UDC 691.32 DOI: 10.31650/2415-377X-2022-87-85-91

CONCRETES ON SECONDARY CRUSHED STONE AS A PROMISING MATERIAL FOR THE RIGID PAVEMENT BASE

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Abstract. In the course of research, the efficiency of application of plasticizers of different type in concretes for bases of highways on secondary crushed stone is defined. In studies of concrete compositions, the type of crushed stone, secondary or granite, changed, which allowed to compare the properties of concrete on secondary crushed stone with the properties of concrete of similar composition on granite crushed stone. In addition, the type of sand changed: Bilyaevsky or Voznesenski quarry. As modifiers used additive lignosulfonate or superplasticizer polycarboxylate type MC-PowerFlow 3200. All concrete mixtures had equal mobility P2, which was provided by variation W/C (water-cement ratio).

It was found that the concrete on the secondary crushed stone is characterized by a significantly higher W/C mixture due to greater porosity and damage to the surface of the coarse aggregate. The average density of concrete on secondary crushed stone is 4.2-4.4% lower compared to the average density of concrete on granite crushed stone. The average density of concrete on the larger sand of the Voznesenski quarry is 25-30 kg/m^3 higher than the average density of concrete on similar gravel and finer sand of the Bilyaevsky quarry.

In composites based on CEM III/A and using lingosulfonate additives, the compressive strength of concrete on secondary crushed stone is 12-13% lower compared to the strength of concrete on granite crushed stone and similar sand. However, when using the more efficient MC-PowerFlow 3200 additive, the difference in concrete strength on secondary and granite crushed stone is only 5.4% (29.8 MPa and 31.4 MPa, respectively). The strength of concrete on the sand of the Voznesenski quarry is 4-6% higher than the strength of concrete on similar gravel and finer sand of the Bilyaevsky quarry.

It was found that the tensile strength when bending concrete on secondary and granite gravel when using the additive MC-PowerFlow 3200 was 2.75 MPa and 2.87 MPa, respectively, which differs by only 4%. Thus, the tensile strength of bending concrete on secondary crushed stone was almost no different from the tensile strength of similar concrete on granite crushed stone. This can be explained by the peculiarities of the aggregate with a porous surface, which is characterized by high adhesion to the cement-sand matrix.

In general, the strength of concrete on secondary crushed stone using slag-containing cements allows them to be used effectively for road bases.

Keywords: secondary crushed stone, resource saving, plasticizer, rigid pavement base, strength.

Introduction. According to current Ukrainian industry building codes NBC V.2.3-37641918-557:2016 [1] during designing and calculating rigid pavement it is necessary to provide for the extensive use of local materials and by-products.

Today secondary crushed stone is a product whose use is becoming increasingly important. It is made of concrete scrap, which arises as a result of dismantling of emergency, damaged and obsolete buildings and structures, reclamation of industrial landfills and directly as waste from the production of precast reinforced concrete structures. It can be argued that the expected increase in the occurrence of concrete waste due to the fact that the service life of buildings massively erected in the 50s-60s of the last century is coming to an end [2-3], as well as due to hostilities. In most large cities of Ukraine there are already technological lines for crushing reinforced concrete structures and production of secondary crushed stone. The use of this rubble for road construction, namely for the manufacture of concrete hard foundations of roads, is a rational solution from an economic and environmental point of view. When installing concrete foundations of roads with the use of secondary materials, additional resource savings can be achieved through cements containing waste, in particular Portland slag cement. According to NBC V.2.3-4:2015 [4] it is in the layers of the base can be used Portland cement with mineral additives and slag Portland cement. Thus, concrete on secondary crushed stone can be considered a promising material for the foundations of roads, respectively, the task of developing such materials using domestic raw materials is relevant.

Analysis of recent research and publications. According to NBC V.2.3-4:2015 "Roads" the basis of pavement is a structural part of pavement designed to reduce pressure on additional layers of pavement and soil, by redistributing the force from the wheels to a larger area. Also according to this standard for concretes of the bottom layer of two-layer monolithic coverings and for a monolithic basis under a covering compressive strength is not regulated. Thus for a monolithic basis under a covering the minimum design class on tensile strength at a bend should be not less than 0.8 (10 kgf/cm^2).

Also according to NBC V.2.3-4:2015 frost resistance of concrete for cement concrete foundations should be respectively: at the average monthly air temperature of the coldest month from 0 to -5 °C – F25; at the average monthly air temperature of the coldest month from -5 to -10 °C – F50. Portland cement with mineral additives and slag Portland cement of brands over 300 can be used in the base layers.

