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High-Quality Concrete Based on Binder with Technogenic Filler

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***Abstract* — The paper presents the most optimum concentration of crushing dust of concrete scrap (CDCS) ground in the laboratory spherical mill to a specific surface of 4000 cm2/g for further replacement of a part of cement. High strength parameters are achieved at partial replacement of cement with various concentrations of CDCS obtained from concrete fragments of reinforced concrete plates produced in 1976. X-ray phase analysis of cement stone samples obtained using 30% of CDCS instead of cement separately and together with Odolit-K and Frem Giper S-TB superplasticizers in 1, 7 and 28 days of hardening in normal conditions is used. The morphology of a cement stone surface with the use of CDCS and superplasticizers in various periods is studied.**

Keywords— *crushing dust of concrete scrap, superplasticizers, X-ray phase analysis, cement stone surface.*

I. INTRODUCTION

It is known that silicon dioxide additives in the form of its nanosized component improve the quality of concrete. The production of cement is technologically complex and power-intensive process bound to the processing of natural raw materials. In this regard, the manufacturers are continuously searching for ways to reduce the cost of their products. The construction materials with the use of industrial wastes caused by dismantling of concrete structures is a relevant task based on the use of residual properties of cement clicker particles in concrete. The introduction of crushed wastes of technogenic raw materials into the composition of concrete mixes is economically viable. Such approach makes it possible to save natural raw materials and improve the environment. The strength indicators of concrete with technogenic waste can compete with the standard content of natural components.

The processing of reinforced concrete structures of dismantled buildings and structures results in 30% of the crushing dust. Its broad application is limited due to heterogeneity and insufficiently studied role of concrete crushing dust. As noted in the given literary review, it is mainly introduced in the production of construction materials when the quantity of binders and other fillers is reduced [1-7].

Mixes, in which the cement component is replaced with fly-ash component, are widely known alongside with such concretes [8].

The study of the structure and surface of ground crushing dust of concrete scrap demonstrate their specific chemical relation and adhesion during mechanochemical activation [9]. The given review indicates problems and prospects of technogenic raw materials. It becomes apparent that the decrease of a cement binder content is a key factor. The given study sets the task of the maximum economy of a cement binder through its replacement with ground crushing dust of concrete scrap. At the same time, the reduction of portland cement shall not affect physical-mechanical properties of obtained cement stone. To solve the above task, we conducted some studies to establish the optimum CDCS dosage to reach high strength indicators.

II. METHODS AND MATERIALS

The study was based on the use of portland cement Chiri-Yurtovsky M500, ground crushing dust of concrete scrap received through a standard sieve by grading of concrete scrap from fragments of reinforced concrete plates produced in 1976. Manufacturer – concrete plant, Vladikavkaz, North Ossetia Republic.

Standard uniform sand in accordance with GOST 6139-2003 was used. The following materials were used for heavy concrete: coarse filler crushed stone from concrete scrap – 5-20 mm, true density – 2.49 g/cm^3, bulk density – 1223 kg/m^3, the strength of crushed concrete stone was defined in accordance with GOST 8269.0-97 and GOST 8267-93, crushing capacity in a cylinder – 600. The sand of Chervlensky pit of the Chechen Republic (CR) enriched by coarse-grained river sand $M_{кр}$ =2.5. Water – tap water. The activity of cement with fine crushing dust of concrete scrap (CDCS) was defined in accordance with GOST 310.4-81(2003). To obtain plasticized mixes and reduce the water-cement ratio of cement and sand mixes and concrete, the polycarboxylate-based plasticizing additive Odolit-K (Russia) and Frem Giper S-TB (Belarus) were used. The CDCS was exposed to grinding within 12 minutes in a spherical mill Retsch PM 100 (Germany). The specific surface of ground crushing dust of concrete scrap (CDCS) was defined via PSH-12SP and made 4000 cm^2/g. The morphology of a cement stone was studied via scanning electron microscope (SEM) using Quanta 3D 200i (USA). X-ray phase analysis of obtained cement stone was conducted using Shimadzu XRD-6000 diffractometer (Japan). The chemical composition of raw materials, cement and its fractions was defined via SEM using dispersion and energy spectrometer by EDAX.

III. Results

The binder mixes were prepared at various CDCS dosage. To define the binder activity of obtained powders the prismoidal specimen (40x40x160 mm) were made in accordance with GOST 310.4-81(2003) "Cements. Methods of determination of compression and bending strength". Table 1 shows the test results.

