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STRENGTH OF CONCRETE FOR BASES OF ROAD CLOTHES ON DIFFERENT TYPES OF SECONDARY GRAVEL AND SAND

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Abstract. The task of developing of concrete for the bases of road clothing using secondary concrete aggregates is relevant for an economic and ecological reasons. The properties of concrete were compared with different types of coarse aggregate of 8-16 mm fraction: granite river gravel, secondary crushed stone from recycled reinforced concrete structures, secondary crushed stone from recycled brickwork and ceramic tiles. Three types of sand with a fraction of 0-4 mm were also used: quartz, secondary sand from recycled reinforced concrete structures, secondary sand from recycled brickwork. 2 series of experiments were conducted. During the first series of experiments Portland cement CEM II/B-S 32.5 R and superplasticizer Soudal Soudaplast was used (1% from weight of cement). For the second series of experiments Portland cement CEM II/B-S 42.5 R and superplasticizer Berament HT28 was used (1.2% from weight of cement). The mobility of all mixtures was equal to S1.

Concretes with Berament HT28 superplasticizer had a lower W/C ratio of mixture than concretes with similar aggregates composition and Soudal Soudaplast superplasticizer. The use of secondary crushed stone requires an increasing of the W/C ratio of the mixture. The simultaneous use of secondary sand additionally increases W/C. Due to the lower W/C, the concretes of the second series have a higher average density than the similar concretes of the first series of the experiment. Concretes based on granite gravel and quartz sand have the highest average density (2369-2465 kg/m^3). When using secondary crushed stone from reinforced concrete structures, the average density decreases by 3-5%. When using secondary crushed stone from brickwork and ceramic tiles – decreases by 8-9%. Concretes based on secondary crushed stone and sand from reinforced concrete structures have a 6-9% lower average density compared to concretes on granite gravel. Concretes based on secondary crushed stone and sand from recycled brickwork and ceramic tiles have the lowest average density – from 2015 to 2061 kg/m^3.

Due to the use of higher grade cement and a more effective superplasticizer, the strength of the concretes of the second series of the experiment at the age of 3 days was 69-190% higher than the strength of similar concretes of the first series, at the age of 28 days – higher by 67 to 147%. When using quartz sand, concrete based on secondary crushed stone from reinforced concrete structures has the greatest strength. At the age of 3 days up to 17.97 MPa and 30.33 MPa, at the design age (28 days) up to 32.07 and 53.41 MPa for the first and second series, respectively. The lowest strength (about 16 MPa in the first series of experiments and 27 MPa in the second) had concretes using only low-strength secondary aggregates from recycled brickwork and ceramic tiles.

In general, all the studied concretes on secondary aggregates were characterized by sufficient strength for their use in the bases of hard road clothes.

Keywords: secondary crushed stone, secondary sand, secondary concrete aggregates, superplasticizer, base of road clothes, strength.

Introduction. The task of processing and reusing of the remains of demolished buildings and structures is becoming more and more relevant for most countries of the world every year. For Ukraine, such task is even more urgent due to the presence of a significant amount of destruction caused by hostilities. Among the entire mass of concrete scrap arising from the dismantling of buildings and structures, the remains of reinforced concrete structures and brick walls should be separated. They can serve as high-quality raw materials for the production of crushed stone and sand.

The recycling of demolished and destroyed structures can provide the production of significant volumes of secondary concrete aggregates, but the main disadvantage of such aggregates is their relatively low homogeneity. Taking this into account, the use of secondary aggregates for concrete for the bases of road clothes can be considered promising. Requirements for the strength and frost resistance of these concretes are relatively not strict, but the volumes of concreting in the foundations of roads are significant. The use of rigid bases of road clothing allows to achieve high durability and functional quality of roads with a cement concrete coating. It is also possible to use cement-concrete basement for roads with an asphalt concrete surface.

Thus, the task of developing concretes for the bases of road clothing using secondary concrete aggregates is relevant both from the economic and ecological points of view. At the same time, it is necessary to develop such concretes taking into account modern modifiers (superplasticizers) and cements of local production available on the market.

