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Building Demolition Products as a Secondary Raw Material for High-Strength Concrete

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***Abstract* – The article presents an analysis of the experience of using the products of buildings and structures demolition, the technology of recycling secondary raw materials to produce secondary raw materials for concrete. The results of tests of heavy high-strength concrete (HSC) on the base of filled binders (FB) obtained using the products of processing of concrete broken materials and crushed bricks are given. Using local natural and man- made raw materials, optimal formulations of highly mobile concrete mixes with a grade of P5 cone sediment and persistence of more than 8 hours designed to obtain HSC classes of compressive strength to B60-B80 with unique performance properties. The physical- mechanical characteristics of HSC of local natural and man- made raw materials of classes B30-B80 are studied and the growth in time of their strength characteristics are evaluated depending on the type of binder. The physical-mechanical characteristics of HSC based on natural and man-caused raw classes B30-B80 and held at the time of growth assessment of their strength properties depending on the type of binder. The coefficient of prism strength for concrete of FB is in the range of 0.82-0.86, when for concrete of a traditionally used PC, this indicator is below 0.78.**

Keywords – building demolition products; concrete broken materials; crushed bricks ; ecology ; recycling; secondary aggregate; fine ground filler; filled binders ; concrete; persistence of concrete mixtures; high strength.

I. INTRODUCTION

Analysis of the local natural and technology-related raw materials of the Chechen Republic showed that the region is unusually rich in the most diverse reserves of natural raw materials necessary for the effective development of the construction industry in the region [1-3]**.**

In addition to natural raw materials, the Chechen Republic has accumulated large volumes of large-tonnage industrial waste. This is, first, waste from the demolition of buildings and structures, after the military events in the 90s and in the early 2000s, which mainly represent concrete broken materials, crushed bricks, reinforced concrete, the amount of waste of which from the total volume is 60% and more [7-11].

The great interest in the use of the secondary product of crushing concrete materials is due to the possibility of its use as a fine-ground mineral component in mixed or so-called filled binders by improved technological and physical-mechanical properties, based on the use of which it is possible to produce high-strength concrete, including for monolithic high-rise construction [12-15].

II. METHODS AND MATERIALS

The natural sand of the Chervlensky field of the Chechen Republic with the following characteristic used as fine aggregate: gradation factor Mcr = 1.8-1.9; porosity - 40.8%; the content of dust and clay particles - 1.7-1.9%; density ρist. = 2617 kg/m^3; density ρnas. = 1512 kg/m^3.

Local crushed gravel of 5-20 mm from the Argunsky and Sernovodsky fields of the Chechen Republic and imported crushed gravel of the 5-20 mm fraction from granite-diabase rocks of the Alagirsky field of the RSO-Alania used as coarse aggregate.

As a binder in experimental studies used additive-free portland cement brand PC 500 D0 of « Chechen cement » production (Chechen Republic, v. Chiri-Yurt) с НГ = 25,5 %, specific surface 3252 sm^2/g, water segregation ≤ 18 % and setting up time 2 h. 15 min. (beginning) и 3 h. 40 min. (ending).

The mineralogical composition of the binder is as follows: C_3S = 59 %; C_2S = 16 %; C_3A = 8 %; C_4AF = 13 %;

As plasticizers additives modern additives of the following manufacturers of chemical construction used:

1. Company «POLIPLAST» – super plasticizer (SP) «Linamiks PK» and hardening retarder « Linamiks RS» on the base of Polyoxyethylene derivatives of polymethacrylic acid, liquid;

2. Companies «MC-Bauchemie» – hyper plasticizer « MC-PowerFlow» on the base of the latest technology of MC polycarboxylate ether, liquid;

3. Companies «Sika» – SP «Sika ViscoCrete 5-600 SK» based on polycarboxylate esters, satisfying the requirements № 2493-005-13613997-2008, liquid;

4. Companies LLC «TOKAR» (Vladikavkaz) - complex multifunctional additive "D-5" that meet the requirements SGAS 24211-2008, dry powder.

