0.1 μm, they are located in the voids between the cement grains, creating a structure of micro concrete in a cement stone, where the coarse grains are large aggregate and the silica particles are small. Such dense packaging, as experience shows, increases the impermeability of concrete at times.

In addition, microsilica is a chemically active mineral additive that binds calcium hydroxide ($Ca(OH)_2$) formed during cement hydration into low-base calcium silicate (CSH), which is not only a more durable mineral, but also more resistant to leaching.

In this study, the value of water-binding ratios for concrete is 0.22-0.27. Under such conditions, complete hydration of the cement is impossible due to the lack of water in the mixture. This means that unreacted cement grains can be perceived as micro-fillers, which further compact the system. It also contributes to the low water resistance of high strength concrete.

As in the previous case, there is an increase in the permeability of high strength concrete with an increase in the cement content. So, at a cement consumption of 600 kg/m^3, the water permeability depth increases by 71% (from 7 mm to 12 mm) compared with concrete with a cement content of 450 kg/m^3. There is also a decrease in concrete strength from 97.6 MPa to 88.4 MPa, which indicates the non-optimality of increasing such cement consumption.

Analyzing the water resistance values of high strength concrete, we can conclude that the most optimal cement content is 450-500 kg/m^3.

Similar tests of water resistance of high strength concrete using microsilica and fine slag as mineral additives are given in [1]. The test of water resistance of concrete here was carried out according to the Chinese standard GBJ 82-85, which basically repeats the method of determining the grade of concrete by water resistance according to GOST 12730.5. The only difference is that the initial pressure supplied to the series of samples is 0.1 MPa, and it increases by 0.1 MPa every 8 hours until there are signs of filtration on the upper end sides. So, in this experiment, the pressure increased to 4.2 MPa, and since there were no signs of filtration, the samples were cracked, and the water permeability depth was measured. The compositions of the investigated concrete and test results are shown in table 3.

Table 3. Test results of high strength concrete with various mineral additives [1].

Concrete mixture, kg/m^3							Cone slump, cm	Concrete strength for 28 days, MPa	Water permeability depth, mm
Concrete	Microsilica	Fine slag	Gravel	Sand	Water	Superplasticizer, %			
600	-	-	1134	610	150	1.5	22.5	81.1	40.0
420	180	-	1134	610	150	1.6	22.5	105.0	14.0
420	60	120	1134	610	150	1.6	23.0	99.6	12.5

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The results of table 3 indicate the high-water resistance of the investigated high strength concrete. The effectiveness of using complex mineral supplements is also obvious. So, with a constant water-binding ratio of 0.25, the water resistance of concrete increases by 185% when replacing part of the cement with microsilica and by 220% when using microsilica and fine slag.

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