NANOMODIFIED SELF-COMPACTING CONCRETE BASED ON RECYCLED AGGREGATES

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Abstract: *The effectiveness study results related to "soft" multi-stage crushing mode of concrete scrap are presented. During the research it was found that the processing of concrete scrap using this technology can significantly improve the characteristics of the secondary concrete aggregate, namely crushability, water absorption and voids. It is achieved by reducing the content of cement bound stones in the secondary crushed stone. Significant volumes of the dispersed material formed as a result of such processing can be used as a fine filler part at production technology of the self-compacting concrete. An optimum organic-mineral additive based on nanoparticle with a superplasticizer, which allows to obtain a homogeneous concrete mixture with additional stabilization properties was used for self-compacting concrete. The stability of the rheological characteristics of the modified cement systems will be insured if an optimum amount of organic-mineral additive is used. It was revealed that 28 days strength of a self-compacting concrete with concrete scrap crushing products content reaches more than 55,6 MPa, hardened under normal conditions and more than 75 MPa after one year under air-dry conditions.*

Keywords: *concrete scrap, recycled aggregate, crushability, multi-stage crushing, self-compacting concrete, water absorption.*

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Introduction

Annually the construction sites are generating several million tons of concrete waste [1]. The main sources of concrete waste are the remains of concrete and reinforced concrete structures accumulated during the demolition of old buildings, waste products and technological waste generated in precast concrete plants and construction sites, waste generated at industry and during natural disasters.

The subsequent concrete waste products separated from rebar and obtained after crushing can be used as a "recycled aggregates". However, it is impossible to produce qualitive filler for concrete without proper separating of the obtained wastes according to their sorts [2,3]. And even if the waste is separated properly, the quality indicators of the produced aggregates will be lower than natural crushed stone. The reason for this is a large amount of cement stone content which has lower strength than natural coarse and fine aggregates [4, 5].

To improve the strength and other characteristics of the recycled aggregates can be achieved mainly by crushing of those at a mode insuring as much as possible the separation of cement stones [6]. And to insure such crushing mode shall be used jaw and cone crushers.

To increase the characteristics of the aggregates can be used a conventional jaw crushers at "soft" multi-stage crushing mode. The discharge opening of the shredder should be maximum wide and shredder shall be filled as much as possible to imitate a "clogging" environment to achieve such "soft" crushing mode. A dispersal and crumbling of the concrete takes place due to the mutual squeezing of the crushing material in this mode, unlike the traditional crushing mode. In the traditional shredding mode, the material is dispersing as a result of its "hard" interaction with the moving steel jaw of the shredder. The "soft" crushing mode mainly ensures the disintegration of low-strength cement stone particles and the mortar part of the concrete, as well as the separation of these components from big stone particles.In such a mode, the degree of crushing of the material decreases, so it should be crushed in two or three stages. During "soft" crushing mode, a large amount of dispersed mineral powders are produced along with recycled crushed stones, and the investigation of their application areas is one of the important matters.

Self-compacting concrete takes an important place among concretes in terms of mineral additives use. Increasing the cement paste amount as a matrix to ensure the rheological properties of the concrete leads to an increase in cement consumption and decreasing economic indicators of the concrete production [7,8]. In order to reduce the consumption of cement in self-compacting concrete (SCC), a high amount of fillers is required. Use of the fillers and effective plasticizers facilitates increasing the cement paste fluidity, reducing water consumption and concrete strength increase [8-10].

Mainly ash, micro silica and grinded slag are presently used as fillers in the composition of SCC [7]. These fillers are even more expensive than portlandcement and have a high specific surface area. From an economic point of view, it is more expedient to use the stone equivalent formed during the processing of scrap as filler. The screened materials, formed during the production of stone crushing are close to the main components of concrete and do not cause its corrosion due to their chemical nature, which indicates their sufficient effectiveness for self compacting concrete. And therefore the purpose of this research is to obtain self-compacting concrete using the screened materials generated during the production of recycled crushed aggregates.

