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Blended binder based on Portland cement and recycled concrete powder

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Abstract. The article investigates the properties of recycled concrete powder obtained by mechanochemical activation of recycled screening waste with organic plasticizer in vibrating mill. The waste concrete powder was considered as a part of blended binder based on Portland cement. The optimal powder ratio in blended binder was 30% by weight of cement with the maintenance of the strength properties. The laser diffraction method, X-ray analysis and IR spectroscopy, as well as standard methods were used to estimate the properties of activated powder. The activation of recycled screening waste in 150 min with 0.5% plasticizer allowed us to achieve the specific surface area of the powder at the range of 457.5 cm2/g with content of fine-grained particles in the size of 0–10 µm (26.6%) and 0–20 µm (31.2%). It was estimated that the increase of powder ratio in blended binder reduces the standard consistency of the paste and extends the setting time of the binder. The optimal content of the powder was 30% by weight of cement with standard consistency of 24.6%. The compressive strength at the age of 2, 7 and 28 days was 24.3, 37.4 and 50.5 MPa respectively. The structure change of recycled screening waste particles by mechanical destruction and surface amorphization of initial crystalline phases was confirmed by XRD method and IR spectroscopy.

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1. Introduction

The growth of energy and resource-saving technologies has become one of the main goals of sustainable development. The construction industry accounts about 50% of the total use of natural raw materials, 40% of energy consumption and almost half of generated worldwide industrial waste. At the present time the increase of world population and the improvement of life quality have led the development of increased construction activity, which further entails certain negative environmental impact.

Concrete is the most widely used building material. Concrete production is considered to have high negative environmental and social costs. According to the data [1], it is about 75.7 million m^2 residential buildings were built in 2018. At the same time, in 2018 global cement production amounted 53.7 million tons, and at the end of 2019, this value increased up to 57.8 million tons. Currently, all industries, including the construction sector, are trying to reduce their impact on the environment.

Construction and demolition waste reuse stay relevant not only for foreign countries, but also for Russia. The growth of concrete production causes the increase of waste of volume from old buildings. In European Union it is annually generated about 850 million tons of industrial waste [2], but only some of it obtained from concrete and demolition waste [3] are used as recycled concrete powder.

Large volume of concrete and demolition waste accumulates in large areas and represents a serious environmental problem [4]. Earlier dismantled concrete elements have not been widely used, they were dumped in landfills or used as sub-base material in road construction [5]. Several countries in Europe have accepted the mix of recycled concrete aggregate into concrete [6]. In recent decades many studies have shown their application as coarse and fine recycled concrete aggregates not only in ordinary concrete, but also in self-compacting concrete mixtures [7-10]. This approach aims to conserve natural resources, reduce construction cost related to aggregates supply and transport, decrease the consumption of non-renewable natural resources, minimize waste and associated emissions.

Recycled concrete aggregates have poor quality due to the presence of mortar in relation to natural aggregates. As a result, their use in load bearing concrete is limited [11].

The process of crashing and screening of demolished concrete forms a significant amount of waste. The maximum content of adhered mortar fraction 5-10 mm is up to 75% of the total mass of recycled concrete aggregate [12, 13].

The production of recycled aggregates is associated with generation of recycled screening waste, its content depends on the crushing method and can be from 30% to 70% of the crushed material [14, 15]. The use of recycled screening waste can be considered as supplementary cementitious materials in preparation of waste powder concrete [3, 16, 17], that can be considered as a part of blended binder based on Portland cement.

Various industrial waste is used as powder in concretes [18, 19]. Industrial waste should be activated due to their diverse chemical composition and properties. The activation increases the reactivity and uniformity of waste. It accelerates chemical reactions, both between solid-phase components and between solid and liquid. It changes the composition and structure of the crushed substance.

The pre-treatment of recycled screening waste is necessary for the preparation of recycled concrete powder with stable properties. Various grinding equipment can be used for preparing recycled screening waste, and the type of the mill significantly affect recycled concrete powder properties [20, 21].

It is known that recycled concrete powder can exhibit cementitious properties due to the content of unreacted particles of clinker minerals. The activation gives the ability to exhibit cementitious properties. It can be assumed that the use of such waste can be a valuable resource in production of the SCC mixture and it is aimed to reduce the consumption of cement.

Mechanochemical activation is considered as a joint grinding of recycled screening waste with a dry superplasticizer Melflux 5581F in vibrating mill. This is necessary to create an adsorptive layer on the surface of recycled screening waste particles, to reduce their strength, deformation and destruction due to the decrease in surface energy, as well as for the subsequent partial dispersion of the composite system [22]. Mechanochemical activation is effective resource- and time-saving method of obtaining binders with low water to binder ratio and active powder for concretes. The method consists in joint grinding of cement or other disperse materials with dry superplasticizer in the mill to accelerate the process of activation. Mechanochemical activation of binders and powders with superplasticizers promotes the formation of polymer shell on the surface of grains, provides faster grinding due to the Rehbinder effect. The specific surface area of the material while mechanical activation increases and its chemical reactivity enhances [23].