TABLE I. Strength Properties Of Cement Stone With Ground Concrete Crushing Dust

No.	Composition of mixed binder C:CDCS (%)	Odolit-K in % of C+ CDCS	Frem Giper S-TB on % from C+ CDCS	W/W	Cone flow diameter, mm	Concrete compression/bending strength in MPa on 1, 7 and 28 days of hardening		
						3	7	28
1	Control	-	-	0.41	108	16.0/2.1	32.3/4.2	39.1/5.1
2	100:0	1.4		0.32	110	31.8/4.3	48.1/6.2	56.4/7.1
3	100:0		0.6	0.313	111	30.6/4.4	50.4/6.5	58.2/7.1
4	80:20			0.42	108	13.3/1.8	29.0/3.9	36.4/4.4
5	80:20	1.4		0.33	110	28.8/3.6	44.1/5.4	52.5/6.2
6	80:20		0.6	0.32	110	29.5/3.9	48.5/6.1	55.1/6.4
7	70:30			0.42	109	12.2/1.5	27.1/3.5	34.3/4.0
8	70:30	1.4		0.34	108	24.1/3.1	42.3/5.0	50.5/6.1
9	70:30		0.6	0.33	108	25.9/3.1	47.7/5.6	53.6/6.3
10	60:40			0.45	110	10.2/1.5	16.2/2.0	22.1/2.4
11	60:40	1.4		0.38	110	12.6/1.4	28.0/3.7	30.5/3.9
12	60:40		0.6	0.39	109	14.1/1.7	29.2/3.9	33.1/4.1

Table 1 shows that the addition of Odolit-K in the amount of 1.4% increases the compression strength on the third day of normal hardening by 99% and the bending strength by 110% in comparison with control samples. The compression strength and the bending strength of samples with Frem Giper S-TB in the amount of 0.6% of cement content in the same age of normal hardening make 91 and 109%. The compression strength of samples at the age of 28 days of normal hardening with the same additives increased by 44.2 and 48.9%. The bending strength in 28 days of normal hardening with Odolit-K and Frem Giper S-TB increased by 39.2% in comparison with control samples.

The introduction of 20% CDCS into cement and sand solution as a part of cement leads to the reduction of compression and bending after 3 days of normal hardening by 17 and 28%. The compression and bending strength of test beams made of cement with 20% CDCS and 1.4% Odolit-K on the third day of normal hardening was higher the control sample by 80 and 71% and the addition of 0.6% Frem Giper S-TB increased the above parameters by 84 and 86%.

The tests of the same samples with Odolit-K on the 28th day of normal hardening increase the compression and bending strength by 34.3 and 21.6% above the control samples, and the addition of 0.6% Frem Giper S-TB leads to the increase of these indicators by 40.9 and 25.5%.

The introduction of 30% CDCS into cement and sand solution as a part of cement leads to the reduction of compression and bending strength on the third day of normal hardening by 24 and 28.6%, and on the 28th day of normal hardening these indicators decrease by 12.3 and 21.6%. The compression and bending strength with the addition of 1.4% Odolit-K on the third day of normal hardening are higher that the control sample by 51 and 47.6%, and the addition of 0.6% Frem Giper S-TB increases the compression and bending strength by 62 and 47.6%.

The tests of the same samples with Odolit-K on the 28th day of normal hardening increase the compression and bending strength by 29.3 and 19.6% above the control samples, and the addition of 0.6% Frem Giper S-TB leads to the increase of these indicators by 36.8 and 23.5%.

The introduction of 40% CDCS into cement and sand solution as a part of cement leads to the reduction of compression and bending strength on the third day of normal hardening by 36 and 28.6%, and on the 28th day of normal hardening these indicators decrease by 43.5 and 52.9%. The compression and bending strength with the addition of 1.4% Odolit-K on the third day of normal hardening are higher that the control sample by 21 and 33.3%, and the addition of 0.6% Frem Giper S-TB makes the compression and bending strength below the control samples by 11.9 and 19%.

The tests of the same samples with Odolit-K on the 28th day of normal hardening make the compression and bending strength by 22 and 23.5% lower the control samples, and the addition of 0.6% Frem Giper S-TB – by 15.3 and 19.6%.

The analysis of obtained results shown in table 1 and taking into account the requirements of item 7.2 of the GOST 30459, GOST 27006 and rules provided in section 10 [12] we selected various compositions of concrete, which are shown in Table 2.

