

PROPERTIES OF FIBER-REINFORCED CEMENT CONCRETES FOR LOWER LAYERS OF RIGID PAVEMENTS ON RECYCLED AGGREGATES

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Article history

Received 23 February 2026

Revised 24 March 2026

Accepted 24 March 2026

Abstract

A series of concretes on recycled aggregates for the construction of lower layers of rigid pavements have been developed, that incorporate micro- and macro- polypropylene fibre and glass fibre. Fibre was added to three base compositions containing different aggregates, i.e. river gravel, quartz sand and coarse and fine size recycled concrete aggregate. All the mixtures used a cement with a high slag content at a dosage of 300 kg/m³ and were designed for an S1 consistency. The inclusion of fibre significantly affected the fresh concrete's water demand, which demonstrated an increase in the w/c by 7 – 15 %. Mechanical testing on the 28th day showed that neither polypropylene fibre improved the compressive strength and even caused a slight reduction (0.3 – 5 %), which was a result primarily attributed to the associated increase in the w/c ratio. The macrofibre also reduced the flexural strength by 5 – 6 %; the microfibre provided only a marginal increase in the flexural strength (1 – 4 %). In contrast, the alkali-resistant glass fibre was the only type to enhance both the compressive and flexural strength, increasing them by 4 – 12 % and 9 %, respectively. All the fibre-reinforced mixtures achieved a frost resistance grade of at least F100. The research concluded that for stiff mixtures made with recycled aggregates, the tested polypropylene fibres are inefficient, whereas the alkali-resistant glass fibre presents a viable option for performance enhancement.

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Key words

- Recycled aggregates,
- Recycled concrete aggregates,
- Road concrete,
- Rigid pavement,
- Fibre,
- Fibre-reinforcement.

1 INTRODUCTION

The construction industry is one of the largest consumers of natural resources worldwide and is simultaneously one of the

major producers of waste. Construction and demolition waste (CDW) arises from the demolition of buildings, renovation of infrastructures, reconstruction of transport networks, industrial activities, military conflicts and natural disasters. According to

the available statistical data, CDW represents the largest waste stream in the European Union; it accounts for approximately 30 – 40 % of the total waste generated annually (Eurostat, 2019) and amounts to 450 – 500 million tons annually as of 2022 (EuRIC, 2024). Similar trends have been reported in North America and Asia, where rapid urbanization and renewal of infrastructures has led to a continuous increase in CDW volumes (Zheng et al., 2017).

Traditionally, CDW has been disposed of in landfills, which causes long-term environmental burdens, occupation of potentially useful lands, and loss of potentially valuable secondary raw materials. At the same time, the demand for natural aggregates for concrete production continues to grow; this results in the depletion of natural resources, the destruction of landscapes, increased energy consumption, and higher greenhouse gas emissions. These issues have intensified the search for sustainable alternatives in construction materials engineering. An analysis of life cycle assessment and demolition technology (Chystiakov et al., 2026) demonstrates the environmental feasibility of using recycled aggregates as building materials and confirms the potential for extracting high-quality recycled raw materials for secondary use.

By processing construction waste, it is possible to obtain a wide range of recycled aggregates that are cheaper, sustainable and can be used for the arranging of certain structures. Recycled aggregates are commonly classified based on their origin. Recycled concrete aggregates obtained from crushed concrete elements consist of natural stone particles covered with adhered cement mortar. This adhered mortar increases porosity and water absorption, which can negatively affect concrete properties (Albero et al., 2024). Recycled masonry aggregates are produced from ceramic bricks and tiles. They are characterized by lower density, higher water absorption, and lower strength compared to recycled concrete aggregate. Mixed recycled aggregates represent heterogeneous mixtures obtained from uncontrolled demolition processes, including natural diseases and military conflicts, and may include concrete, mortar, aerated concrete, masonry, asphalt, and minor contaminants.

