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# PROPERTIES OF CONCRETE AND FIBER-REINFORCED CONCRETE FOR BASES OF ROAD CLOTHES BASED ON SECONDARY AGGREGATES WITH HETEROGENEOUS COMPOSITION

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**Abstract.** The problem of disposal of concrete scrap of dismantled building structures is relevant for most countries of the world. For Ukraine, this problem is even more acute due to the significant amount of destruction caused by hostilities and rocket attacks.

In current research the properties of concrete and fibre-reinforced concrete for the bases of road clothes based on natural and secondary aggregates were compared: granite river gravel, secondary crushed stone with a heterogeneous composition, quartz sand and secondary sand from recycled reinforced concrete structures. CEM III/A slag Portland cement with a blast furnace slag content of 65% and a polycarboxylate type superplasticizer were used.

Three series of samples were studied: without fibre; with glass fibre ANTI-CRAK HP 12 (length 12 mm, diameter 0.017 mm, equivalent thread diameter 0.3 mm) in the amount of 1 kg/m$^3$; with polypropylene fibre BeneSteel 55 (length 55 mm, equivalent thread diameter 0.48 mm) in the amount of 4 kg/m$^3$. In each series, concrete on granite gravel and quartz sand, concrete on secondary crushed stone and quartz sand, concrete on secondary crushed stone and secondary sand were studied. The workability of all mixtures was equal to S1.

Due to the use of different types of aggregates and fibres, the W/C of concrete mixtures differed significantly. Concretes on secondary aggregates had a higher W/C than on natural aggregates. When using the Anti-Crak HP 12 fibre, the mobility of mixtures with equal W/C increased by 5.5 – 6.9 %. When using BeneSteel 55 fibre, W/C increased by 10.6 – 15.5 %.

The type of aggregate had a significant effect on the average density of concrete. When using secondary crushed stone and quartz sand, the average density decreased by 3.8 – 4.6 %. When using secondary crushed stone simultaneously with secondary sand, the average density of concrete decreased by 5.2 – 8.5 %. When using Anti-Crak HP 12 fiber, the average density of concrete decreases by 2 %, when using BeneSteel 55 fibre – up to 4.1 %.

Concretes on secondary crushed stone with heterogeneous composition and quartz sand had 4 % higher compressive strength and 2 % higher tensile strength in bending than concretes on granite gravel and similar sand (29.8 MPa and 3.18 MPa, respectively). When secondary crushed stone is used simultaneously with secondary sand, the compressive strength of concrete is only 1.1 % lower than the strength of concrete on natural aggregates, and the tensile strength in bending is 10 % lower. This confirms the possibility of effective use of these concretes for arranging of bases of road clothes. The high-quality performance of secondary aggregates in concrete explains due to their better adhesion to the cement-sand matrix.

Dispersed fibre reinforcement with Anti-Crak HP 12 has a positive effect on the compressive strength of concrete on all types of aggregate and increases the tensile strength of concrete on natural aggregates. The use of BeneSteel 55 fibre was not effective due to a significant increase in the W/C of the mixture when it was introduced. In general, taking into account the economic factor, dispersion reinforcement of concrete on secondary aggregates with the types of fibres used in the research is not advisable.

**Key words:** secondary crushed stone, heterogeneous composition, secondary sand, secondary concrete aggregates, polymer fiber, plasticizer, base of road clothing, strength.

**Introduction.** The problem of processing and disposal of concrete scrap and dismantled building structures is relevant for all developed countries of the world. This is due to the fact that the buildings, which were massively constructed in the second half of the 20th century, are physically and morally outdated and are gradually being decommissioned. For Ukraine, the problem of disposal of concrete scrap is even more acute due to the significant amount of destruction of buildings and structures as a result of hostilities and shelling.

The most effective method of using of demolished building structures is their processing into secondary crushed stone. The technologies of such processing are constantly improving. However, the heterogeneity of secondary crushed stone still remains one of the main limiting factors for its mass application for concrete production.

During processing of concrete structures that were damaged as a result of hostilities, it is even more difficult to achieve homogeneity of the secondary material. This is because the dismantling of the structures is not carried out according to the plan with using of optimal demolition technologies and in conditions of probable additional contamination with associated materials.