Experimental part

Following materials were used in the experiments:

- as a binder - CEM II/A-L 42.5 class portland cement of the HOLCIM cement plant with a normal concentartion of 28%, an activity of 50 MPa;
- as a coarse part - crushed natural granite stone of fraction of 5 – 10 mm and 10-20 mm;
- as a fine part - Bahramtepe sand with a fineness modulus Mi = 3.16;
- C-3, Glenium ACE 430 and Glenium SKY 303 plasticizing admixture from BASF company;
- nano silica obtained by sol-gel process (particle size 80 nm);
- recycled aggregates (5-10 mm and 10-20 mm fr.) and screened powder fillers (fineness modulus Mi = 3.16) obtained from the crushing of demolition concrete;
- finnely dispersed filler with a specific surface of 330 m^2/kg, obtained by grinding recycled waste.

Spreadability of the concrete mixture is determined according to EN 12350-5:2019, compressive strength of concrete according to EN 12390-3:2019, the water absorption of crushed stone according to EN 1097-6:2022, and porosity according to EN 1097-3:1999. The strength tests were performed on samples stored for 1 and 28 days under normal conditions, and on samples stored for a year in an air-dry environment.

Results and discussion

In order to determine the possibility of using superplasticizers in self-compacting concrete, the effect of various organic additives on the normal stiffness of cement was studied first (Fig. 1). As can be seen from the figure, the water-reducing capacity of polycarboxylate-based additives is higher than that of naphthalene sulfonate. This is due to the different mechanism of action of additives in cement systems. Additives based on naphthalene sulfonate (C-3) remove water molecules from cement particles due to the electrostatic repulsion effect, while polycarboxylates create a sliding effect by having a steric effect. Regardless of the mechanism of action, when choosing one or another supplement, preference is given to the more efficient one. In self-compacting concrete, polycarboxylate-based additives, which have high drainage properties, are used as superplasticizers. It was determined that the introduction of nanomodifying additives into the water-cement system increases the hydration of cement several times. Therefore, nano silica and polycarboxylate-based organic-mineral additive (OMA) obtained by the sol-gel process were used in the research work [11].

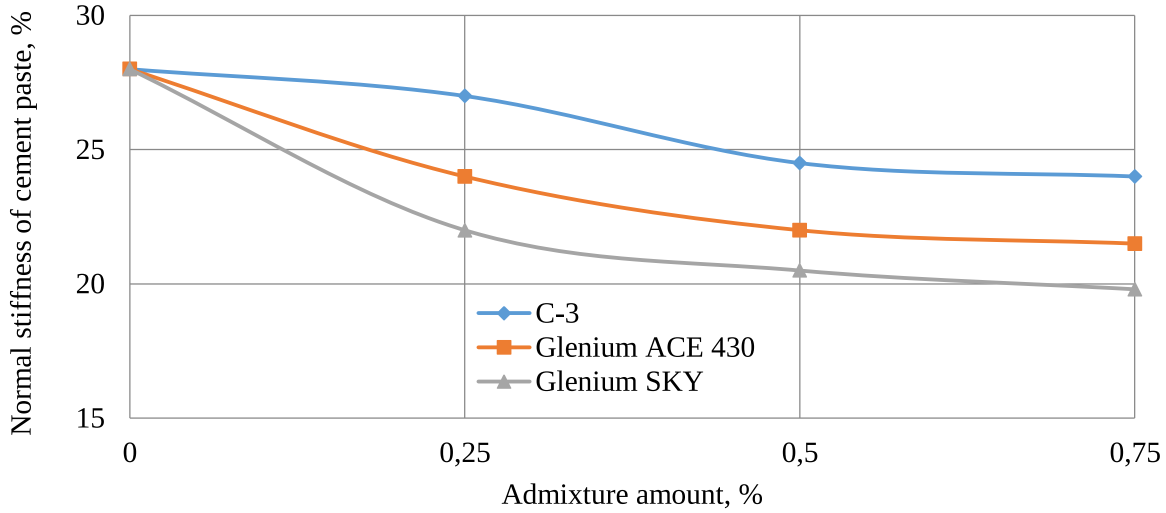

Fig. 1. Dependence of the normal stiffness to the type and quantity of the additive

OMA is obtained by titrating polycarboxylate solution with liquid glass solution mixed with water in a ratio of 1:3. Titration is carried out until the pH of the medium is 7.5. When the hyperplasticizer solution is neutralized with liquid glass solution with continuous stirring at 30^0C, colloidal aggregates of SiO_2 are formed and they are stabilized by carboxylate molecules.