In recent years, the practice of arranging road bases from secondary raw materials, in particular concrete scrap, has been increasingly used. This allows to solve the urgent problem of processing and use of the remains of dismantled reinforced concrete structures. Thus, in France, approximately 38 million tons of concrete scrap are produced per year [5], in the United States – 143 million tons, and this figure is increasing every year [6]. Extensive use of secondary gravel will not only solve the problem of processing incoming concrete waste, but also to rehabilitate landfills [7].

In Europe and the world as a whole, cement-concrete coatings are becoming more and more widespread both for the construction of highways and for auxiliary sections of roads. For example, in [8] the possibility of using secondary gravel for the device of the lower layers of cement-concrete pavements was investigated.

Analysis of scientific publications on the dismantling of reinforced concrete structures shows the gradual development of modern technologies for the extraction of high quality secondary gravel from concrete scrap [9]. The strength characteristics of concrete with a large aggregate in the form of secondary crushed stone do not allow to make critical load-bearing reinforced concrete structures, but it can be used in road construction for cement concrete coatings [10, 11].

At present, the international scientific community has insufficient knowledge about the properties and choice of concrete compositions from secondary crushed stone. This is primarily due to the large variety of large and small aggregates, cement, which can vary significantly depending on the region or country of manufacture, and the wide range of plasticizer additives available on the market. The combination of certain components significantly affects the properties of concrete, which was confirmed during tests. Moreover, the topic of cement concrete roads is new to many European countries, and the amount of concrete scrap resulting from the dismantling of buildings as a result of the reconstruction of entire territories is increasing [12].

It is advisable to cover the needs for construction materials with the maximum use of secondary resources. In addition to secondary crushed stone, it is possible to use other raw materials with secondary products, in particular cement with a high content of ash and slag of metallurgical production. Thus, in [13] to increase the use of secondary resources as a binder, it was proposed to use Portland slag cement, which has a high content of ash and slag of metallurgical production (up to 60%).

The above confirms the relevance of research on concrete based on secondary gravel as materials for the foundations of roads. It is also advisable to use cements that contain a significant proportion of by-products.

The aim of the work is to determine the effectiveness of the use of plasticizers of different types in the concrete of the foundations of roads on secondary crushed stone, as well as to compare the strength of concrete on secondary and granite crushed stone.

Materials and methods of research. The following materials were used as aggregates for concrete:

– secondary crushed stone fraction of 5…20 mm. Gravel grade by crushing 600. Bulk density of secondary crushed stone – 1310 kg/m^3;

– granite crushed stone of fraction of 5…20 mm. Gravel grade by crushing 1200. Bulk density of granite gravel – 1390 kg/m^3;

– quartz sand of Bilyaevsky quarry (Odessa region) with a modulus of size 1.56. Bulk density of sand – 1420 kg/m^3.

– quartz sand of Nikitovsky (Voznesenski) quarry (the Nikolaev region) with the modulus of size 2.29. Bulk density of sand – 1490 kg/m^3. These two types of quartz sand were used as the most common types of fine aggregate for concrete in southern Ukraine;

– superplasticizer additive SP-1 (S-3), TU 5745-001-97474489-2007 (TU 5870-005-58042865-05), manufactured by Polyplast LLC, Novomoskovsk;

– additive plasticizer lignosulfonate, manufactured by LLC Doronik-Ukraine, Svalyava;

– additive superplasticizer of polycarboxylate type MC-PowerFlow 3200, production of LLC MC Bauhemi, Berezan, Kiev region;

– Portland slag cement CEM III/A 32.5. Ground blast furnace slag content up to 60%;

– Portland cement CEM II/B-S 32.5. Ground blast furnace slag content up to 35%. Both cements of CRH production of JSC Podilsky Cement.

All concretes had equal mobility P2. The actual settling of the cone of the mixtures was from 4 to 7 cm, which was achieved by selecting the amount of water in the compositioni.

At the exploratory stage of the work were studied concretes on secondary crushed stone, the compositions of which are shown in Table 1. Physical and mechanical properties of the studied at this stage of the concrete are shown in Table 2.