Accordingly, the mass use of secondary aggregates, especially in the conditions prevailing in Ukraine, is possible in structures that do not have high requirements for strength and frost resistance. To such structures include bases of road clothing. The urgency of arranging of concrete bases for road clothing is due to the constant increase in the load on the road network. For Ukraine, it is also caused by large amounts of destruction of the transport infrastructure, which must be restored.

One of the most important quality indicator for concrete bases of road clothing is the tensile strength in bending. It is known that dispersed reinforcement is an effective and relatively inexpensive method of increasing of the tensile strength of concrete. Accordingly, it is relevant to study the effect of dispersed reinforcement on the properties of concrete bases of road clothing on secondary aggregates.

**Analysis of research and publications.** Concrete is one of the most common construction materials in the world, including for road construction [1]. In road construction, the largest volumes of concrete are used for the arranging of hard road surfaces. It is known that rigid cement concrete pavements have certain advantages over non-rigid asphalt concrete pavements at relatively close cost of construction. The main advantages are high durability and resistance to rut formation [2]. Due to this, in the developed countries of the world, in particular in Ukraine, the share of roads with rigid cement concrete pavement is gradually increasing [3, 4].

Concrete on secondary aggregates has the prospect of use for the bases of road clothing, which are arranged to reduce the pressure on the soil of the subgrade. Concrete bases allow to redistribute the load from transport over a larger area, which has a positive effect on the durability and quality of roads [5]. The base layers of road clothing are made of cement concrete of relatively low strength. According to Ukrainian norm GBN B.2.3-37641918-557:2016, it is recommended to use concretes with tensile strength class $B_{tb}$ 1.0 and $B_{tb}$ 1.2 for bases [6]. The requirements for the frost resistance of the concrete bases of road clothing are also not strict. According to DBN B.2.3-4:2015, when the average monthly temperature of the coldest month is up to minus 5 °C, frost resistance must be at least F25, at temperatures up to minus 10 °C – at least F50 [5].

There is experience in the use of concrete on secondary aggregates for the arrangement of the bases of road clothing. For example, concrete with strength of up to 6 MPa was obtained in research [7] using secondary crushed stone and sand, as well as blast furnace slag as a binder. In [8], waste from the dismantling of buildings was used in bases concrete, while laying the base layer was carried out by the rolling method. About 20,000 tons of secondary concrete aggregates were used in the construction of the base of the 2-kilometer section of the Lahti highway in Finland. The experience of operating this heavily trafficked area has shown its high quality [9]. Approximately 25.000 m$^3$ of secondary aggregates were used for the concrete base of the airfield surface during the reconstruction of the Lisbon airport. The secondary crushed stone obtained during the dismantling of the old coating had a maximum size of 40 mm. The average density of concrete based on it was 2026 – 2116 kg/m$^3$, and water absorption – from 6.7 to 9.0 %. According to experts' estimates, this decision made it possible to save about 500.000 euros [10]. Directly secondary crushed stone was used for arranging of the basement of highways, in particular temporary ones, backfilling sites for parking equipment, etc. [11].

Control of the structure and properties of concrete on secondary aggregates is carried out by methods that are generally similar to methods of controlling of "ordinary" concrete on mass-using aggregates [12]. For concrete road surfaces and their bases, dispersed reinforcement is one of the most effective methods of increasing the tensile strength, frost resistance, and wear resistance [13, 14]. Various types of fibres are used in road construction, but polypropylene, glass, and basalt fibres are the most effective considering cost and corrosion resistance [15, 16]. The introduction of dispersed reinforcement also makes it possible to reduce the opening width of cracks in the road surface and change the nature of its destruction from brittle to ductile [15-18].

The mentioned above confirms the relevance of the study of the possibility of improving the quality of concrete for the bases of road clothing based on secondary aggregates by the use of dispersed reinforcement with resistant to corrosion fibre.

**The purpose of the work** is to determine the impact on the concrete properties for the bases of road clothes of secondary crushed stone with a heterogeneous composition and secondary sand, as well as dispersed reinforcement with resistant to corrosion fibres of different geometries.

**Research materials and methods.** The properties of concrete and fibre concrete on natural and secondary aggregates were compared.