Analysis of recent research and publications. The volumes of waste from the dismantling of buildings and structures are constantly growing [1, 2]. Every year, it threatens the environment and human health more and more [3]. Due to the increase in the use of secondary aggregates for concrete producing, it is possible to solve the problem of processing not only "new" concrete waste, but also potentially carry out reclamation of construction waste landfills [4].

A promising industry for the use of concrete on secondary aggregates is road construction, namely the installation of concrete foundations for highways. The basis of road clothing is designed to reduce the pressure on additional layers of road clothing and the soil of the ground surface. This happens due to the redistribution of loads from the wheels of transport on a larger area [5]. When designing rigid road clothing according to ДБН В.2.3-4 "it is necessary to provide the using of the of local materials and industrial waste" [5].

According to ГБН В.2.3-37641918-557, the foundation layers are made from low-strength cement concrete. It is recommended to use concretes with a design class of B_{tb} 1.0 and B_{tb} 1.2 in terms of tensile strength when bending [6]. And according to ДБН В.2.3-4, for a monolithic bases, the minimal class is B_{tb} 0.8 (10 kgf/cm^2), frost resistance at the average monthly temperature of the coldest month from 0 to minus 5°C – F25, from minus 5 to minus 10°C – F50 [5]. Thus, the relatively non-strict requirements for the strength and frost resistance of road wear bases concretes open up the possibility of their wide use as part of secondary concrete aggregates, in particular low-strength aggregates.

Some experience has been accumulated in the use of secondary crushed stone in road construction. In [7] it was established that when replacing up to 30% of granite crushed stone with secondary concrete crushed stones, the strength of concrete remained sufficient for the construction of road surfaces. At the same time, four variants of the state of use of the secondary aggregate were compared: initial, saturated superficially dry, fully saturated, dried. It was established that the saturated surface-dry state of the aggregate gives the best results in terms of concrete strength, and the lowest strength is observed when fully saturated crushed stone is used.

In [8], concrete for the bases of road clothing with a compressive strength of up to 6 MPa was obtained using secondary concrete aggregates and blast furnace slag as a binder. Such a material has a minimal carbon footprint due to the fact that it is produced only from waste. Material similar in properties to the foundations of rural roads was obtained in the study [9]. When using secondary aggregates, lime and fly ash, a strength of up to 3 MPa was achieved. In [10], the effectiveness of the use of building demolition waste for the concrete of highway foundations, which are laid by the rolling method, is shown. Due to the use of dispersed reinforcement in [11], concrete based on secondary aggregates was obtained, which meets the requirements for the installation of rigid road surfaces.

However, as shown in [12], the use of secondary concrete aggregates in road construction is limited due to their heterogeneity, low resistance to fragmentation, and high water absorption. In particular, it reduces the wear resistance of concrete. That is, concrete on secondary aggregates is effective precisely for the foundations and lower layers of road clothing, taking into account the conditions of their operation.

The aim of the work is to determine the influence of secondary crushed stone and sand, made from dismantled reinforced concrete structures, as well as brickwork and ceramic tiles, on the properties of the concrete bases of road wear.

Materials and methods of research. For the production of concrete, the following types of coarse aggregate of the same size, fraction 8-16 mm, were used (Fig. 1):

– granite river gravel mined in the Slovak part of the Danube River. Bulk density of gravel ρ_b=1570 kg/m^3, water absorption 0.70%;

– secondary crushed stone from recycled reinforced concrete structures. Bulk density of this crushed stone ρ_b = 1260 kg/m^3, water absorption 5.94%;

– secondary crushed stone from recycled brickwork and ceramic tiles. Bulk density of this crushed stone ρ_b = 1150 kg/m^3, water absorption 8.53%.

granite river gravel

secondary crushed stone from recycled reinforced concrete structures

secondary crushed stone from recycled brickwork and ceramic tiles

Fig. 1. Types of coarse aggregate used for concrete production

In addition, three types of sand fraction 0-4 mm were used (Fig. 2):

– quartz sand with a coarseness modulus of 3.19. Bulk density of sand ρ_b = 1935 kg/m^3;

– secondary sand from recycled reinforced concrete structures. The coarseness module of this sand is 3.83, bulk density ρ_b = 1500 kg/m^3;

– secondary sand from recycled brickwork and ceramic tiles. The coarseness module of this sand is 3.72, bulk density ρ_b = 1375 kg/m^3.