It is advisable to apply recycled screening waste in self-compacting concrete in order to expand the range of supplementary cementitious materials (microsilica, ground blast furnace slag, fly ash). Therefore, the aim of this study is to obtain the high-fineness recycled concrete powder by the mechanochemical activation and evaluate its properties for use in self-compacting concrete. Thus, the efficiency of activating recycled screening waste can be evaluated by specific surface area on the recycled powder and its particle size distribution. It is necessary to establish the required amount of superplasticizer and activation time, to obtain the recycled powder with specified properties to measure the effect of recycled powder on properties of composite binder.

2. Materials and Methods

2.1. Materials

The cement used in this study was Ordinary Portland Cement type CEM I 42.5 R Mordovcement in accordance with Russian standard 31108-2016. The mineralogical composition of the clinker is presented in Table 1. The specific surface area of cement was 344.5 m^2/kg. The main physical properties and chemical composition of cement are presented in Table 2 and Table 3.

The choice of cement was due to the low content of C_3A and its granulometric composition. The low content of C_3A contributes the reduction of heat release of the concrete. Furthermore, the effect of superplasticizers is most evident in low-alumina Portland cement. The granulometric composition of the selected Portland cement contributes the uniform particle size distribution, which allows to get the structure of blended binder with dense packing of the particles when the powder is added.

Table 1. Mineralogical composition of the clinker.

Mineral content (%)			
C_3S	C_2S	C_3A	C_4AF
62.40	17.56	5.49	14.55

Table 2. Main physical properties of cement.

Standard water requirement (%)	Setting time (min)		Compressive strength (MPa)		Expansion (mm)
	initial	final	2 days	28 days	
26.5	185	245	23.3	54.4	0

Table 3. Chemical composition of the clinker.

Components (%)									
Loss ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	K_2O	Na_2O	R_2O
0.21	21.65	4.73	4.36	65.47	0.40	1.27	0.84	0.26	0.81

Superplasticizer Melflux 5581F as grinding aid for recycled concrete powder was used. The recommended dosage of superplasticizer is 0.1–0.5 % by mass of cement. At the same time, it was taken into account that the subsequent overdose of the plasticizer leads to segregation, retardation and lack of concrete mixture setting with reduction the mechanical characteristics of the concrete.

The recycled concrete powder was produced from the internal wall panel of a residential building in Moscow (Table 4). The chemical and phase composition of recycled screening waste are presented in Table 5 and Table 6.

Table 4. Particle size distribution of recycled screening waste.

Fractions (mm)	2.5	1.25	0.63	0.315	0.16	pallet
Partial sieve residue (%)	25.1	15.5	19.1	21.5	13.3	5.7
Total sieve residue (%)	25.1	40.5	59.6	81.1	94.3	100

Table 5. Chemical composition of recycled screening waste.

Oxide	Content (%)
CaO	49.02
SiO_2	39.45
Al_2O_3	3.74
Fe_2O_3	2.50
MgO	1.76
K_2O	1.12
SO_3	1.05
Na_2O	0.587
TiO_2	0.222
P_2O_5	0.153
ZnO	0.0917
MnO	0.0851

Oxide	Content (%)
SrO	0.0742
BaO	0.0631
CuO	0.0222
Cl	0.0190
ZrO_2	0.0152
Cr_2O_3	0.0139
Co_3O_4	0.0072
V_2O_5	0.0064
Loss ignition	0.0139

Table 6. Phase composition of recycled screening waste.

Phase	Content (%)
Quartz	53.5
Foshagite	11.0
Microcline	8.6
Muscovite	2.4
Chlorite	0.7
Calcite	11.2
Dolomite	3.3
Alite	0.6
Belite	1.3
Brownmillerite	1.0
portlandite	0.6
Ettringite	0.8
Amorphous phase	5.0

2.2. Methods

The main properties of the binder were determined in accordance with Russian standard 310. The laser diffraction analysis was used to determine the particle size distribution of Portland cement and recycled concrete powder. The X-ray diffractometer ARL X'tra was used to determine the phase composition of recycled screening waste. The ARL Optim'X X-ray fluorescence spectrometer was used to determine the chemical composition of the samples. The Vertex 70 Fourier spectrometer was used in IR spectroscopy.

3. Results and Discussion

The demolished internal wall panel was broken mechanically and cleaned from reinforcement. Recycled screening waste with fraction 0–2.5 mm was activated in a laboratory vibration mill during 150 min with dry superplasticizer Melflux 5581F content of 0.1–0.5 % by mass of recycled screening waste. The mode of activation was experimentally established with optimal operation of the equipment. The purpose of activation was to obtain the activated powder with specific surface area at the range of 450 m^2/kg. The optimal dosage of Melflux 5581F was 0.5%. The specific surface area increases from 395.6 to 457.5 m^2/kg (Table 6).