In the experimental studies, two types of coarse aggregate of fraction 8-16 mm were used (DSTU B EN 12620:2013 [19]):

– granite river gravel mined in Slovakia in the floodplain of the Danube River. Bulk density of gravel 1570 kg/m$^3$, water absorption 0.70 %. It was selected as one of the most widespread aggregate types in Central Europe;

– secondary coarse aggregate (crushed stone) with a heterogeneous composition. Approximate composition of this coarse aggregate: 35.8 % of cement-sand concrete matrix; 30.2 % of granite combined with cement-sand matrix; 24.68 % of pure granite; 9 % of pieces of brick and ceramic tiles; 0.8 % of asphalt concrete; 0.4 % of steel wire. The bulk density of this crushed stone is 1170 kg/m$^3$, water absorption is 13.03 %. Such coarse aggregate is as close as possible to mass secondary crushed stone available on the construction market. It can also be considered close to heterogeneous crushed stone, which is obtained during the processing of destroyed buildings and structures.

Two types of sand with a fraction of 0 – 4 mm were used as fine aggregate [19]:

– quartz sand with fineness modulus 3.19, the bulk density is 1850 kg/m$^3$;

– secondary sand from recycled reinforced concrete structures. The fineness modulus of this sand is 3.83, the bulk density is 1500 kg/m$^3$.

Portland slag cement CEM III/A manufactured by CRH Cement Multicem, Germany, with a blast furnace slag content of 65 % was used as a binder. This choice of cement is due to the need to maximize the use of secondary resources, in particular metallurgical waste.

Additive superplasticizer polycarboxylate type Soudal Soudaplast manufactured by Soudal, Czech Republic was used. The additive was introduced in a rational amount of 1.2 % of the mass of cement. The rational quantity was determined as a result of previous experiments.

Two types of fibre were used as dispersed reinforcement:

– Anti-Crak HP 12, glass fiber, fiber length is 12 mm, fiber diameter is 0.017 mm, equivalent thread diameter is 0.3 mm. Tensile strength according to EN 14889-2 is 1000...1700 MPa. Manufacturer is Owens Corning, USA [20].

– BeneSteel 55, polypropylene fibre, fibre length is 55 mm, equivalent diameter is 0.48 mm. Tensile strength according to EN 14889-2 is 610 MPa. Manufacturer is SKLOCEMENT BENES, Czech Republic [21].

Three series of samples were studied, respectively without fibre (1a – 3a), with ANTI-CRAK HP 12 fibre in the amount of 1 kg/m$^3$ (1b – 3b) and with BeneSteel 55 fibre in the amount of 4 kg/m$^3$ (1c – 3c). This amount of fibre was chosen in accordance with the recommendations of manufacturers and the results of previous experiments. In each series, the following were investigated: concrete based on granite gravel and quartz sand as a control composition; concrete using secondary crushed stone and quartz sand; concrete using secondary crushed stone and secondary sand. The workability of all mixtures was equal to S1, with cone slump (CS) = 1…2 cm. Such workability meets the requirements of DBN B.2.3-4:2015 [5]. The amount of water was accordingly adjusted depending on the composition of the concrete mixture. The compositions of the studied concretes and fibre concretes of the bases of road clothes are shown in Table 1.

Table 1 – Compositions of the studied concretes and fibre concretes for the bases of road clothes

| № | Cement (kg/m$^3$) | Coarse aggregate (type, kg/m$^3$) | Sand (type, kg/m$^3$) | Additive (kg/m$^3$) | Fiber (type, kg/m$^3$) | Water (l/m$^3$) | W/C |
|---|---|---|---|---|---|---|---|
| First stage of experiment | | | | | | | |
| 1a | 300 | granite gravel, 1252 | quartz, 752 | 3.6 | - | 129 | 0.430 |
| 2a | | secondary, 1102 | | | | 166 | 0.553 |
| 3a | | secondary, 1050 | secondary, 744 | | | 190 | 0.633 |
| Second stage of experiment | | | | | | | |
| 1b | 300 | granite gravel, 1252 | quartz, 740 | 3.6 | Anti-Crak HP 12, 1.0 | 137 | 0.457 |
| 2b | | secondary, 1102 | | | | 175 | 0.583 |
| 3b | | secondary, 1050 | secondary, 722 | | | 203 | 0.677 |
| Third stage of experiment | | | | | | | |
| 1c | 300 | granite gravel, 1232 | quartz, 737 | 3.6 | BeneSteel 55, 4.0 | 149 | 0.497 |
| 2c | | secondary, 1092 | | | | 185 | 0.,617 |
| 3c | | secondary, 1030 | secondary, 719 | | | 210 | 0.700 |

**Research results.** As can be seen from Table 1, due to the use of different types of aggregates, the water consumption and, accordingly, the W/C of concrete mixtures differed significantly. Also, the presence and type of dispersed reinforcement influenced on W/C of the mixtures. In Fig. 1 shown a diagram built according to the data of Table 1, which reflects the influence of the type of aggregate and fibre on the W/C of mixtures of equal mobility.