The raw materials for the production of dispersed man-made mineral fillers (MMF) were local materials that were available, mainly man-made, concrete broken materials, ceramic crushed bricks (CCB), ash-and-slag mixture of the Grozny TPS and very small substandard quartz sands used in comparative tests.

III. RESULTS

In order to obtain optimal formulations of high-strength concrete with the integrated use of local raw materials, including man-made nature, compositions filled binders (FB) with finely ground man-made mineral filler((MMF) were developed, allowing obtain a high-strength cement stone with noticeably smaller pores and less shrinkage (Tables 1 and 2).

Due to the fact that for designing complex, concrete of different strength classes (B40, B75-B80) was laid, the task was to develop a line of high-strength concrete (HSC), starting from the middle classes B40-B50 and ending with high-strength concrete class B80-B90, with the integrated use of local raw materials, including man-made nature.

TABLE I. COMPOSITION OF FBS WITH FINE GROUND MMF

Type of binder	Composition of FB , % by weight			
	PC M500 Д0 « Chechen cement »	MMF		Additive D-5
		concrete broken materials	ceramic crushed bricks (CCB)	
Filled binder(FB) brand -75:25	75	16	7	2
Filled binder(FB) brand , -60:40	60	27	11	2

Formulations designed mark on cone P5 (CC = 22 ± 2 sm).

The compositions and properties of high-quality concrete mixtures of increased persistence and durability presented in Tables 3 and 4.

TABLE II. PROPERTIES OF FBS WITH FINE GROUND MMF

Type of binder	FB, %	S_b binder, m^2/kg	True density, kg/m^3	Water separation, %	Setting up time, h. - min.		Activity, MPa
					beginning	ending	
FB-75:25	17	558	2986	15,5	3-40	5-30	71,3
FB-60:40	19	577	2905	14,7	3-55	5-35	60,7
PC M500 D0 « Chechen cement» *(for comparison)*	26	325	3115	18,0	2-15	3-40	52,6

The chemical additives used as super plasticizer (SP) «Linamiks PK» and hardening retarder «Linamiks RS».

The hyper plasticizer « Linamiks PK » was metered in concrete mixtures on FB in an amount of from 0.3 to 0.4% by weight of cement, i.e. in a small amount, since FB has already a complex modifying additive D-5, which has plasticizing properties.

The additive «Linamiks RS» was dozed in the amount for 0.7% by weight of cement and used in concrete mixtures of increased persistence (7-8 hours or more).

Thus, using local natural and man- made raw materials optimal formulations of high-performance concrete mixes with a grade of P5 cone sediment and persistence of more than 8 hours to produce HSC have been designed.

The prism compressive strength of the HSC compositions studied by us was determined at the age of 28 days on control prisms with dimensions of 100x100x400 mm.

TABLE III. COMPOSITIONS OF CONCRETE MIXTURES BASED ON LOCAL NATURAL AND MAN-MADE RAW MATERIALS

№ of composition	Design class (brand) of concrete	Consumption of concrete components, kg/m³							
		Break-stone		Sand	Binder		Water	Additive	
		Argunsky	Sernovodsky	Chervlensky	FB-60:40	FB-5:25		Linamiks K (%by eight)	Linamiks RS (% by eight)
1.	B30 (M400)	1000	-	855	385	-	161	1,1 (0,3)	2,5 (0,7)
2.	B40 (M500)	1000	-	795	435	-	158	1,3 (0,3)	3,0 (0,7)
3.	B45 (M600)	1000	-	765	470	-	162	1,4 (0,3)	3,3 (0,7)
4.	B55 (M700)	-	1000*	735	-	540	161	1,6 (0,3)	3,8 (0,7)
5.	B60 (M800)	-	1000*	685	-	600	165	1,8 (0,3)	4,3 (0,7)
6.	B80 (M1000)	-	1000*	620	-	700	170	2,1 (0,3)	4,9 (0,7)

a. Note: * - used enriched more durable crushed stone fraction of 5-20 mm with a mark of crushiness M1200.