The influence of activated recycled concrete powder on properties of blended binder was estimated by the maximum change of main properties: standard consistency of the binder, setting time and compressive strength. It was found that the optimal content of the powder in blended binder is 30%. It was determined that standard consistency of blended binder has reduced from 26.5% up to 24.6%.

The Melflux 5581F superplasticizer acts as an activation intensifier to obtain the grain composition of the powder with increased number of fine particle fractions, which creates an adsorbed layer of polycarboxylate molecules on the grains of the powder.

The chemical reactions and initial hydration activity of the powder are accelerated due to application of mechanochemical activation. The mechanochemical activation is considered as a process of activation of recycled concrete particles and dry polycarboxylate superplasticizer Melflux 5581F in vibrating mill. The formation, movement, and multiplication of various structural defects under high-intensity destructive action on solid state is theoretical background of activation [24]. The penetration of polycarboxylate molecules into microcracks occurs simultaneously and is accompanied by the Rebinder effect. The destruction of the material is facilitated and the newly formed surface is modified with a polymer modifier. Mechanochemical activation brings an increase of chemical activity of substance due to the accumulation of energy in structural defects [25]. When the mechanical action stops, it causes the stabilization of the solid body structure. The period of relaxation processes occurs, the activity of the substance decreases. In this case, the inculcation of polycarboxylate fragments on activated powder contributes to the consolidation of defects in its structure [26].

The results of mechanochemical activation of the powder are estimated by the change in particle size distribution and the specific surface area (Table 7).

Table 7. Particle size distribution of 150 min activation.

Dosage of Melflux 5581F in % by mass of recycled screening waste	Specific surface area, m^2/kg	Fraction content (%)					
		0–5 µm	5–10 µm	10–20 µm	0–10 µm	0–20 µm	>80 µm
0	395.6	3.3	21.0	14.9	17.6	40.3	2.9
0.1	415.6	4.4	18.7	16.7	18.2	40.1	1.9
0.2	432.6	5.5	15.4	17.8	20.9	38.8	1.5
0.3	441.0	6.1	15.9	18.3	23.6	34.9	1.2
0.4	448.5	6.3	16.3	15.8	27.0	33.6	1.0
0.5	457.5	7.2	14.9	19.3	26.6	31.2	0.8

The use of the Melflux5581F has positive effect on fineness of activated powder which is directly proportional to its content. The specific surface area increases by 15.65% compared to the plain powder (from 395.6 to 457.5 m^2/kg) with 0.5 % of Melflux 5581F in recycled screening waste and significantly reduces the energy consumption of activation (Figure 1).

In Fig. 1 the curve is linear within 60 min of activation in vibrating mill with different content of superplasticizer, and it corresponds with Rittinger law [26, 27]. The specific surface area of the powder increases with growth of Melflux 5581F dosage. Further activation does not lead to a significant specific surface area growth of the powder due to particles agglomeration, that observes in plain composition.

The superplasticizer as grinding intensifier provides less agglomeration of the particles due to the disjoining and electrostatic repulsion of the particles containing superplasticizer on their surface. The activation efficiency evaluated by degree of dispersion and size change of the powder particles. It depends on time of exposure in vibrating mill and dosage of Melflux 5581F. The granulometric composition of the powder and Portland cement showed in Figure 2.

The main properties of blended binder consisted of Portland cement and activated powder with content from 10 up to 70% was studied. The properties were compared with the properties of Portland cement in accordance with Russian standards. The results are shown in Table 8. It was found that the optimal content of the powder was 30% with uniform distribution of the powder by volume of cement matrix. The necessary properties were achieved with minimum change in setting time and compressive strength.

The obtained data corresponds with the data of other authors. Previous studies have shown [28] the effect of recycled concrete powder on properties of concrete at the age of 28 days with 0.35 water-cement ratio. It was determined that compressive strength with content of the powder 10, 20, 30, and 40% was 60.69, 59.19, 56.18, and 45.64 MPa respectively. It has been shown [29] that the strength of cement paste with water-cement ratio of 0.4 and mechanoactivated recycled screening waste in the amount of 0.1% at the age of 3, 28 days was 21.2 and 47.6 MPa; with content of 0.2% - 18.8 and 43.3 MPa respectively. In research [16] it was determined that adding of 5, 10, and 15% increases the strength of concrete by 167, 228 and 333 % in comparison with plain composition. Previous studies reported [28] that the initial setting time of cementitious materials containing 0, 15, 30 and 45% recycled concrete powder was approximately 273, 288, 298 and 309 min respectively, and the results for the final setting time were 469, 520, 539 and 590 min.