Analysis of the diagram shows that concretes and fibre concretes on granite gravel and quartz sand are as expected have the lowest W/C. When using secondary crushed stone with a heterogeneous composition, due to the water absorption of the aggregate, the W/C of the mixtures increases. When secondary crushed stone is used simultaneously with secondary sand, the W/C increases to an even higher level, to 0.633 – 0.7. However, it can be noted that most of the additional water in these concrete mixtures will be adsorbed by the porous aggregate. Accordingly, increasing of W/C in this case plays a double role. On the one hand, the content of free water increases, which affects the porosity of hardened concrete, on the other hand, the conditions of hardening of the material and the adhesion of the cement-sand matrix to the aggregate improve [22].

For concrete on all types of aggregates, when using Anti-Crak HP 12 fibre (in the amount of 1 kg/m$^3$), the W/C of mixtures of equal mobility increases by 5.5 – 6.9 %. When using BeneSteel 55 fibre (in the amount of 4 kg/m$^3$), the W/C of the mixtures increases by 10.6 – 15.5 % compared to mixtures without dispersed reinforcement. That is, despite the larger diameter and length due to the higher fibre dosage, BeneSteel 55 requires the use of more water to ensure the necessary mobility of the mixture.

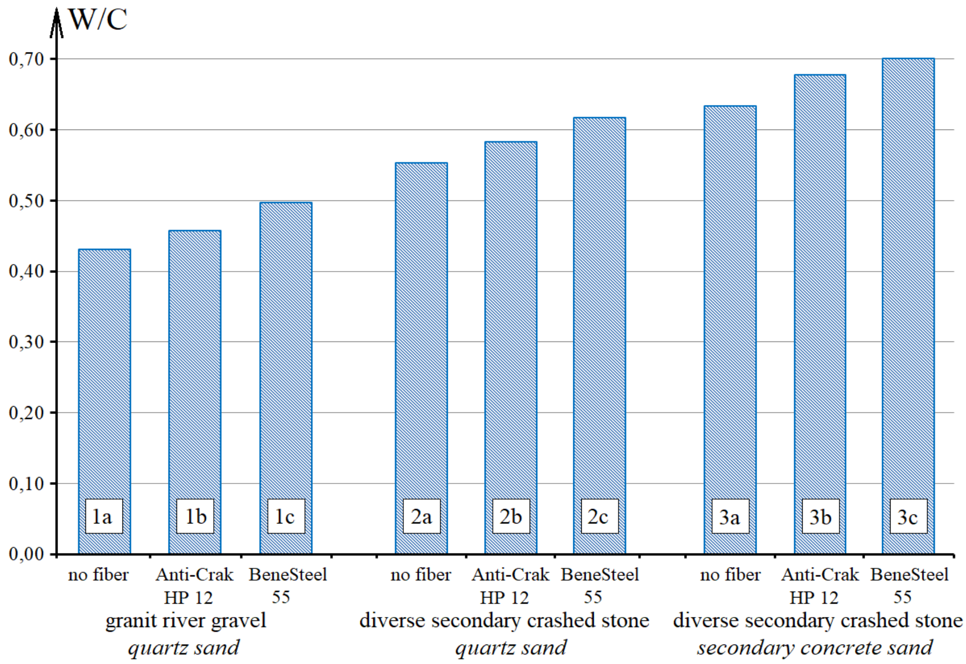

Fig. 1. Influence of the type of aggregates and fibre on the W/C of concrete mixtures (CS = 1...2 cm)

For all studied concretes and fibre concretes, their average density, compressive strength and tensile strength in bending were determined (Table 2).