2 series of experiments were conducted. In the first series (formulations №1a – №5a, №1b – №5b) was used Portland cement CEM II/B-S 32.5 R manufactured by the Slovak company Cementaren Ladce (brand 400, containing up to 35% blast furnace slag) and additive superplasticizer polycarboxylate type Soudal Soudaplast, manufactured Soudal (Czech Republic). The amount of additive was 1% of the weight of cement.

In another series (formulations №1c – №5c, №1d – №5d) was used Portland cement CEM II / B-S 42.5 N produced by the Slovak company Cementaren Ladce (brand 500, containing up to 21% blast-furnace slag) and additive superplasticizer polycarboxylate type Berament HT 28, production BetonRacio (Slovakia). The amount of additive was 1.2% of the weight of the cement.

The rational quantity for both additives of superplasticizers was determined by the results of previous experiments.

quartz sand | secondary sand from recycled reinforced concrete structures | secondary sand from recycled brickwork and ceramic tiles

Fig. 2. Types of sand used for concrete production

In each series, concretes based on granite gravel and quartz sand (basic composition), secondary crushed stone from reinforced concrete structures and quartz sand, secondary crushed stone from brickwork and quartz sand, secondary crushed stone from reinforced concrete structures and secondary sand from reinforced concrete structures, secondary crushed stone from brickwork and ceramic tiles and secondary sand from brickwork have been researched.

According DBN B.2.3-4 [5], when using a concrete paver with a sliding formwork, the mobility of the concrete mixture of the base of the road clothing should be from 1 to 5 cm, depending on the speed of the concrete paver. It is also possible to use mixtures with hardness from 3 to 10 s. Accordingly, the mobility of all the studied mixtures was in the range of cone subsidence from 1 to 2 cm. To ensure the necessary mobility with different compositions of concrete, the amount of water varied. The compositions of all the studied concretes of the base of road clothing are shown in Table 1.

Table 1 – Compositions of the investigated road surface concretes

№	Cement (type, kg/m^3)	Coarse aggregate (type, kg/m^3)	Sand (type, kg/m^3)	Additive (type, kg/m^3)	Water (l/m^3)	W/C
First series of the experiment						
1a	CEM II/B-S 32.5 R, 300	granite gravel, 1245	quartz, 735	Soudal Soudaplast, 3	132	0.440
2a		secondary from reinforced concrete constructions, 1100			142	0.473
3a		secondary from brickwork, 980			180	0.600
4a		secondary from reinforced concrete constructions, 1100	secondary from reinforced concrete constructions, 665		169	0.563
5a		secondary from brickwork, 980	secondary from brickwork, 580		231	0.770
1b	CEM II/B-S 32.5 R, 350	granite gravel, 1230	quartz, 695	Soudal Soudaplast, 3.5	144	0.411
2b		secondary from reinforced concrete constructions, 1085			146	0.417
3b		secondary from brickwork, 965			192	0.549
4b		secondary from reinforced concrete constructions, 1085	secondary from reinforced concrete constructions, 625		174	0.497
5b		secondary from brickwork, 965	secondary from brickwork, 530		242	0.691

№	Cement (type, kg/m^3)	Coarse aggregate (type, kg/m^3)	Sand (type, kg/m^3)	Additive (type, kg/m^3)	Water (l/m^3)	W/C
Second series of the experiment						
1c	CEM II/B-S 42.5 R, 300	granite gravel, 1252	quartz, 762	Berament HT28, 3.6	124	0.413
2c		secondary from reinforced concrete constructions, 1122			138	0.460
3c		secondary from brickwork, 982			175	0.583
4c		secondary from reinforced concrete constructions, 1070	secondary from reinforced concrete constructions, 755		168	0.560
5c		secondary from brickwork, 803	secondary from brickwork, 765		229	0.762
1d	CEM II/B-S 42.5 R, 350	granite gravel, 1233	quartz, 727	Berament HT28, 4.2	136	0.389
2d		secondary from reinforced concrete constructions, 1112			141	0.403
3d		secondary from brickwork, 968			183	0.523
4d		secondary from reinforced concrete constructions, 992	secondary from reinforced concrete constructions, 752		166	0.474
5d		secondary from brickwork, 789	secondary from brickwork, 704		232	0.663

Research results. Due to the use of different types of aggregates, two types of cement in the amount of 300 and 350 kg/m^3 of mixture, as well as two types of superplasticizers, the water consumption of concrete mixtures differed significantly. Accordingly, the W/C of the mixtures changed, as shown in Fig. 3 diagrams.