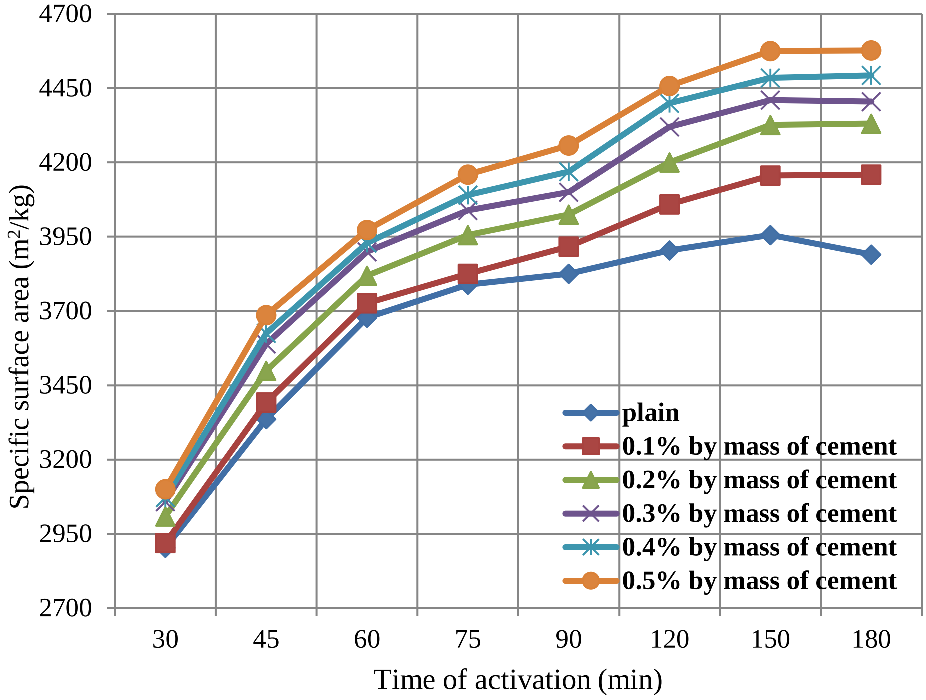

Figure 1. Effect of activation time on specific surface of recycled concrete powder.

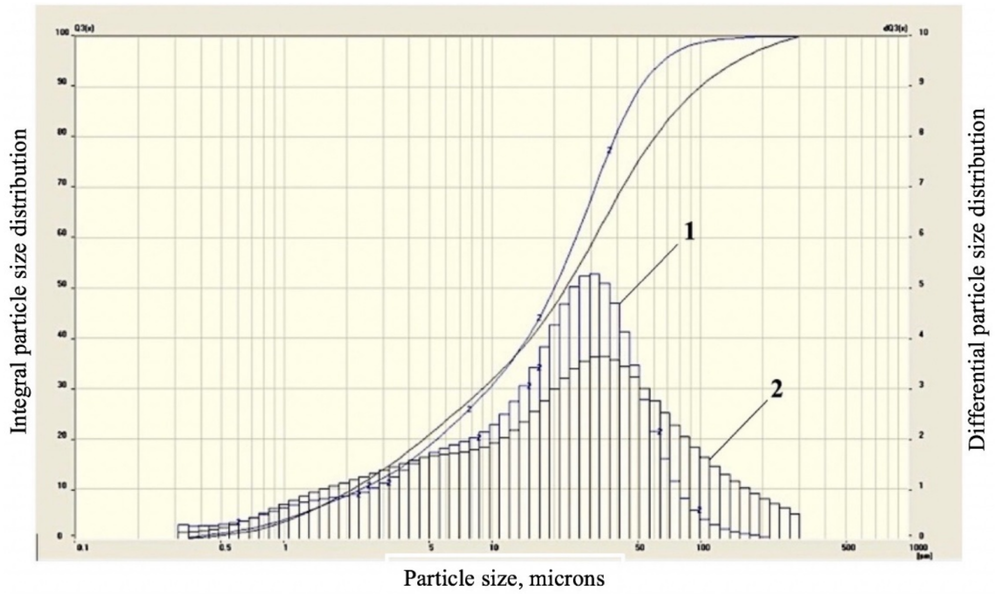

Figure 2. Particle size distribution of recycled concrete powder (1) and Portland cement CEM I 42.5 R (2).

Table 8. Properties of blended binder based on recycled concrete powder and Portland cement.