Table 2 – Physical and mechanical characteristics of the studied concretes and fibre concretes

| № | Average density (kg/m$^3$) | Compressive strength (MPa) | Tensile strength in (MPa) |
|---|---|---|---|
| 1a | 2346 | 28.1 | 3.12 |
| 2a | 2258 | 29.2 | 3.18 |
| 3a | 2224 | 27.8 | 2.78 |
| 1b | 2339 | 29.8 | 3.41 |
| 2b | 2230 | 32.7 | 3.29 |
| 3b | 2179 | 28. 9 | 2.78 |
| 1c | 2331 | 27.4 | 2.93 |
| 2c | 2226 | 29.0 | 3.04 |
| 3c | 2132 | 26.3 | 2.65 |

In Fig. 2 shown a diagram built according to the data of Table 2, which shows the influence of the type of aggregates and fibre on the average density of the studied concretes for the bases of road clothes. As can be seen from the diagram, the average density of the studied concretes is mainly influenced by the type of aggregate. Concrete and fibre concrete on granite gravel and quartz sand have the highest density. Concretes based on secondary crushed stone with a heterogeneous composition and quartz sand have a 3.8 – 4.6 % lower average density. When using secondary crushed stone simultaneously with secondary sand, the average density of concrete is 5.2 – 8.5 % lower compared to concrete on granite gravel. When using dispersed reinforcement, due to the increase in the W/C mixture, the average density of concrete on all types of aggregate decreases – up to 2 % when using Anti-Crak HP 12 fibre and up to 4.1 % when using BeneSteel 55 fibre.

However, the type of aggregates and fibres had a different effect on the strength of the studied concretes than on the average density of the material. The compressive strength of the studied concretes and fibre concretes for the bases of road clothing is shown in the diagram in Fig. 3.

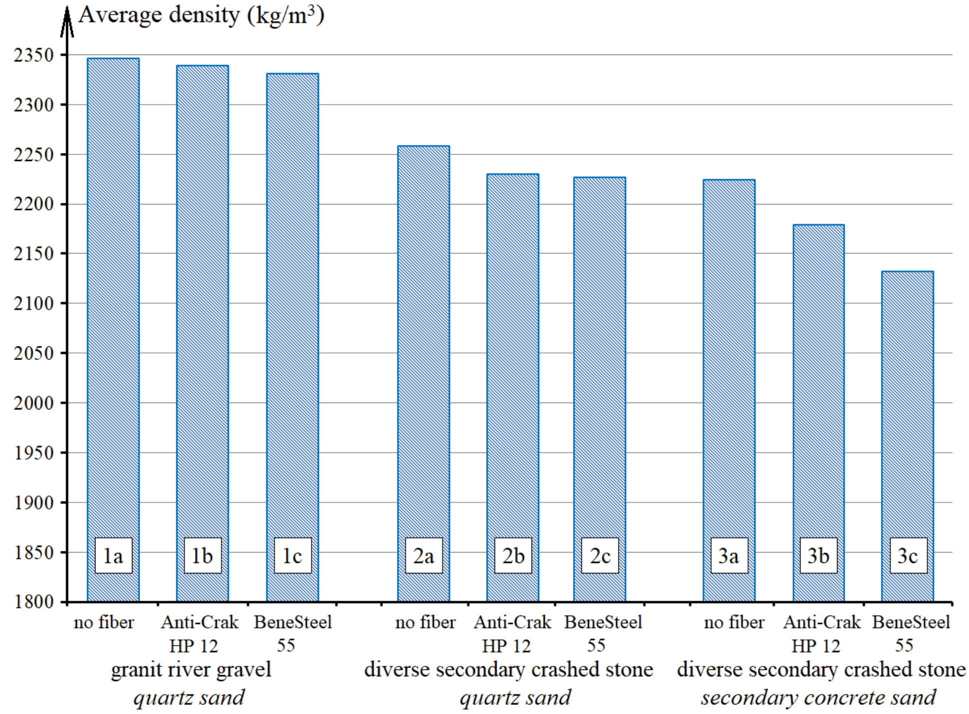


Fig. 2. Influence of the type of aggregates and fibre on the average density of concrete