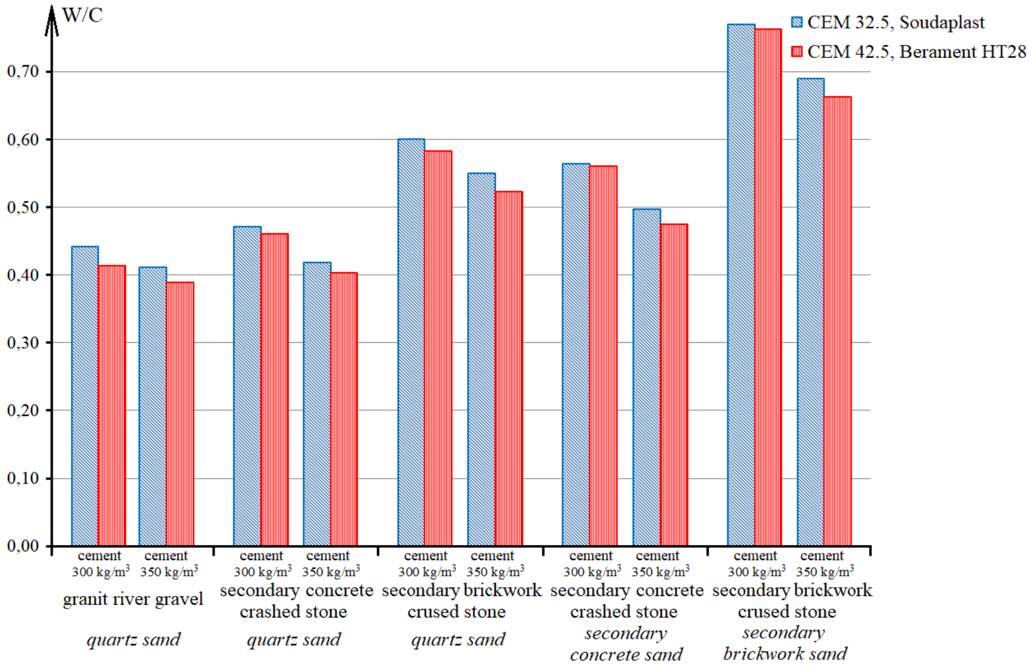

Fig. 3. Effect of concrete composition on W/C of mixtures (cone subsidence =1…2 cm)

As can be seen from the diagram and the data in Table 1, concretes with Berament HT28 superplasticizer have a lower W/C of mixture than concretes with similar aggregates when using Soudal Soudaplast superplasticizer. The different effectiveness of the additives may also be due to the different types of cement used in the first and second series of the experiment [13, 14].

Concretes based on granite gravel and quartz sand were expected to have the least W/C. When using secondary crushed stone from reinforced concrete structures, the W/C of the mixtures increased due to the absorption of part of the water by the aggregate. Accordingly, the use of secondary crushed stone from brickwork and ceramic tiles made it necessary to increase the W/C of the mixture even more. When secondary crushed stone was used simultaneously with secondary sand, the W/C of the mixtures increased further and was the maximum for concretes based on crushed stone and sand from brickwork and ceramic tiles. It should be noted that a significant part of the water in concrete on secondary aggregates, which are porous, is spent precisely on the saturation of the aggregate. This has a rather ambiguous effect on the structure of concrete: on the one hand, it increases the total porosity of the composite material, on the other hand, it improves the conditions of concrete hardening and the adhesion between the aggregate and the cement matrix [14, 15]. At the same time, the strength and porosity of the aggregate, in turn, have a significant impact on the properties of concrete.