Powder content in mixture (%)	Standard water requirement (%)	Setting time (min)		Compressive strength (MPa)		
		initial	final	2 days	7 days	28 days
0	26.5	185	245	23.3	38.3	51.4
10	25.5	217	255	23.5	38.0	54.5
20	25.0	226	275	24.1	37.9	54.2
30	24.6	233	305	24.3	37.4	50.5
40	24.0	265	345	18.6	30.2	42.5
50	23.5	275	365	16.5	26.5	39.5
60	23.5	300	380	14.5	25.2	35.6
70	23.0	315	415	13.8	24.9	34.2

The results of X-ray analysis of recycle concrete powder before and after activation are presented in Figure 3 and Figure 4. It was determined that the activation changes the structure of recycle concrete powder particles by mechanical destruction and amorphization of the initial constituent phase of calcium silicate hydrates. It is confirmed the XRD diffraction of unactivated recycle concrete powder (Figure 3) shows the presence of peaks: calcium silicate hydrates of foshagite type $Ca_4Si_3O_9(OH)_2$ (d = 0.4914; 0.2894; 0.2196), calcium carbonate $CaCO_3$ (d = 0.3858; 0.3033) and silica SiO_2 (d = 0.4260; 0.3345; 0.1821; 0.1604). During the life cycle, calcium silicate hydrate undergoes transformation. In the initial stage of concrete hardening, calcium silicate hydrates as foshagite contain a large amount of crystal and adsorbed water. In the late stage of hardening, when the concrete dries the adsorbed water disappears, and calcium silicate hydrates become dehydrated. The crystal water of calcium silicate hydrates as foshagite undergo their changes along with the structure. In long-term hardening concretes they are formed with a minimum amount of water (1.5–2)H_2O. In hardened concrete foshagite is identified as $Ca_4Si_3O_9(OH)_2$ according to the international classification. Such calcium silicate hydrate is formed in lime-sand mixtures during synthesis in laboratory hydrothermal treatment.

The intensive mechanical impact on recycle concrete powder shows the absence of peaks of calcium silicate hydrates and the presence of intense lines of quartz and calcium carbonate at the X-ray diffraction diagram. It causes the surface amorphization with deep phase material change (Fig. 4) and transition to an amorphous state.

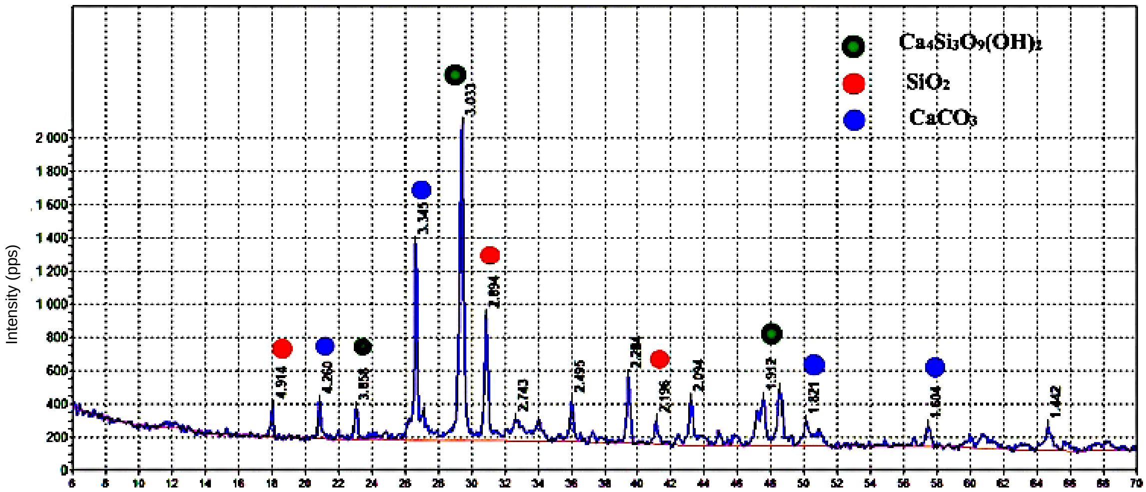

Figure 3. X-ray diffraction diagram of recycle concrete powder before activation.