TABLE II. SELECTION OF COMPOSITIONS OF CONCRETE MIXES WITH VARIOUS CONTENT OF CONCRETE CRUSHING DUST

Composition	**Cement**	**Sand**	**Crushed stone**	**Water**	**Concrete crushing dust (CCD), %**	**Odolit-K, %**	**Frem Giper S-TB,%**	**Concrete compression strength in MPa on 1, 7 and 28 days of hardening**		
								1 day	*7 days*	*28 days*
	1	2	3	4	5	6	7	8	9	10
1	350	650	1036	200	0	0	0	91	273	310
2	350	650	1036	170	0	1.4	0	96	310	378
3	350	650	1036	170	0	0	0.6	91	308	372
4	280	650	1036	200	20	0	0	42	205	298
5	280	650	1036	170	20	1.4	0	89	290	348
6	280	650	1036	170	20	0	0.6	91	286	352
7	245	650	1036	210	30	0	0	41	219	289
8	245	650	1036	191	30	1.4	0	90	269	331
9	245	650	1036	190	30	0	0.6	92	270	336
10	210	650	1036	220	40	0	0	28	131	169
11	210	650	1036	210	40	1.4	0	71	209	240
12	210	650	1036	210	40	0	0.6	71	214	246

According to the table, the increase of the crushing dust of concrete scrap in cement by 30% decreases the concrete strength in comparison with the control structure by 11.6%, and further increase in CDCS concentration leads to deterioration of strength indicators and makes only a half of the control sample. As a result of Odolit-K and Frem Giper S-TB introduction, the strength of samples on the first day of hardening almost does not differ from control samples, however after 7 and 28 days of hardening it is seen that the strength indicators exceed the control values with 20 and 30% of CDCS, and in certain cases – with 10%. The increase of CDCS content of up to 40% of the cement weight in concrete prepared with superplasticizers increases the strength up to 30% of the control sample. Such increase is caused by residual hydration properties of non-hydrated cement grains present in CDCS due to insufficient depth of hydration during hardening. At repeated steeping these grains show residual properties, and the higher strength in comparison with control samples is reached as a result of W/C decrease due to the decrease of water interfacial tension with superplasticizers. According to [10, 11], it is known that the introduction of surfactants decreases the interfacial tension of mixing water, thereby increasing the penetration capacity of water to get into cracks of cement grains.

The dispersing impact of water on binder grains leads to spontaneous dispersion of CDCS and portland cement grains thus leading to the increase of a "solid substance-liquid" boundary layer and increase of the hydration potential of binder particles. CDCS has nanosized Ca(OH) crystals, which appeared as a result of CDCS crushing due to destruction of ion bonds of cement grains. The nanosized particles in the structure of a cement stone based on mixed binder CDCS+cement shall strengthen the structure of a binder matrix in concrete [13]. The obtained results, demonstrating the change of strength indicators, indicate the possibility to use ground crushing dust of concrete scrap as a filler replacing up to 30% of cement powder in combination with Odolit-K or Frem Giper S-TB without damaging the strength of obtained materials, which leads to substantial saving of fabricated binders.

The X-ray phase analysis of cement compositions and crushing dust of concrete scrap with their optimum ratio was conducted to study the optimum CDCS quantity as part of cement in hydration processes with and without superplasticizers. Figures 1-6 show roentgenograms, which confirm the strength indicators of obtained cement stone samples.