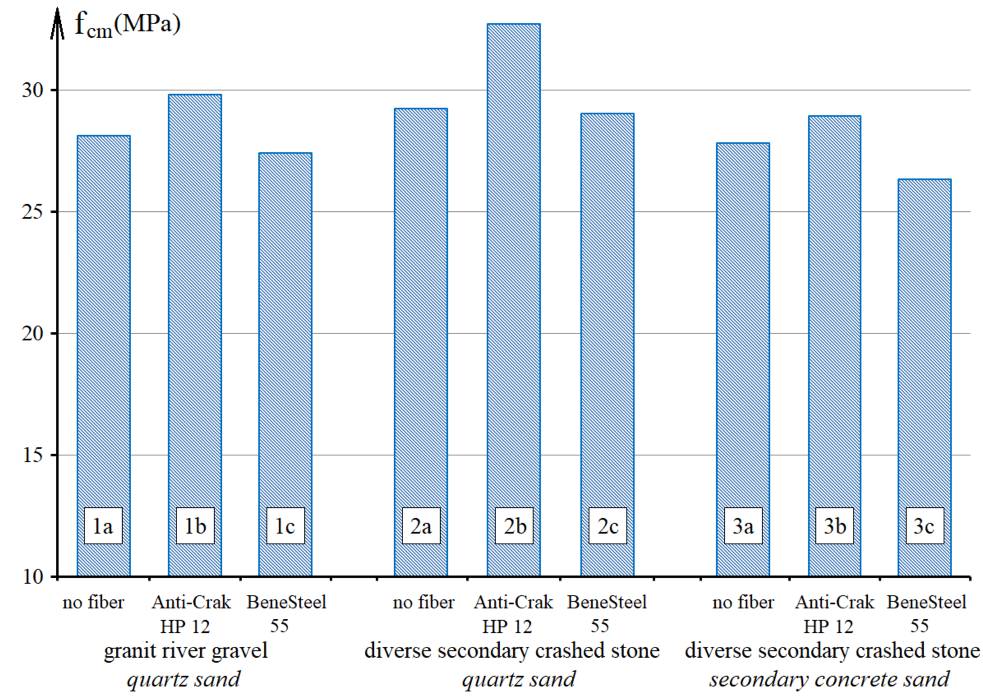


Fig. 3. Influence of the type of aggregates and fibre on the compressive strength of concrete

Analysis of the diagram and data in Table 2 shows that the strength of concrete on secondary crushed stone with a heterogeneous composition and quartz sand was 1.1 – 2.9 MPa (3.9 – 9.7 %) higher than the strength of concrete on granite gravel and similar sand. This is explained by the fact that the gravel has a worse adhesion to the cement-sand matrix, than the gravel with streamline shape [23]. In addition, as noted above, secondary crushed stone, due to its own porosity, provides an additional increase in adhesion with the matrix and improves concrete hardening conditions due to "internal care" [22, 23]. The confirmation of such a structure-forming role of porous aggregate is also the fact that concretes on secondary crushed stone and secondary sand had a compressive strength of only 0.3 – 1.1 % lower than concretes on granite gravel and quartz sand.

Dispersed fibre reinforcement with Anti-Crak HP 12 has a positive effect on the compressive strength of concrete on all types of aggregate, even despite a small increase in W/C mixtures. The strength of concrete with this type of fibre is 4.0 – 11.8 % higher than the strength of non-reinforced concrete on similar aggregates. However, the use of BeneSteel 55 fibre was not effective. Concretes dispersed-reinforced with this type of fibre showed 0.7 – 5.4 % lower strength than similar concretes without fibre. That is, the effect of a significant increase in W/C of the mixture, which was necessary when using this type of fibre, was not compensated by the effect of dispersed reinforcement on the redistribution of loads on the concrete structure.

As defined above, the main requirement for concretes for the bases of road clothing is their tensile strength in bending [6]. This is due to the loads acting on road structures. In Fig. 4 presented a diagram showing the effect of the type of aggregates and fibre on the tensile strength in bending of the tested concretes.