For all studied concretes, their average density and compressive strength at the age of 3 and 28 days were determined. The results of determining these indicators are shown in Table 2.

Table 2 – Properties of the investigated concretes for the bases of road wear

№	Average density, kg/m^3	Compressive strength at the age of 3 days, MPa	Compressive strength at the age of 28 days, MPa
First series of the experiment			
1a	2369	12.21	23.88
2a	2303	14.78	25.35
3a	2171	8.28	16.88
4a	2214	10.40	20.27
5a	2015	4.39	10.95
1b	2373	14.21	29.57
2b	2298	17.97	32.07
3b	2164	11.70	24.85
4b	2224	13.85	22.40
5b	2030	6.39	16.07
Second series of the experiment			
1c	2458	28.28	47.99
2c	2341	29.45	49.16
3c	2238	21.29	41.63
4c	2288	15.61	35.47
5c	2061	13.04	27.05
1d	2465	29.81	50.18
2d	2358	30.33	53.41
3d	2238	22.23	42.66
4d	2247	23.62	39,77
5d	2034	13.85	27,65

At Fig. 4 is a diagram showing the average density of the tested concretes for pavement bases.

Analysis of the diagram and the data in Table 2 shows that the concretes of the second series (Portland cement CEM II/B-S 42.5 N, superplasticizer Berament HT28) have a higher average density than the concretes of the first series of the experiment, which are similar in terms of the type of aggregates. This is explained by the lower W/C of the mixtures due to the use of a more effective superplasticizer. Both for the first and for the second series of experiments, the amount of Portland cement does not significantly affect the average density of concrete.