In the next stage of the research, was studied a quality of the impact crushing mode of recycled crushed stone. Conducted studies have shown that the properties of recycled crushed stone can be improved during the application of the multi-stage crushing method. As can be seen from the results given in table 1, after crushing in 3-4 stages in the "soft" mode, the properties of 5-10 mm fractioned crushed stone - water absorption, porosity, and average grain thickness - improved significantly.

Additionally, as the crushing stage increases, water absorption of crushed stone decreases. Thus, when the waste concrete is crushed one time, the water absorption of the crushed stone is equal to 7.54%, and after the 2nd, 3rd and 4th stages of crushing, it is 7.42%, 6.56% and 5.67%, respectively. As the crushing stages increases, the thickness of the cement stone on the surface of the crushed stone decreases. Therefore, the porosity of crushed stone obtained from concrete waste decreases from 4.78% to 4.55% due to increase of crushing stages.

Table 1. Influence of crushing on the properties of secondary crushed stone fr. 5-10 mm

Number of crushing stages	Water absorption, %	Average grain thickness, mm	Porosity, %
1	7.54	4.78	4.78
2	7.42	5.24	4.73
3	6.56	5.53	4.64

4	5.67	5.89	4.55

As the crushing stage increases, the kinetics of change in the strength of crushed stone obtained from concrete waste is shown in fig. 2. According to the graph, the strength increases as the crushing stage of 5-10 mm and 10-20 mm size fractions increases. Based on the requirements of GOST 32495-2013, the crudhing strength class after one stage crushing become to 300 for 10-20 mm. fraction crusher, while this indicator increases to 600 during 3-stage crushing.

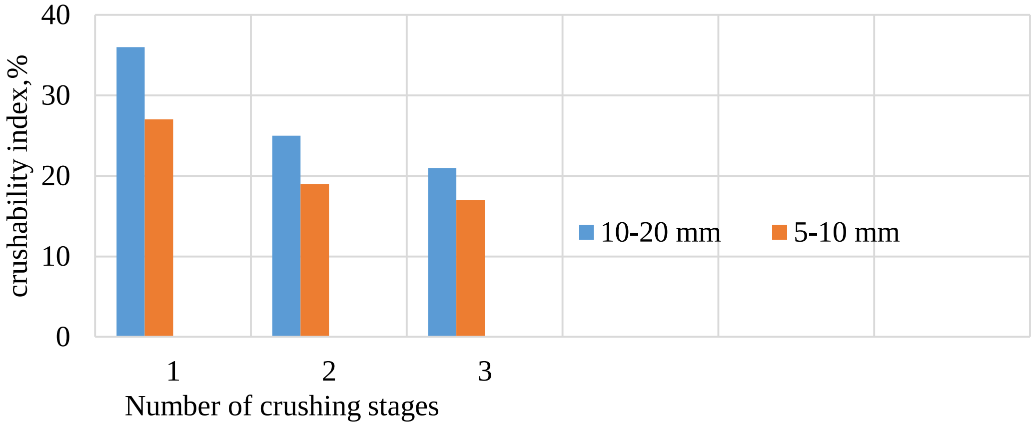

Fig. 2. The effect of repeated crushing on the strength of various fractions of recycled crushed stone

These results show that in accordance with the requirements of the standard, up to concrete grade 300 can be produced using crushed stone obtained from 3-stage crushing. The crushing strength class of 5-10-fraction crushed stone obtained during 1-stage crushing was 400, while this indicator increased to 800 during 3-stage crushing. According to the requirements of the standard, the brand of concrete should be 2 times lower than the brand of crushed stone. And it can be concluded that 5-10 mm fractional recycled crushed stone can be successfully used as a filler in concerete grade 400 without using a modifier. As the number of crushing stages increases, the amount of small and fine fractions formed also increases. It is not recommended to use the aggregate fractions produced during the crushing stage in the preparation of the ordinary concrete mix, because these fractions have low strength and cannot replace natural sand. Since the amount of cement stone in the large amount of aggregate fractions created during crushing is high, it is necessary to determine their area of use.