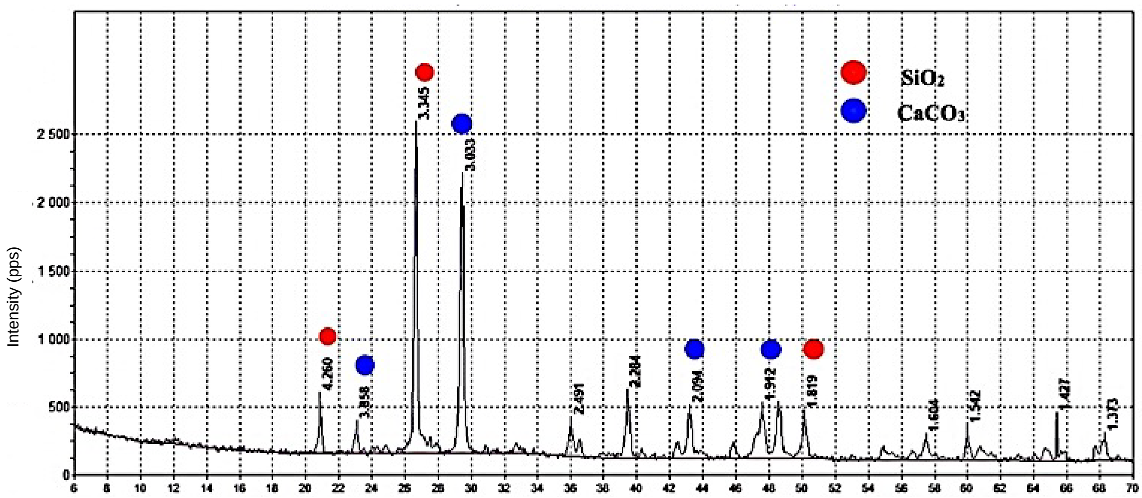

Figure 4. X-ray diffraction diagram of recycle concrete powder after 150 min activation with 0,5 % Melflux 5581F.

The IR spectroscopy results of recycle concrete powder before and after activation are presented in Fig. 5, 6. They show the change in structure of the material before and after mechanochemical activation. IR reflectance spectrums have differences, which are expressed in changes in the intensity of absorption bands in the range of 3500–2500 cm^{-1}, 1100–1000 cm^{-1} and 900–750 cm^{-1}. The change in high-frequency absorption band at the range of 3000–2800 cm^{-1} after activation indicates the presence of carbonyl groups of superplasticizers that confirms its chemisorption by the surface of the powder. The appearance of organic compound shows the increase of the peak at the range of 1100–1000 cm^{-1}. The transformation of silicon component indicates the presence of an absorption line contour in frequency range of 900–750 cm^{-1} that explains the amorphization of the surface during mechanochemical activation.

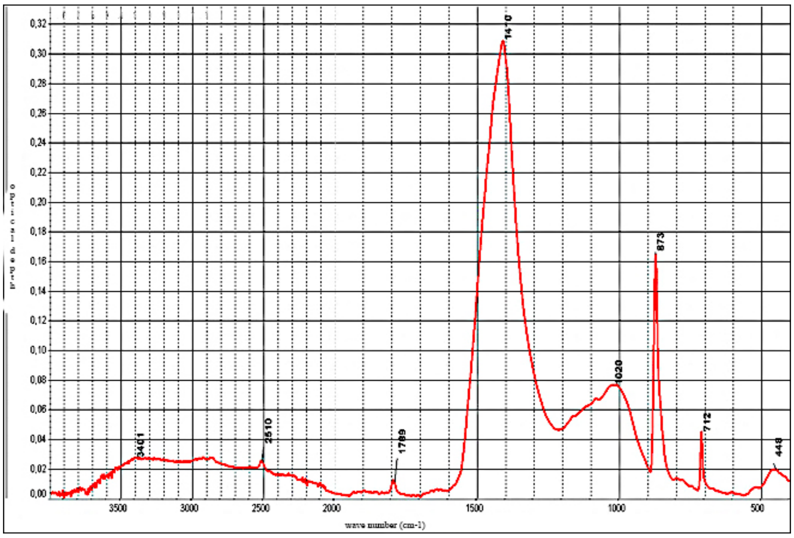

Figure 5. IR reflectance spectrum of recycle concrete powder before activation.

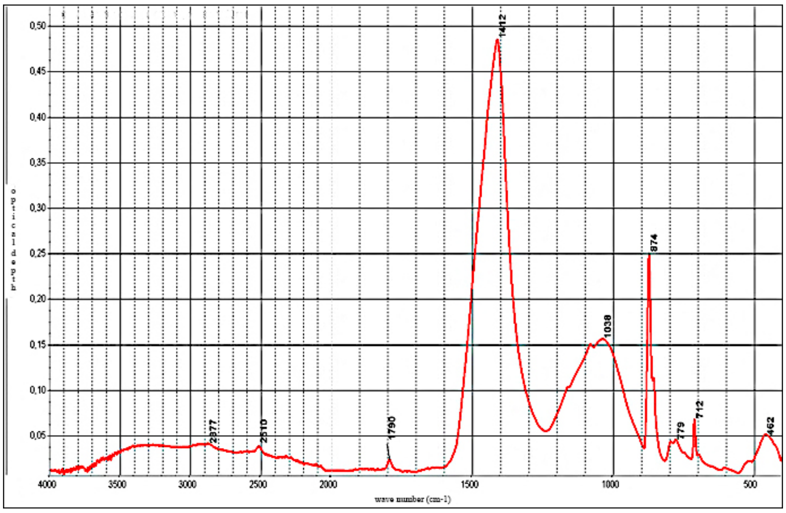

Figure 6. IR reflectance spectrum of recycle concrete powder after 150 min activation with 0.5 % Melflux 5581F.

4. Conclusion

1. The results of experimental investigation showed the potential of recycled concrete powder that can be used as an alternative supplementary material with residual cementitious properties.