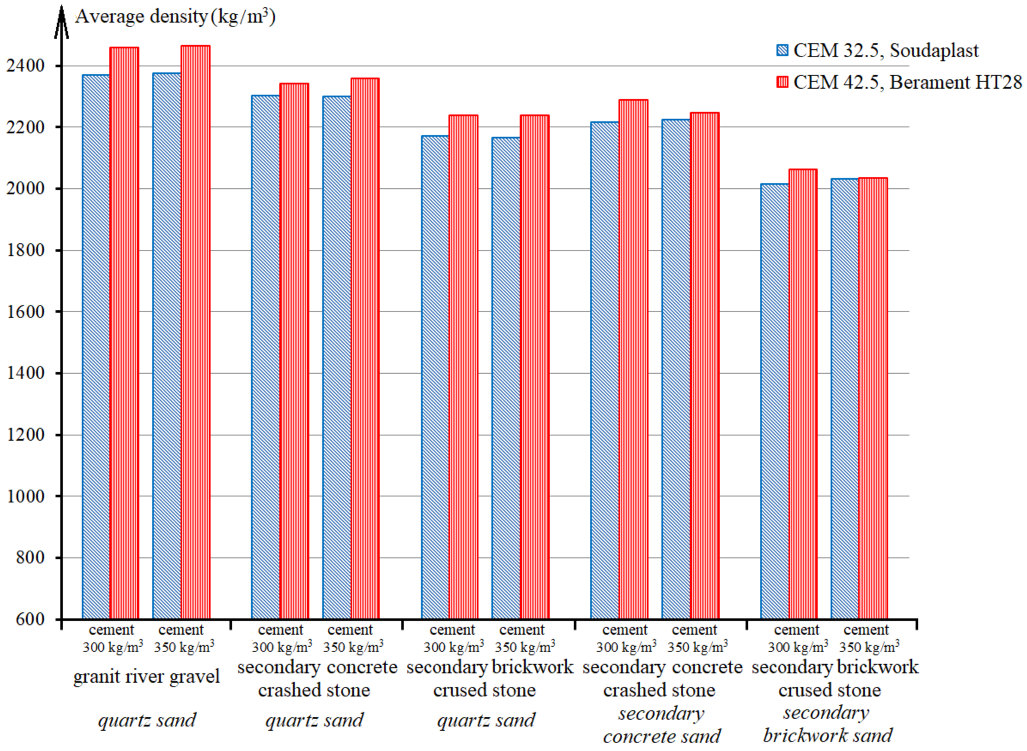

Fig. 4. Average density of the studied concretes

The general effect of the type of aggregate on the average density of concrete is similar for both series of the experiment. Concretes based on granite gravel and quartz sand have the highest density. When using secondary crushed stone from reinforced concrete structures, the average density decreases by 3-5%. When using secondary rubble from brickwork and ceramic tiles – by 8-9%. Concretes based on secondary crushed stone and sand from reinforced concrete structures have a 6-9% lower average density compared to "basic" compounds on granite gravel. The smallest average density (from 2015 to 2061 kg/m^3) has concretes based on secondary crushed stone and sand from recycled brickwork and ceramic tiles. This is 14-17% less than the average density of "basic" concretes on granite gravel. Such influence of aggregates is expected and is explained by their own average density and porosity [16]. To confirm this, in the second series of experiments, the water absorption of the tested concretes was determined, which is actually their open porosity and is shown in Table 3.

Table 3 – Water absorption of the tested concretes of the second series of the experiment (% by volume)

№	1c	2c	3c	4c	5c	1d	2d	3d	4d	5d
Water absorption	6.2	7.6	9.7	7.8	13.9	5.6	7.6	8.7	7.7	12.4

However, the type of Portland cement, superplasticizer and aggregates has a significantly greater influence on the strength of the studied concretes than on the average density. The compressive strength of the studied concretes for the foundations of road clothing at the age of 3 and 28 days is shown in the diagrams in Fig. 5.

Analysis of the diagrams and data in Table 2 shows that the strength of the concretes of the second series of the experiment was much higher in comparison with the strength of the aggregates similar in type to the concretes of the first series. At the age of 3 days, the difference was from 69 to 190%, at the age of 28 days – from 67 to 147%. This is explained by the use of cement with a higher grade and, at the same time, a more effective superplasticizer, which provided a lower W/C of the mixtures.