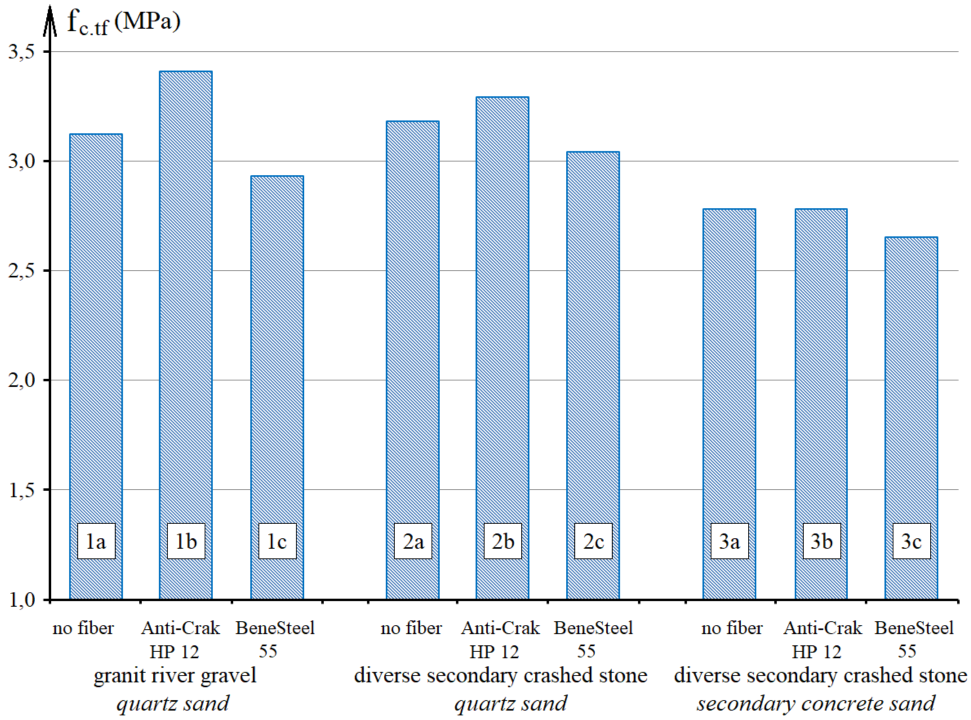


Fig. 4. Influence of the type of aggregates and fibre on the tensile strength in bending of concrete

Analysis of the diagram and data in Table 2 shows that concrete without dispersed reinforcement on secondary crushed stone with heterogeneous composition and quartz sand (2a) had tensile strength similar to concrete on granite gravel (1a). The determined tensile strength of composition 2a was even 2 % higher than the strength of composition 1a. When using both coarse and fine secondary aggregates (3a), the tensile strength in bending of concrete is only 10.8 % less than the strength of the "basic" composition 1a. That is, concretes on secondary aggregates are characterized by sufficiently high tensile strength in bending. This is also due primarily to the high adhesion of the aggregate to the sand-cement matrix, which increases the resistance to tensile stresses [22].

However, the effectiveness of dispersed reinforcement in concrete on secondary aggregates from the point of view of increasing of tensile strength was low. When using Anti-Crak HP 12 fibre, the flexural strength of concrete on granite gravel and quartz sand increases by 9.3 %. Similar dispersed reinforcement of concrete on secondary crushed stone and quartz sand reduces its tensile strength by only 3.5 %, which is within the accuracy of the experiment. For concretes on secondary crushed stone and secondary sand, reinforcement with Anti-Crak HP 12 fiber had no effect on the level of tensile strength.

Such a difference in the effectiveness of dispersed reinforcement for concrete based on natural and secondary aggregates can be explained by their different structure. More porous secondary aggregates, as shown above, provide relatively high tensile strength in bending. However, their own strength is lower than the strength of natural aggregates (gravel and quartz sand). Rubble of secondary aggregates can pinch the fibres of dispersed reinforcement, which affects their work in the composite material.

From the point of view of influence on tensile strength in bending, the use of BeneSteel 55 fibre in the studied concretes was not effective, as well as from the point of view of influence on compressive strength.

**Conclusions and prospects for further research.** The studied concretes on secondary crushed stone with heterogeneous composition, including concretes on secondary sand, have compressive strength from 26.3 to 32.7 MPa and tensile strength in bending from 2.65 to 3.29 MPa. That is, the strength of concrete obtained in laboratory conditions on secondary aggregates is 50 – 100 % higher than the level of minimum requirements for the strength of concrete for a monolithic bases according to DBN B.2.3-4:2015 [5] and GBN B.2.3-37641918-557:2016 [6]. This confirms the prospect of effective use of these concretes for the bases of road clothing, even taking into account the poorer quality of similar concretes during their industrial production.