2. The obtained blended binder consisted of Portland cement and recycled concrete powder. The optimal content of recycled concrete powder in blended binder was 30%. The powder was obtained while activation of recycled screening waste in vibration mill during 150 min with 0.5 % of Melflux 5581F.

3. It was determined that the obtained recycled concrete powder while activation consisted of fine particles with size 0-10 µm and 0-20 µm in the range of 26.6% and 31.2% respectively.

4. The efficiency of mechanochemical activation was confirmed by XRD and IR spectroscopy. It was determined that activation of recycled screening waste and polycarboxylate superplasticizer Melflux 5581F in vibration mill leads to production the powder with hydraulic properties.

5. It was established that the standard consistency of blended binder was 24.6%. The recycled concrete powder in the amount of 30% provides the appropriate setting time (initial – 233 min; final – 305) and compressive strength of 50.5 MPa.

References

1. Evans, L., Mutter, M. Ekologicheskij rejting cementa [Ecological rating of cement]. Cement and its application. 2019. 4. Pp. 24–27.
2. EEA, European Environment Agency. EU as a recycling society: present recycling levels of Municipal Waste and Construction & Demolition Waste in the EU. ETC/SCP working paper, Denmark. 2009. 73 p.
3. Ma, Zh., Liu, M., Duan, Zh., Liang, Ch., Wu, H. Effects of active waste powder obtained from C&D waste on the microproperties and water permeability of concrete. Journal of Cleaner Production. 2020. 257. P. 120518. DOI: 10.1016/j.jclepro.2020.120518
4. Cantero, B., Bravo, M., de Brito, J., Saez del Bosque, I.F., Medina, C. Mechanical behaviour of structural concrete with ground recycled concrete cement and mixed recycled aggregate. Journal of Cleaner Production. 2020. 275. P. 122913. DOI: 10.1016/j.jclepro.2020.122913
5. Engelsen, Ch. J., Van der Sloot, H. A., Petkovic, G. Long-term leaching from recycled concrete aggregates applied as sub-base material in road construction. Science of the Total Environment. 2017. 587/588. Pp. 94–101. DOI: 10.1016/j.scitotenv.2017.02.052
6. Nedeljkovic, M., Visser, J., Savija, B., Valcke, S., Schlangen, E. Use of fine recycled concrete aggregates in concrete: A critical review. Journal of Building Engineering. 2021. 38. P. 102196. DOI: 10.1016/j.jobe.2021.102196
7. Naruts, V. V., Larsen, O. A. Optimizaciya sostava samouplotnyayushchegosya betona na osnove betonnogo loma dlya polov promyshlennyh zdanij [Optimization of composition of self-compacting concrete based on recycled concrete for the floors of industrial buildings]. BST-Bulletin of construction Equipment. 2020. 3(1027). Pp. 56–59.
8. Larsen, O. A., Naruts, V. V., Voronin, V. V. Tekhnologiya pererabotki betonnogo loma s cel'yu polucheniya samouplotnyayushchegosya betona [Technology of processing of concrete scrap for the purpose of obtaining self-compacting concrete]. Construction and reconstruction. 2020. 2(88). Pp. 61–66. doi: 10.33979/2073-7416-2020-88-2-61-66.
9. Naruts, V. V., Larsen, O. A., Samchenko, S. V., Alexandrova, O. V., Bulgakov, B. I. Razrabotka sostavov samouplotnyayushchegosya betona na osnove betonnogo loma s ispol'zovaniem strukturnyh harakteristik [Development of compositions of self-compacting concrete on the basis of recycled concrete with the use of structural characteristics]. Vestnik BSTU. 2020. 4. Pp. 8–16. doi: 10.34031/2071-7318-2020-5-4-8-16.
10. Sun, C., Chen, Q., Xiao, J., Liu, W. Utilization of waste concrete recycling materials in self-compacting concrete. Resources, Conservation and Recycling. 2020. 161. P. 104930 DOI: 10.1016/j.resconrec.2020.104930
11. Santos, S., da Silva, P.R., de Brito, J. Self-compacting concrete with recycled aggregates – A literature review. Journal of Building Engineering. 2019. 22. Pp. 349–371. DOI: 10.1016/j.jobe.2019.01.001
12. Pacheco-torgal, F., Ding, Y., Miraldo, S., Abdollahnejad, Z., Jabrincha, A. L. The suitability of concrete using recycled aggregates for high-performance concrete. Handbook of recycled concrete and demolition waste. Woodhead Publishing Limited. Sawston, Cambridge, 2013. 17. Pp. 424–438.