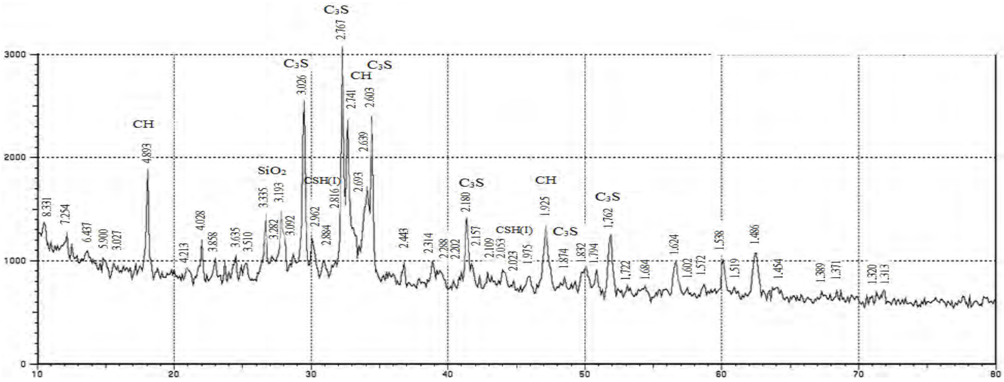

Fig. 1. 70% cement + 30% CDCS, 1 day of hardening

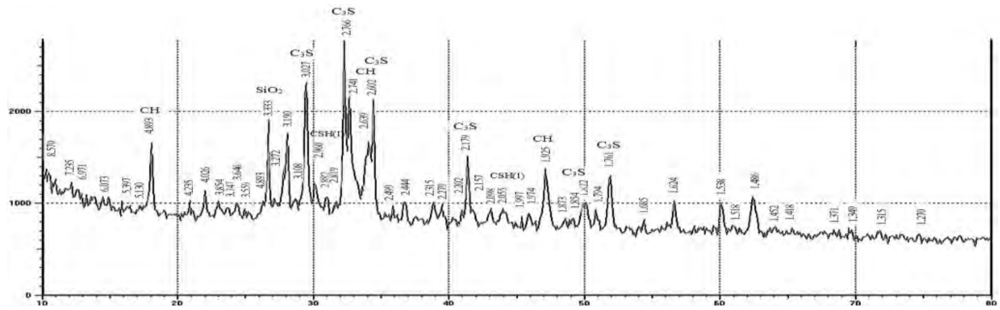

Fig. 2. 70% cement + 30% CDCS + 1.4% Odolit-K, 1 day of hardening

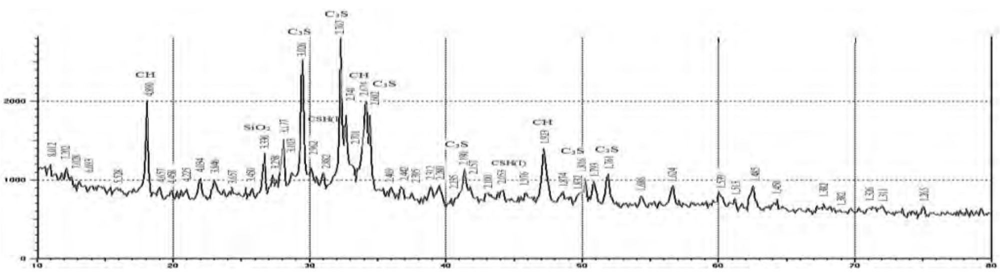

Fig. 3. 70% cement + 30% CDCS + 0.6% Frem-Giper S-TB, 1 day of hardening

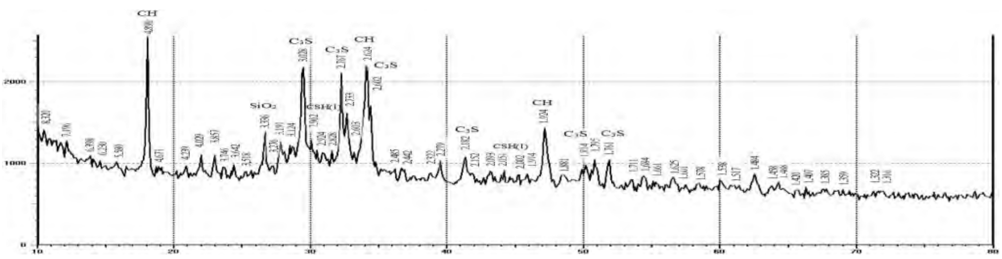

Fig. 4. 70% cement + 30% CDCS, 28 days of hardening

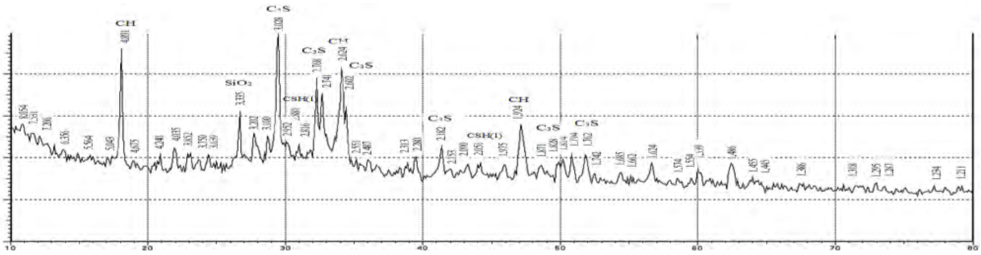

Fig. 5. 70% cement + 30% CDCS + 1.4% Odolit-K, 28 days of hardening

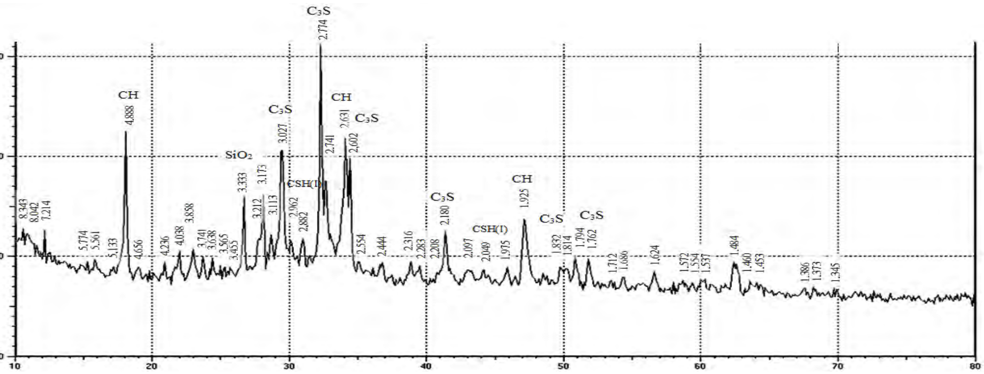

Fig. 6. 70% cement + 30% CDCS + 0.6% Frem-Giper S-TB, 28 days of hardening

The obtained roentgenograms show CDCS peaks, peaks of quartz sand present in large quantities within CDCS. At different hardening periods the CDCS peaks decrease and the cement stone peaks are mainly seen on roentgenograms. In 1 day of hardening the samples with 1.4% Odolit-K and 0.6% Frem Giper S-TB showed higher CSH(1) phase content than the control samples, and the concentration of portlandite is reduced. In 28 days of hardening the concentration of CSH(1) phase was approximately the same. In a cement stone after one day of hardening the $Ca(OH)_2$ content in the control sample was lower in comparison with samples with superplasticizers and was gradually decreasing. On the 28th day of hardening it was lower than in the control sample, which is also confirmed by higher strength indicators. However, the peak of quartz sand, which remained from the crushing dust of concrete scrap, was slightly higher for a sample with an additive than for the control one during the entire period of hardening of a cement stone. The opposite result was obtained by the content of $CaCO_3$ impurities in CDCS, according to roentgenogram, on the 28th day of hardening it shows much less calcite content in a sample with superplasticizers, which confirms deeper hydration of a cement stone. The microlevel study of a cement stone surface also confirms these results. Figures 7-12 show considerable changes on a cement stone surface as a result of joint use of a plasticizing additive with ground crushing dust of concrete scrap.

According to micrographs, microcracks, which considerably differ in width and duration, were formed at each stage of hardening of the cement stone without a superplasticizer. The surface of a cement stone with Odolit-K and Frem Giper S-TB is smooth, the amount of pores and dislocations was reduced compared to a sample without superplasticizers. Large areas of cement gel distribution and high density of a stone demonstrate the increase of a cement binder hydration. Besides, the images without Odolit-K and Frem Giper S-TB show more portlandite crystals and needle structures, which reduce the strength properties of a cement stone.