Self-compacting concretes are considered the most promising area for the application of this material, considering the granular composition of multi-stage crushing products. Thus, since one of the important elements of the technology of self-compacting concrete is the use of aggregate filler, it allows the use of a large volume of fillers and aggregate fractions formed during the crushing of concrete waste [9]. In addition, restrictions are placed on the amount of large filler and its maximum size in self-compacting concrete, which is one of the arguments proving the advantages of the crushed concrete scrap products use in this technology. It should be noted that the increase in the use of mineral powders with different dispersions obtained during the processing of concrete waste as aggregate filler in self-compacting concrete is considered as one of the ways to reduce its cost.Two compositions were developed and studied in order to evaluate the possibilities of using fillers obtained during the crushing of concrete waste in self-compacting concrete technology.

In the first composition, granite crushed stone with a density of 2880 kg/m^3, strength grade 1200, and crushed stone used to optimize the granular composition of the fine filler, as well as limestone flour with Shx = 340 m^2/kg are used as a aggregate filler.

In the second composition, recycled crushed stone with a fraction of 5-10 and 10-20 mm was used as a large filler, and sand with a fraction of 0.63-5 mm obtained from waste crushing was used to optimize the granular composition of the fine filler. Powders with a specific surface area of 340 m^2/kg obtained from the grinding of fine sand smaller than 0.63 mm in a laboratory ball mill are used as a aggregate dispersion filler.

Sand from the Bahramtepe quarry is used as a fine filler in both compositions. Since the amount of grains smaller than 0.63 mm in the composition of sand is more than 90%, natural sand is enriched with the slurry obtained from the crushing of crushed stone or concrete scrap. To ensure the necessary spreading, Glenium SKY superplasticizer and nanosilica-based organic-mineral additive (OMA) obtained by special synthesis is applied. The use of OMA in an optimal amount ensures the stability of the rheological characteristics of modified cement systems 2 times more than in unmodified systems. Therefore, during the researches, OMA was used. The compositions of the studied concretes, their strength are shown in table 2.

Table 2. The compositions of the studied concretes and their properties

№ mix	Composition of concrete	Components consumption, kq/m^3	Spread of standard cone, mm	Strength, MPa		
				1 day	28 days	365 days
1	Cement Water Sand Grushed stone (10-20) Grushed stone (5-10) Screening Limestone filler OMA	313 172 256 256 510 720 290 1.3	575	22.6	58.4	76.6
2	Cement Water Sand Crushed concrete (10-20) Crushed concrete (5-10) Concrete sand Fine filler based on crushed concrete OMA	313 190 256 256 450 690 285 1.3	548	15.2	55.6	75.4

As can be seen from the results given in table 2, despite the higher water consumption in the concrete mixture prepared with the use of concrete waste grinding products, its spreading is less. Replacing high-quality aggregate with recycled crushed stone leads to a 2-fold decrease in the strength of concrete at the age of 1(one) day. This is due to the higher water consumption in the secondary filler formulation, which causes a longer blocking effect of the plasticizer. After 28 days, the strength of concrete on crushed scrap is also lower, but the decrease is only 4.8%.

During the storage of the samples prepared with recycled crushed stone in an air-dry environment for one year, the concrete achieves a strength of 75.4 MPa.

Conclusion

The conducted research allows us to conclude the following:

- concrete waste can be used as filler in self-compacting concrete after multi-stage crushing in "soft" mode;
- replacement of high-quality fillers in self-compacting concrete with concrete waste crushing products reduces strength by 4.8%. However, the properties of the obtained concrete, in particular, having a strength of more than 55 MPa after 28 days of hardening under normal conditions, allow their use in the constructions of modern buildings and facilities;
- the proposed technology of concrete waste processing allows for the purchase of cheap filler with the necessary granular composition for the production of highly efficient new types of concrete - self-compacting concrete.

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