13. Golovin, N. G., Alimov, L. A., Voronin, V. V. Problema utilizacii zhelezobetona i poisk effektivnyh putej ee resheniya [The problem of utilization of reinforced concrete and the search for effective ways to solve it]. Vestnik MGSU. 2011. 2. Pp. 65–71.
14. Tam, V.W.Y., Soomro, M., Evangelista, A.C.J. A review of recycled aggregate in concrete applications. Construction and Building Materials. 2018. 172. Pp. 272–292. DOI: 10.1016/j.conbuildmat.2018.03.240
15. Mourtazayev, A.Yu., Ismailova, Z.K., Khasiyev, A.A., Nakhaev, M.R. Utilizaciya otseva drobleniya betonnogo loma [Recycling of Concrete screening waste]. Ecology and Industry of Russia. 2012. 8. Pp. 26–28. DOI: 10.18412/1816-0395-2012-8-26-28
16. Krasinikova, N.M., Kyrillova, E.V., Khozin, V.G. Vtorichnoe ispol'zovanie betonnogo loma v kachestve syr'evyh komponentov cementnyh betonov [Reuse of concrete waste as input products for cement concretes]. Construction materials. 2020. 1/2. Pp. 56–65. DOI: 10.31659/0585-430X-2020-778-1-2-56-65
17. Tang, Q., Ma, Z., Wu, H., Wang, W. The utilization of eco-friendly recycled powder from concrete and brick waste in new concrete: A critical review. Cement and Concrete Composites. 2020. 114. P. 103807 DOI: 10.1016/j.cemconcomp.2020.103807
18. Okamura, H., Ouchi, M. Self-Compacting Concrete. Journal of Advanced Concrete Technology. 2003. 1(1). Pp. 5–15.
19. Grdic, Z. J., Toplicic-Curcic, G. A., Despotovic, I. M., Ristic, N. S. Properties of self-compacting concrete prepared with coarse recycled concrete aggregate. Construction and Building Materials. 2010. 24(7). Pp. 1129-1133. DOI: 10.1016/j.conbuildmat.2009.12.029
20. Babaev, Sh. T., Bashlykov, N. F., Goldina, I. Ya. Povyshenie prochnosti cementnogo kamnya [Increasing the strength of cement stone]. Cement. 1990. 9. Pp. 13-15.
21. Higerovich, M. I. Gidrofobnyj cement i gidrofobno-plastificiruyushchie dobavki [Hydrophobic cement and hydrophobic-plasticizing additives]. Moscow: Promstroyizdat, 1957. 208 p.
22. Bazhenov, Y.M., Alimov, L.A., Voronin, V.V. Structure and properties of concrete with nanomodifiers based on technogenic waste [Struktura i svojstva betonov s nanomodifikatorami na osnove tekhnogennyh othodov]. ASV: Moscow, 2013. 204 p.
23. Gusev, B., Samchenko, S., Krivoborodov, Y. The temperature effect on the properties of the binder recovered from waste concrete (Wpływ temperatury na właściwości spoiwa odzyskanego z odpadów betonowych). Cement, Wapno, Beton. 2019. 5. Pp. 407–412. doi: 10.32047/CWB.2019.24.5.7
24. Bazhenov, Y. M., Demyanova, V. S., Kalashnikov, V. I. Modificirovannye vysokokachestvennye betony [Modified high performance concrete]. Moscow: ASV, 2006. 368 p.
25. Yarlushkina, S. Kh. Fiziko-himicheskie processy i ih rol' v formirovanii prochnosti cementnogo kamnya s zapolnitelyami [Physico-chemical processes and their role in the formation of the strength of cement stone with aggregates]. Sbornik trudov NIIZHB ''Structure formation of concrete and physico-chemical methods of its research''. Moscow. Stroyizdat, 1980. Pp. 60–69.
26. Trautvain, A. I., Yadykina, V. V., Gridchin, A.M. Povyshenie reakcionnoj sposobnosti napolnitelej v rezul'tate pomola [Increasing the reactivity of fillers as a result of grinding]. Vestnik BSTU. 2010. 12. Pp. 82–85.
27. Meloni, P., Carcangiu, G., Delogu, F. Specific surface area and chemical reactivity of quartz powders during mechanical processing. Materials Research Bulletin. 2012. 47. Pp.146–151. DOI: 10.1016/j.materresbull.2011.09.014
28. Kim, Y.J., Choi, Y.W. Utilization of waste concrete powder as a substitution material for cement. Construction and Building Materials. 2012. 30. Pp. 500–504. DOI: 10.1016/j.conbuildmat.2011.11.042.
29. Murtazaev, S-A. Yu., Saidumov, M. S., Abdullaev, M. A-V., Khasiev, A. A. Ispol'zovanie mekhanoaktivirovannyh otsevov drobleniya betonnogo loma v proizvodstve betonokompozitov [The use of mechanoactivated screenings of recycled concrete in

production of concrete composites]. Vestnik Dagestanskogo gosudarstvennogo tekhnicheskogo universiteta. Technical sciences. 2011. 22. Pp. 136–140.

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