TABLE IV. PROPERTIES OF CONCRETE MIXTURES BASED ON LOCAL NATURAL AND MAN-MADE RAW MATERIALS

№ of composition	Design class (brand) of concrete	Required strength, MPa	Characteristics of the mixture			
			V/C	Density, kg/m³	CC, sm	Persistence, h
1.	B30 (M400)	39,3	0,45	2398	23	7,0
2.	B40 (M500)	52,4	0,36	2407	21	7,0
3.	B45 (M600)	58,9	0,34	2427	23	8,0
4.	B55 (M700)	72,0	0,31	2451	23	8,5
5.	B60 (M800)	78,6	0,30	2462	21	9,0
6.	B80 (M1000)	104,7	0,32	2481	24	10,0

The test results developed HSC based on man- made raw materials presented in Tables 5 and 6.

From the analysis of Table 5, we can see that the dynamics of the curing of concrete on FB are markedly different from the dynamics of the growth of the strength of concrete at PC. We can note noted in Figure 1.

It was established that the process of concrete strength increase in FB at an early age (1-3 days) accelerated by 1.5-2 times. Therefore, concrete on FB at the age of 1 day has strength of about 33-36% of the design, and 3 days old - this indicator reaches up to 70%. The 7-day strength of concrete obtained using FB is about 85-90% of the design strength, which is significantly higher than traditional compositions of a conventional PC. These indicators for concrete on PCs at the age of 1, 3 and 7 days are about 24, 35 and 70% of the design strength, respectively. This phenomenon is markedly rapid increase in strength of concrete on FB due to the feature of the additive D-5, which is part of the filled binder for 2% of its mass.

TABLE V. PHYSICAL AND MECHANICAL PROPERTIES OF HSC ON THE BASIS OF RAW MATERIALS OF DIFFERENT NATURE

№ of composition	D_c, kg /m³	Compressive strength at the age of ..., MPa					R_{pr} / R	Rtc
		R				R_{pr}		
		1 day	3 days	7 days	28 days	28 days		
1.	2336	14,3	31,7	41,1	46,7	38,3	0,82	4,8
2.	2352	17,8	38,9	51,7	58,1	47,6	0,82	5,7
3.	2358	22,3	45,5	59,9	65,8	54,6	0,83	6,4
4.	2365	26,4	54,1	69,6	77,3	65,7	0,85	8,2
5.	2383	29,5	59,8	75,3	85,4	72,6	0,85	8,6
6.	2408	40,9	81,8	106,1	115,3	99,2	0,86	9,7

b. Note: where Dc – density of concrete, kg/m³; R – concrete cube compressive strength, MPa; R_{pr} – compressive prism strength of concrete, MPa; R_{pr} /R – the ratio of prism strength of concrete to cubic, characterizing its homogeneity; Rtc – flexural strength of concrete, MPa.

TABLE VI. DEFORMATIVE PROPERTIES OF HSC BASED ON THE RAW MATERIALS OF VARIOUS NATURE

№ composition from Table 3	$E_c \cdot 10^3$, MPa	Deformation ε, mm/m		Poisson's ratio,μ	Concrete shrinkage, m/m	W_M, % by weight	W	F
		longitudinal deformation of concrete ε_1	lateral deformation of concrete ε_2					
	43,5	2,08	0,49	0,237	0,62	2,7	W14	F400
2.	44,8	1,99	0,47	0,235	0,60	2,7	W14	F400
3.	46,2	1,96	0,46	0,234	0,55	2,5	W16	F500
4.	47,5	1,96	0,45	0,228	0,40	2,4	W18	F500
5.	52,4	1,95	0,43	0,222	0,36	2,4	W20	F600
6.	54,5	1,90	0,40	0,210	0,31	2,2	W20	F600

c. Note: where $E_c \cdot 10^3$ – modulus of elasticity of concrete, MПa; ε – deformation, mm/m; ε_1 – longitudinal deformation of concrete, mm/m; ε_2 – lateral deformation of concrete, mm/m; μ – Poisson's ratio (transverse strain ratio); W_M –water absorption of concrete by weight, %; W – concrete grade for water resistance; F – brand of concrete for frost resistance.