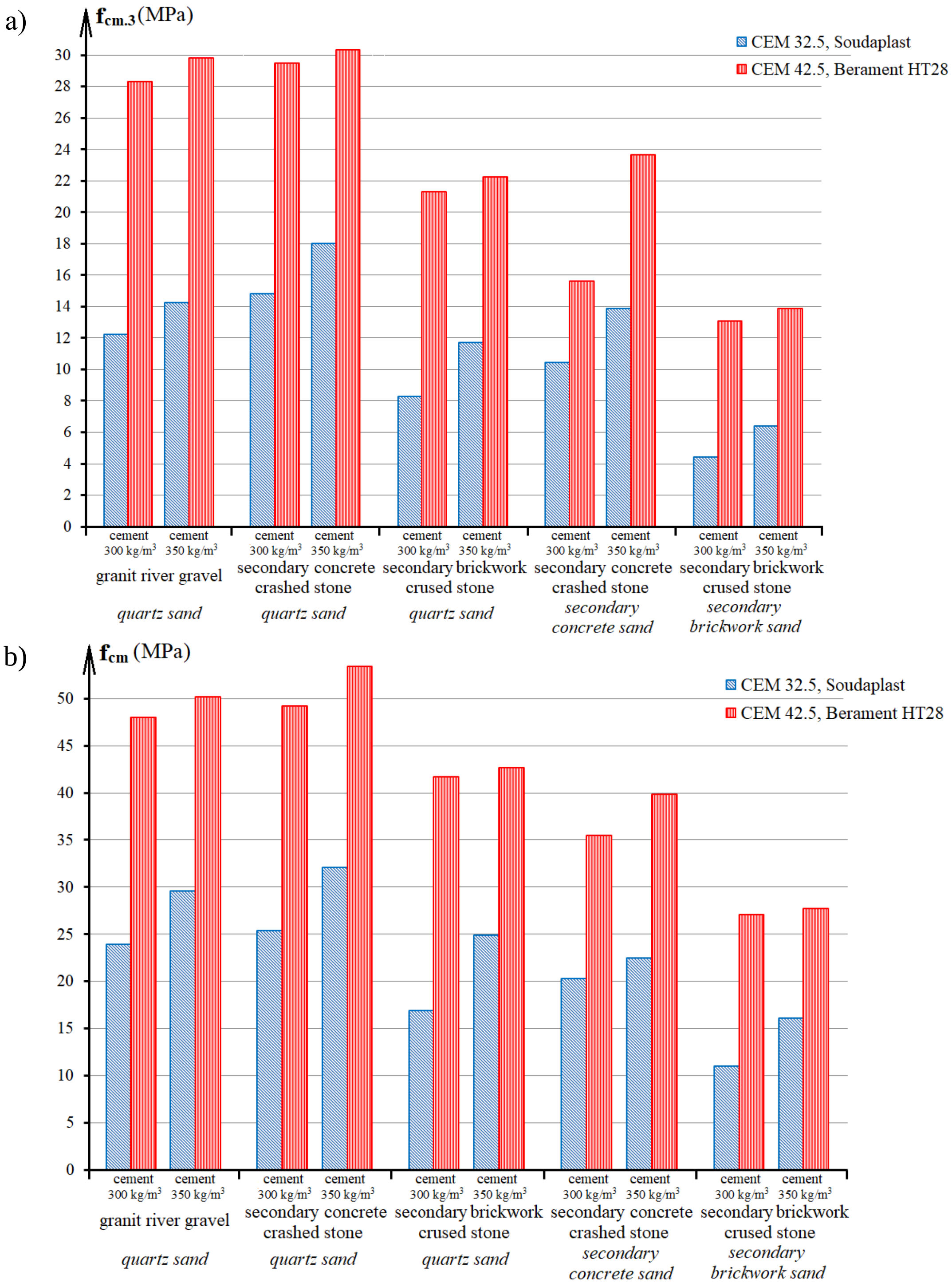

Fig. 5. Strength of the studied concretes at the age of 3 days (a) and 28 days (b)

At the same time, the general trends of the influence of the type of aggregate on strength were similar for the concretes of the first and second series of the experiment. When using quartz sand, concretes based on secondary crushed stone from reinforced concrete structures have the highest strength at the age of 3 and 28 days – up to 30.3 MPa and 53.4 MPa, respectively. At the design age, the strength of concrete on such secondary crushed stone is 2-8% higher than the strength of concrete on granite gravel. At the age of 3 days for the first series of experiments, the difference in strength was even greater. This effect is explained primarily by the use in concrete of "basic" compositions of granite gravel, which has a rolled shape. It is known that gravel has less adhesion to the cement-sand matrix, which affects the strength of the composite [14]. Secondary crushed stone has a non-rolled shape and, as noted above, relatively high porosity, which ensures sufficient adhesion with the matrix and improves concrete hardening conditions [15]. However, for many European countries, river gravel is the main type of coarse aggregate for concrete.

When using secondary crushed stone from brickwork and ceramic tiles (quartz sand as a fine aggregate), the strength of concrete becomes lower compared to concrete on granite gravel by 18-32% at the age of 3 days and by 13-29% at the age of 28 days. This is explained by the fact that this coarse aggregate has the lowest strength among those used in research.

When using secondary crushed stone from reinforced concrete structures simultaneously with secondary sand, the strength of concrete decreases by 15-26% compared to concrete of "basic" compositions. This can be explained by a decrease in the strength of the cement-sand matrix due to the use of porous sand and a corresponding increase in the W/C of the mixture.

When using secondary crushed stone and sand from brickwork and ceramic tiles, the strength of concrete is 44-56% less than the strength of similar concretes of "basic" compositions on granite gravel, that is, approximately twice. However, even such concretes with the use of only low-strength secondary aggregates due to the use of an effective superplasticizer (the second series of the experiment) have a strength at the design age of about 27 MPa, which satisfies the requirements for the material of the road wear base. It should be noted that the tensile strength of such concretes during bending was determined in additional studies. Its value was from 2.8 to 2.9 MPa, which also confirms the possibility of using such concrete in road construction.

In general, all the studied concretes on secondary aggregates were characterized by sufficient strength for their use in the basements of hard road wear. At the same time, the concretes of the second series of experiments based on secondary crushed stone and sand from reinforced concrete structures, as well as on the basis of any crushed stone and quartz sand, have strength that allows such materials to be considered as an alternative to "traditional" concrete when arranging the bottom layer of a two-layer hard coating. However, for use not only in basements, but also directly in road surfaces, concrete must meet sufficiently high frost resistance requirements (F100, F150) [5]. When using secondary aggregates, it is quite difficult to achieve this level of frost resistance and it requires additional research.