Table 1 – Compositions of concrete studied at the exploration stage

№ of comp.	Cement CEM III/A 32.5, kg/m^3	Secondary crushed stone, kg/m^3	Send of Bilyaevsky quarry, kg/m^3	Additive, kg/m^3 (%)	Water, l/m^3	W/C
A	320	1170	700	lignosulfonate 3.2 (1%)	221	0.691
B		1180	720	lignosulfonate 4.8 (1.5%)	193	0.603
C		1170	705	СП-1 2.56 (0.8%)	219	0.684

Table 2 – Physics-mechanical parameters of concrete studied at the exploration stage

№ of comp.	Average density, kg/m^3	Strength at the age of 7 days, MPa	Strength at the age of 28 days, MPa
A	2158	7.9	15.3
B	2204	9.9	20.4
C	2198	8.0	18.0

Thus, the search experiment showed that the best strength indicators both at the age of 7 days and at the vintage age has a composition B, which contains 1.5% of lignosulfonate additive. Additive SP-1 is not effective enough in concretes based on secondary crushed stone and CEM III/A 32.5. Thus, the composition of concretes modified with the addition of lignosulfonate in the amount of 1.5% by weight of cement was studied at the main stage. The composition №1 in subsequent studies is identical to the composition B in Table 1. Also compared for comparison, concretes modified with superplasticizer polycarboxylate type MC-PowerFlow 3200.

Research results. At the first stage of work in the compositions of the studied concretes of the bases of highways, the type of crushed stone on which the concrete was made changed: secondary or granite. This allows to compare the properties of concrete on secondary crushed stone with the properties of concrete of similar composition on "ordinary" granite crushed stone. The type of sand also changed: Bilyaevsky or Voznesenski quarry. The compositions of the concrete studied at this stage are shown in Table 3. For all compositions used Portland slag cement CEM III/A 32.5.

Table 3 – Compositions of the investigated concretes on various types of crushed stone and sand, CEM III/A 32.5, additive lignosulfonate

№ of comp.	Cement CEM III/A 32.5, kg/m^3	Crushed stone, type, kg/m^3	Send, type, kg/m^3	Additive lignosulfonate, kg/m^3	Water, l/m^3	W/C
1	320	secondary, 1180	Bilyaevsky, 720	4.8 (1.5%)	193	0.603
2		granite, 1185	Bilyaevsky, 730		183	0.572
3		secondary, 1185	Voznesensky, 735		177	0.553
4		granite, 1195	Voznesensky, 755		146	0.456

Further, taking into account that the concretes based on Bilyaevsky quarry sand which were characterized by increased W/C, in the second stage the concrete based on send of Voznesenski quarry were modified, modified with polycarboxylate superplasticizer MC-PowerFlow 3200. Portland cement CEM II/B-S 32.5with a content of ground blast furnace slag up to 35%. The compositions of the concretes studied at this stage are shown in Table 4. All concrete mixtures (№1-№7) had equal mobility P2.

Table 4 – Compositions of the investigated concretes on different types of crushed stone, CEM II/B-S 32.5, polycarboxylate MC-PowerFlow 3200

№ of comp.	Cement, kg/m^3	Crushed stone, type, kg/m^3	Send, type, kg/m^3	Additive polycarboxylate MC-PowerFlow 3200 kg/m^3	Water, l/m^3	W/C
5	320	secondary, 1185	Voznesensky, 732	3.84 (1.2%)	181	0.566
6		secondary, 1185	Voznesensky, 740	4.48 (1.4%)	172	0.537
7		granite, 1195	Voznesensky, 760		144	0.450

As can be seen from the data in Tables 3 and 4, the concrete on the secondary crushed stone is characterized by a significantly higher W/C of mixture due to the naturally greater porosity and damage to the surface of the coarse aggregate. For all tested concretes (№1 – №7) was determined the average density and compressive strength at the age of 28 days, which are shown in Table 5.

Figure 1 shows a diagram illustrating the average density of the studied concrete. In Fig. 2 is a diagram illustrating the compressive strength of these concretes.

Analysis of the data in Table 5 and Figure 1 shows that the average density of concrete on secondary crushed stone is 4.2-4.4% lower compared to the average density of concrete on granite crushed stone and similar sand and with a similar additive. This is due to both the higher W/C of mixtures and the characteristics of the gravel itself, which is less dense than granite. In fact, the surface of the secondary crashed stone is quite porous, which affects both the W/C and the density of the composite as a whole. The average density of concrete on the larger sand of the Voznesenski quarry is 25-30 kg/m^3 higher than the average density of concrete on similar gravel and finer sand of the Bilyaevsky quarry.