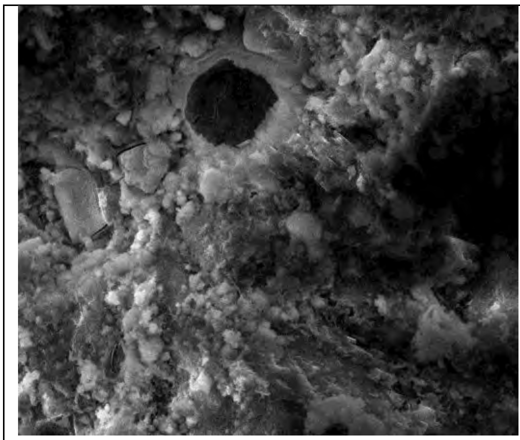

Fig. 7. Cement stone (cement + 30% CDCS) in 1 day of hardening

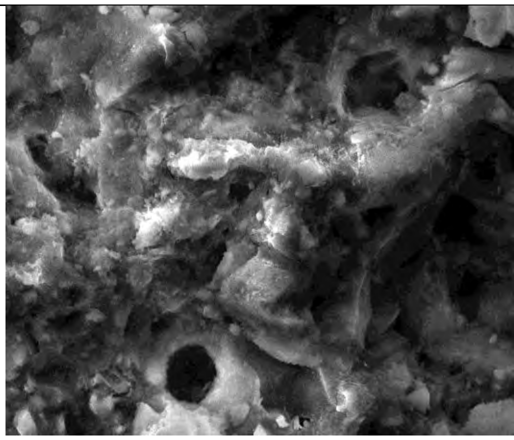

Fig. 8. Cement stone (cement + 30% CDCS +1.4% Odolit-K) in 1 day of hardening

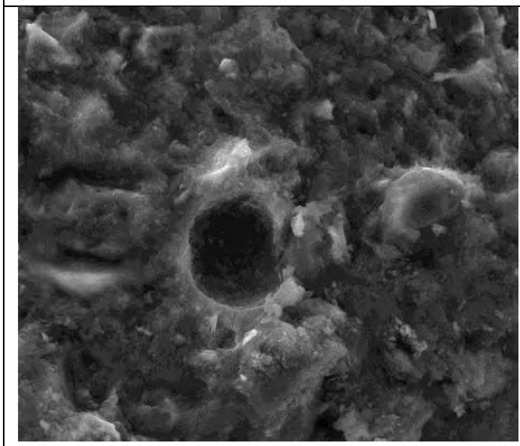

Fig. 9. Cement stone (cement +30% CDCS + 0.6% Frem Giper S-TB) in 1 day of hardening

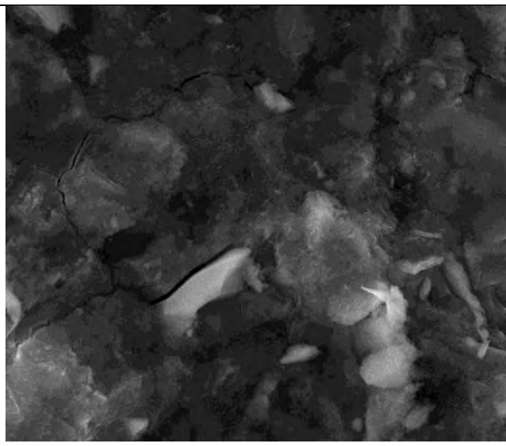

Fig. 10. Cement stone (cement + 30% CDCS) in 28 days of hardening

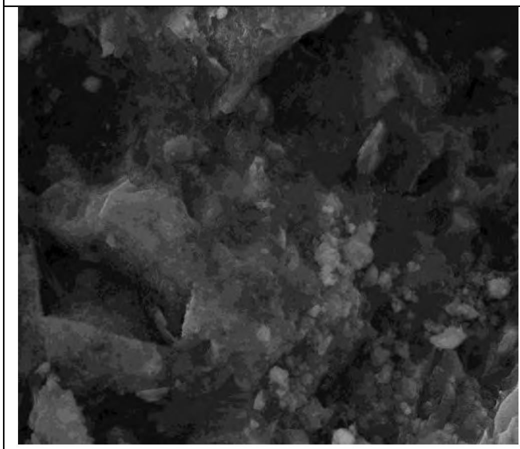

Fig. 11. Cement stone (cement + 30% CDCS + 1.4% Odolit-K) in 28 days of hardening

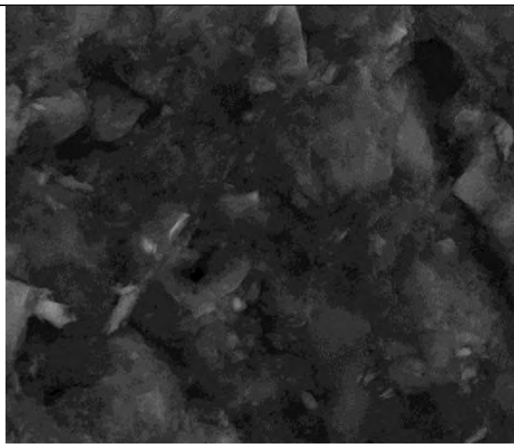

Fig. 12. Cement stone (cement + 30% CDCS + 0.6% Frem Giper S-TB) in 28 days of hardening

IV. Conclusions

The introduction of crushing dust of concrete scrap into production of construction materials to decrease the consumption of the main binder will allow preserving natural and energy resources. The pilot studies made it possible to set the optimum concentration of concrete scrap crushing dust for partial replacement of portland cement. The study demonstrates the efficiency of polycarboxylate superplasticizers Odolit-K and Frem Giper S-TB reducing the water demand of mortar mixes, which contain ground CDCS, thus increasing the strength throughout hardening. The obtained results will make it possible to solve an environmental problem via the utilization of small fractions of CDCS unclaimed in construction production, to reduce the amount of construction debris and dust content.

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