Conclusions and prospects for further research. The conducted studies confirmed the prospects of using concrete on secondary aggregates for the arrangement of the bases of hard road clothing. When using an effective superplasticizer, even concretes based on low-strength aggregates from recycled brickwork and ceramic tiles have sufficient strength for such structures.

Further research is planned to determine the flexural strength and frost resistance of concrete on secondary aggregates. It is also planned separately to determine the degree of homogeneity of the properties of such concretes, which is important given the potentially high heterogeneity of the composition and properties of secondary aggregates.

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МІЦНІСТЬ БЕТОНІВ ОСНОВИ ДОРОЖНЬОГО ОДЯГУ НА РІЗНИХ ВИДАХ ВТОРИННОГО ЩЕБЕНЮ І ПІСКУ

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Анотація. Задача розробки бетонів для основи дорожнього одягу з використанням вторинних заповнювачів є актуальною з економічної та екологічної точок зору. Порівняно властивості бетонів з різними типами крупного заповнювача фракції 8-16 мм: гранітного річкового гравію, вторинного щебеню з перероблених залізобетонних конструкцій, вторинного щебеню з переробленої цегляної кладки та керамічної плитки. Також використовувалося три типу пісків фракції 0-4 мм: кварцовий, вторинний пісок з перероблених залізобетонних конструкцій, вторинний пісок з переробленої цегляної кладки. Проведено 2 серії експериментів. У першій серії використовувався портландцемент CEM II/B-S 32.5 R та суперпластифікатор Soudal Soudaplast (1% від маси цементу). У другій серії використовувався портландцемент CEM II/B-S 42.5 R та суперпластифікатор Berament HT28 (1,2% від маси цементу). Рухомість всіх суміші була рівною S1.

Бетони з суперпластифікатором Berament HT28 мали меншу В/Ц суміші, ніж бетони з аналогічними заповнювачами та суперпластифікатором Soudal Soudaplast. Використанні вторинного щебеню вимагає підвищення В/Ц суміші. Одночасне використання вторинного піску додатково підвищує В/Ц. Завдяки меншому В/Ц бетони другої серії мають вищу середню густину, ніж аналогічні бетони першої серії експерименту. Найбільшу середню густину (2369-2465 кг/м^3) мають бетони на основі гранітного гравію і кварцового піску. При використанні щебеню з залізобетонних конструкцій середня густина знижується на 3-5%. При використанні щебеню з цегляної кладки та керамічної плитки – на 8-9%. Бетони на основі вторинного щебеню і піску з залізобетонних конструкцій мають на 6-9% меншу середню густину у порівнянні з бетонами на гранітному гравії. Найменшу середню густину мають бетони на основі вторинного щебеню і піску з переробленої цегляної кладки та керамічної плитки – від 2015 до 2061 кг/м^3.

Завдяки застосуванню цементу вищої марки і більш ефективного суперпластифікатору міцність бетонів другої серії експерименту у віці 3х діб була на 69-190% вище міцності аналогічних бетонів першої серії, у віці 28 діб – вище на 67 до 147%. При використанні кварцового піску найбільшу міцність мають бетоні на основі вторинного щебеню з залізобетонних конструкцій. У віці 3х діб до 17,97 МПа та 30,33 МПа, у проєктному віці до 32,07 і 53,41 МПа для першої і другої серії відповідно. Найменшу міцність (близько 16 МПа у першій серії експерименту і 27 МПа у другій) мали бетони з використанням лише маломіцних вторинних заповнювачів з переробленої цегляної кладки та керамічної плитки.

В цілому всі досліджені бетони на вторинних заповнювачах характеризувалися достатньою міцністю для їх використання в основах жорсткого дорожнього одягу.

Ключові слова: вторинний щебінь, вторинний пісок, вторинні заповнювачі бетону, пластифікатор, основа дорожнього одягу, міцність.

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