Due to the above-described features of secondary crushed stone in composites based on CEM III/A 32.5 and lignosulfonate additives, the compressive strength of concrete on secondary crushed stone is 12..13% lower compared to the strength of concrete on granite crushed stone and similar sand (Fig. 2). However, during using the more efficient MC-PowerFlow 3200 polycarboxylate additive, the difference in concrete strength between secondary and granite crushed stone is only

5.4%. The strength of concrete on the sand of the Voznesenski quarry is 4…6% higher than the strength of concrete on similar gravel and sand of the Bilyaevsky quarry. It can also be noted that concretes of compositions №6 and №7 due to lower W/C and the use of cement with a lower proportion of blast furnace slag were characterized by the highest strength among the studied.

Table 5 – The average density and compressive strength of the studied concrete on different types of crushed stone and additives

№ of composition	Average dentistry, kg/m^3	Compressive strength, MPa
1	2210	20.4
2	2302	22.9
3	2231	21.6
4	2326	24.5
5	2248	22.5
6	2320	29.8
7	2421	31.4

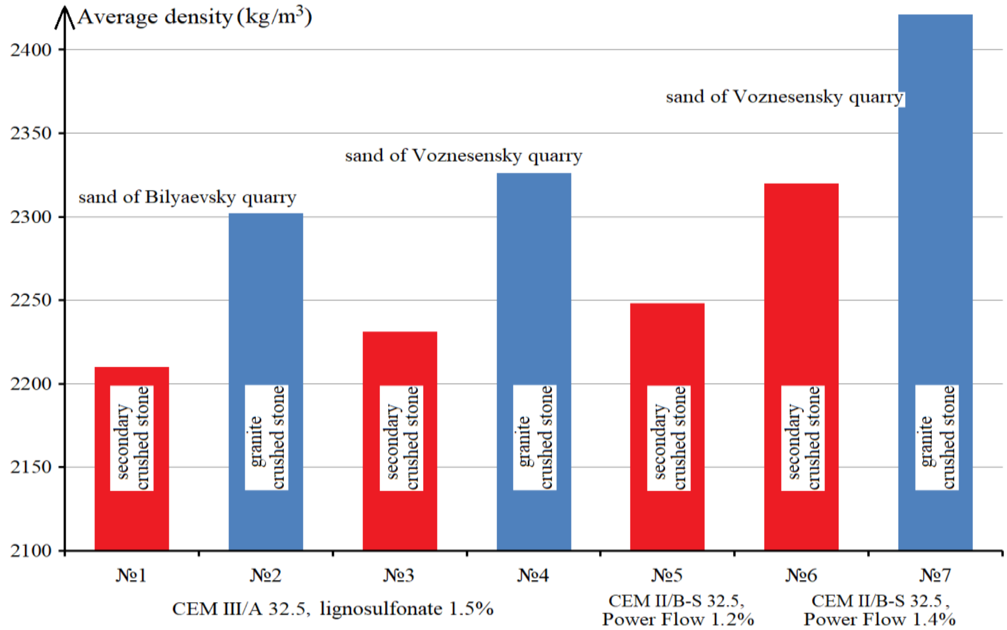

Fig. 1. The average density of the studied concrete

For compositions №6 and №7 in this work was also determined tensile strength in bending, which was respectively 2.75 MPa and 2.87 MPa, which differs by only 4%. Thus, the tensile strength of bending for concrete on secondary crushed stone was almost no different from the tensile strength of similar concrete on granite crushed stone. This can be explained by the peculiarities of the aggregate with a porous surface, which is characterized by high adhesion to the cement-sand matrix, which in turn has a positive effect on the composite during stretching [14].

In general, the strength of concrete on secondary crushed stone with the use of slag-containing cements allows them to be used effectively for road bases that have better durability and performance [15], in particular by preventing the formation of ruts.

Conclusions and prospects for further research. Due to the high tensile strength in bending with satisfactory compressive strength of concrete on secondary crushed stone using slag-containing cements, they can be effectively used for the foundations of roads. This makes such materials promising in road construction.

Further research will determine the effect of superplasticizers and the type of cement on the frost resistance of concrete on secondary crushed stone and improving of technology of preparation of concrete mix taking into account the peculiarities of the use of aggregate with a porous surface.