The additive D-5, which noticeably increases the mobility of concrete, mixes in the first hours of its preparation (1-3 hours) due to its plasticizing effect, already in the first day, to a certain extent, turns into the role of "additive accelerator". This feature of this additive makes it multifunctional (complex).

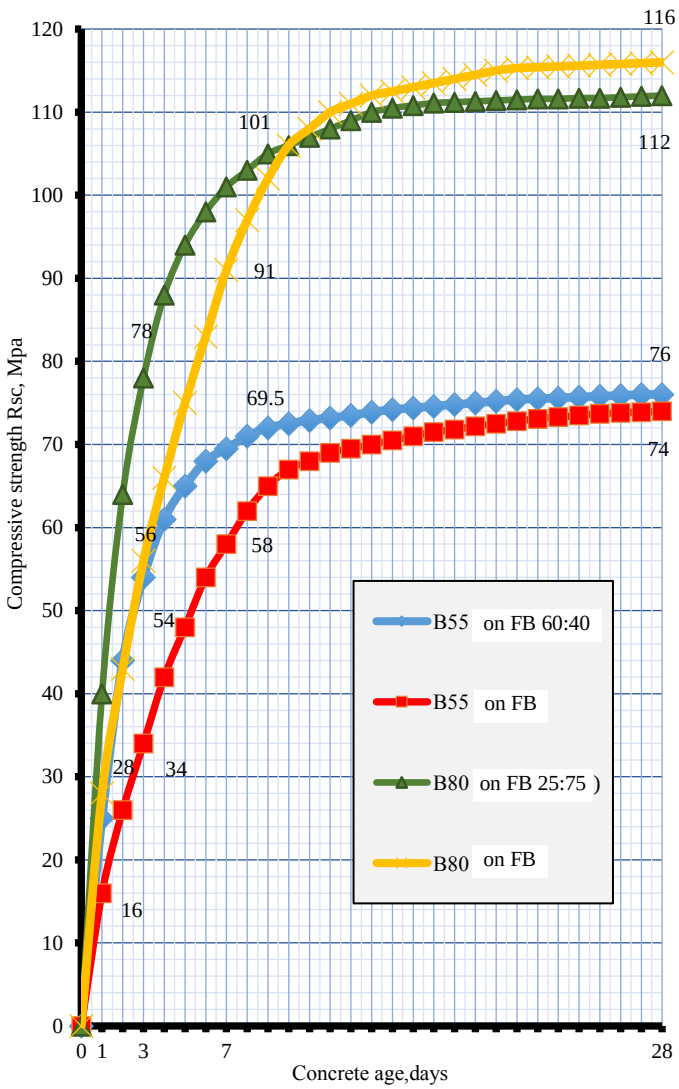

Fig. 1. Estimation of the growth in time of the strength characteristics of concrete depending on the type of binder.

According to test results ,with the transition to FB instead of traditional PC, the difference between cubic and prism strength is noticeably reduced, which indicates a higher homogeneity of concrete on HB compared to compositions on a traditional PC. Thus, the coefficient of prism strength (i.e., the ratio of R_{pr} / R) for concrete on HB is in the range of 0.82-0.86 , when this value is lower than 0.78 for concrete on a traditionally used PC. At the same time, the coefficient of prism strength increases with an increase in the activity of the filled binder and a decrease in the proportion of MMF (Figure 2).

In domestic literature [1-5, 16-22], the coefficient R_{pr} / R for concrete of middle classes is usually determined by using the following relationship:

$$R_{pr} / R = (0{,}77\text{-}0{,}00125\ R) \qquad (1)$$

where R – cubic strength, MPa;

R_{pr} – prism strength, MPa.