The impracticality of using of the fibre types used in these studies in concrete on secondary crushed stone with a heterogeneous composition of dispersed reinforcement has been experimentally established. The introduction of fibre did not significantly improve the strength of concrete. Taking into account the economic factor, it is not possible to recommend the use of this type of dispersed reinforcement.

In further studies, it is planning to study the effect of dispersed reinforcement on the frost resistance of concrete on secondary aggregates, in particular when using cements with a high content of slag.

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# ВЛАСТИВОСТІ БЕТОНІВ І ФІБРОБЕТОНІВ ОСНОВ ДОРОЖНЬОГО ОДЯГУ НА ВТОРИННОМУ ЩЕБЕНІ З НЕОДНОРІДНИМ СКЛАДОМ

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**Анотація.** Проблема утилізації бетонного брухту і демонтованих будівельних конструкцій є актуальною для більшості країн світу. Для Україні ця проблема є ще гострішою через значні обсяги руйнувань внаслідок бойових дій та обстрілів.

Порівнювалися властивості бетонів і фібробетонів для основ дорожнього одягу на природних і вторинних заповнювачах: гранітному річковому гравії, вторинному щебені з неоднорідним складом, кварцовому піску і вторинному піску з перероблених залізобетонних конструкцій. Використовувався шлакопортландцемент CEM III/A з вмістом доменного шлаку 65% і суперпластифікатор полікарбоксилатного типу.

Досліджено три серії зразків: без фібри; з скляною фіброю ANTI-CRAK HP 12 (довжина 12 мм, діаметр 0,017 мм, еквівалентний діаметр нитi 0,3 мм) у кількості 1 кг/м$^3$; з поліпропіленовою фіброю BeneSteel 55 (довжина 55 мм, еквівалентний діаметр 0,48 мм) у кількості 4 кг/м$^3$. У кожній серії досліджено: бетон на гранітному гравії та кварцового піску, бетон з використанням вторинного щебеню і кварцового піску, бетон з використанням вторинного щебеню і вторинного піску. Рухомість всіх сумішей була рівною S1.

Завдяки застосуванню різних типів заповнювачів і фібри В/Ц бетонних сумішей суттєво відрізнялося. Бетони на вторинних заповнювачах мали вищу В/Ц, ніж на природних. При використанні фібри Anti-Crak HP 12 В/Ц сумішей рівної рухомості зростало на 5,5-6,9%. При використанні фібри BeneSteel 55 В/Ц підвищувалося на 10,6-15,5%.

Тип заповнювача суттєво впливав на середню густину бетонів. При використанні вторинного щебеню та кварцового піску середня густина знижувалася на 3,8-4,6%. При використанні вторинного щебеню одночасно зі вторинним піском середня густина бетонів знижувалася на 5,2-8,5%. При застосуванні фібри Anti-Crak HP 12 середня густина бетонів знижується на величину до 2%, при використанні фібри BeneSteel 55 – до 4,1%.

Бетони на вторинному щебені з неоднорідним складом та кварцовому піску мали на 4% вищу міцність на стиск і на 2% вищу міцність на розтяг при згині, ніж бетони на гранітному гравії та аналогічному піску (29,8 МПа і 3,18 МПа відповідно). При застосуванні вторинного щебеню одночасно зі вторинним піском міцність бетону на стиск є лише на 1,1% менше міцності бетонів на природних заповнювачах, а міцність на розтяг при згині – на 10% меншою. Це підтверджує можливість ефективного використання даних бетонів в основах дорожнього одягу. Якісна робота вторинних заповнювачів в бетонах пояснюється їх кращою адгезією до цементно-піщаної матриці.

Дисперсне армування фіброю Anti-Crak HP 12 оказує позитивний вплив на міцність на стиск бетонів на всіх типах заповнювача та підвищує міцність на розтяг при згині бетону на природних заповнювачах. Використання фібри BeneSteel 55 не було ефективним через значне підвищення В/Ц суміші при її введенні. В цілому з врахуванням економічного чинника дисперсне армування бетонів на вторинних заповнювачах використаними в дослідженнях типами фібри не є доцільним.

**Ключові слова:** вторинний щебінь, неоднорідний склад, вторинний пісок, вторинні заповнювачі бетону, полімерна фібра, пластифікатор, основа дорожнього одягу, міцність.

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