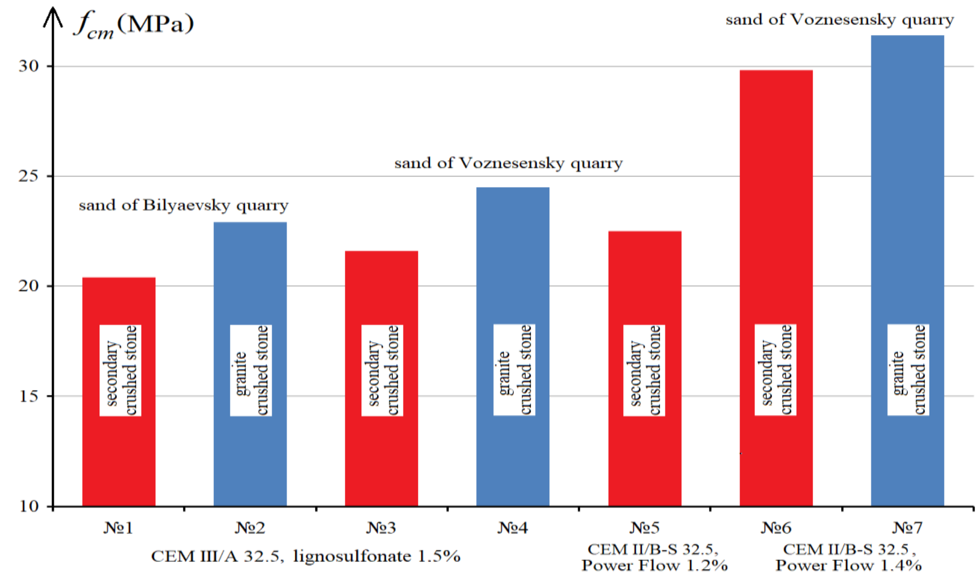

Fig. 2. Compressive strength of the studied concretes

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БЕТОНИ НА ВТОРИННОМУ ЩЕБЕНІ ЯК ПЕРСПЕКТИВНИЙ МАТЕРІАЛ ДЛЯ ОСНОВ АВТОМОБІЛЬНИХ ДОРІГ

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Анотація. В ході дослідження визначено ефективність застосування пластифікаторів різного типу в бетонах основ автомобільних доріг на вторинному щебені. В дослідженнях в складах бетонів змінювався тип щебеню, вторинний або гранітний, що дозволило порівняти властивості бетону на вторинному щебені з властивостями бетону аналогічного складу на гранітному щебені. Крім того змінювався тип піску: Біляєвського або Вознесенського кар’єру. У якості модифікаторів використовувалися добавка лігносульфанат або суперпластифікатор полікарбоксилатного типу MC-PowerFlow 3200. Всі бетонні суміші мали рівну рухомість П2, що забезпечувалося варіюванням В/Ц.

Встановлено, що бетони на вторинному щебені характеризуються відчутно вищім В/Ц суміші завдяки більшої пористості та пошкодженності поверхні крупного заповнювача. Середня густина бетонів на вторинному щебені є на 4,2-4,4% меншою в порівнянні з середньою густиною бетонів на гранітному щебені. Середня густина бетонів на більш крупному піску Вознесенського кар’єру є на 25-30 кг/м^3 вищій, ніж середня густина бетонів на аналогічному щебені та більш дрібному піску Біляєвського кар’єру.

В композитах на основі цементу ССШПЦ 400-Д60 та при використанні добавки лігносульфанату міцність на стиск бетонів на вторинному щебені є на 12..13% меншою в порівнянні з міцністю бетонів на гранітному щебені і аналогічному піску. Але при використанні більш ефективної добавки MC-PowerFlow 3200 різниця у міцності бетону на вторинному та гранітному щебені складає лише 5,4% (29,8 МПа і 31,4 МПа відповідно). При цьому міцність бетонів на піску Вознесенського кар’єру є на 4..6% вищій, ніж міцність бетонів на аналогічному щебені та більш дрібному піску Біляєвського кар’єру.

Встановлено, що міцніть на розтяг при згині бетонів на вторинному та гранітному щебені при використанні добавки MC-PowerFlow 3200 відповідно склала 2,75 МПа і 2,87 МПа, що відрізняється лише на 4%. Таким чином міцність на розтяг при згині бетонів на вторинному щебені майже не відрізнялася від міцності на розтяг аналогічного бетону на гранітному щебені. Це можна пояснити особливостями роботи заповнювача з пористою поверхнею, яка характеризується високою адгезією до цементно-піщаної матриці.

В цілому міцність бетонів на вторинному щебені із використанням цементів, що містять шлак, дозволяє ефективно використовувати їх для основ автомобільних доріг.

Ключові слова: вторинний щебінь, ресурсозбереження, пластифікатор, основа дорожнього покриття, міцність.

Стаття надійшла до редакції 6.05.2022