Dependence (1), which has been rather well studied and tested on concrete of the middle classes (up to B50), has not been practically studied for high-strength concrete, with the exception of a small group of scientists, including Mkrtchian A. M., Aksenov V. N. and others.

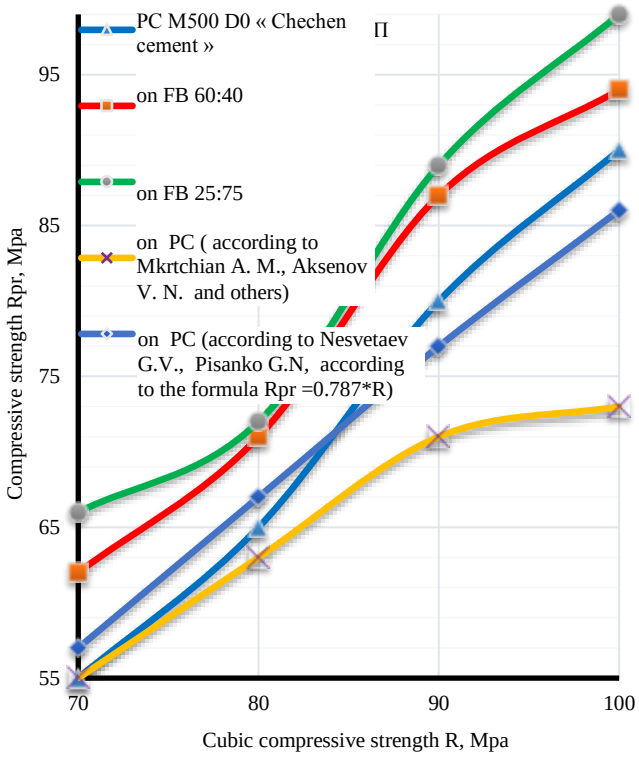

Fig. 2. Dependence of prism strength R_{pr} on cubic R when using binders of various nature.

In Eurocodes for high strength concrete classes above B60-B80, a constant prism strength coefficient is given, equal to 0.8. O. IA. Berg in his scientific works cites this dependence as R_{pr} = f(R) and indicates that it is linear. At the same time, for heavy concrete, including high-strength, the prism strength coefficient recommended as constant, equal to 0.78.

As can be seen from the comparative analysis and Figure 2, the obtained dependences Rpr = f (R) do not contradict the known literature data. The coefficient of prism strength of concrete on the base is significantly higher than that of equal strength concrete on PC. This indicates high degree of homogeneity of concrete on FB.

IV. CONCLUSION

Thus, formulations of filled binders (FB) with an activity of 60-71 MPa with finely dispersed MMCs from concrete broken materials and crushed bricks with a ratio of 70:30%, respectively have been developed and investigated, while the proportion of the filler mixture in HB was 25 and 40% by weight of the binder . The use of MMC from concrete broken materials and crushed bricks is to its hydraulic activity due to non-hydrated grains of cement in the composition of concrete broken materials in an amount up to 20-25% of the binder, used in the preparation of recyclable concrete, which being located between the particles FB and significantly strengthens the cement stone by reducing the differential voidness of the original water-based paste to smaller pores and voids, which leads to the formation of cement;

The optimal formulations of highly mobile concrete mixtures are designed using local natural and man-made raw materials with a grade of P5 cone sediment and persistence for more than 8 hours to obtain HSC classes of compressive strength up to B60-B80 with unique performance properties;

According to test results, with the transition to FB instead of traditional PC, the difference between cubic and prism strength is noticeably reduced, which indicates a higher homogeneity of concrete on FB compared to compositions on a traditional PC. Thus, the coefficient of prism strength (i.e., the ratio of R_{pr} / R) for concrete on FB is in the range of 0.82-0.86, when this value is lower than 0.78 for concrete on a traditionally used PC. At the same time, the prism strength coefficient increases with an increase in the activity of the filled binder and a decrease in the proportion of MMP.

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