The recycling of CDW into aggregates suitable for concrete production represents a key strategy within the framework of sustainable development and the circular economy. Recycled aggregates enable partial or full replacement of natural aggregates, reduce landfill demand, and decrease the environmental footprint of concrete production. However, recycled aggregates generally exhibit a higher degree of porosity, higher water absorption, and a more heterogeneous composition compared to natural aggregates, which may negatively influence the properties of concrete by reduction of its mechanical characteristics. Research has demonstrated that recycled aggregate concretes generally exhibit lower compressive strength and modulus of elasticity compared to conventional concrete, particularly at high replacement ratios (Kou et al., 2009; Poon et al., 2002). However, for non-critical structural applications and road construction, the properties achieved are often sufficient.

The use of chemical admixtures, optimised grading

curves, and fibre reinforcement can significantly improve the mechanical performance and durability of recycled aggregate concrete (Rosales et al. 2025). Fine recycled aggregates, although challenging to work with, offer significant potential for the development of sustainable material when properly incorporated into compositions designs. Katkhuda et al. (2017) produced concrete based on recycled concrete aggregate with a compressive strength of 22.5 MPa on the 28th day. Zheng et al. (2021), in their review, compared six recycled aggregate concretes with similar compositions created by different scientists. All the concretes were on bases of recycled concrete aggregates and had the same water/cement ratio (w/c) and cement concentration; the recycled aggregates had different water absorptions, density, dustiness and cement-sand matrix contents. Such indicators are significantly involved in produced concrete properties. The compressive strength on the 28th day of curing of those concretes was 35.89 MPa (Wang et al., 2019), 47 MPa (Shi et al., 2018), 62 MPa (Shi et al., 2018), 46 MPa (Shi et al., 2018), 22.5 MPa (Katkhuda et al., 2017), and 25.5 MPa (Ryou and Lee, 2014), depends on the recycled concrete aggregate applied. This review shows the significant effect of the microstructure and properties of recycled aggregates on the characteristics of the resulting concrete. The properties of recycled-aggregate concretes for rigid pavements that are optimised with polypropylene fibres (Kroviakov et al., 2026), demonstrate compressive strength of ≥ 40 MPa, flexural strength of ≥ 5 MPa, and frost resistance of F200. Recycled-aggregate concretes of (Kryzhanovskiy et al., 2026) for road and airfield applications, which are modified by polypropylene fibres, demonstrate even better mechanical characteristics, i.e. is a compressive strength of at least 50 MPa and flexural strength of no less than 5 MPa at the project age of 28 days. However, given the high variability of recycled aggregates and the production technologies of concrete, which are mainly due to the local availability of raw materials, the relevance of further research on the production of concrete from recycled aggregates still exists.

Considering the above analyses, the most optimal application of concrete on recycled aggregates is for arranging structures with low strength requirements, such as the bases and lower layers of rigid pavements made from cement-concrete. According to STN 73 6123, the lower layers of rigid pavements are made from cement-concrete of low grades, e.g. C12/15 – C16/20 or C16/20 – C20/25, and a frost resistance at least F50 or F100, depending on the road class. The dispersal reinforcement of the concretes can increase the flexural strength, which is an important indicator for road structures.

1.1 Novelty of the research

This study focuses on a systematic investigation of distinct concrete compositions using recycled aggregates of different types and sizes derived from CDW with dispersal reinforcement using glass and polymer fibre; it is intended primarily for the construction of road bases. The research is oriented towards practical applications, particularly the lower layers of rigid pavements, where large material volumes are required and where the use of recycled aggregates can bring significant environmental and economic benefits.

The originality of the research presented lies in the comprehensive comparison of concretes on different types of recycled aggregates, including recycled concrete aggregates of coarse (8/16 mm) and fine (0/4 mm) sizes, which are rarely applied in practice. The research also evaluates the effect of fibre reinforcement and slag-rich cement on the performance of recycled aggregate concrete.

2 MATERIALS AND METHODS

2.1 Materials

Cement CEM III/A 32.5 N, with a blast furnace slag content of 65 wt.% (CRH Cement Multicem, Germany), was used for the production of the fibre-reinforced concretes studied on recycled aggregates. The polycarboxylate-type superplasticizer Berament HT28 (BetonRacio Ltd., Slovakia) was applied in an amount of 1.2 % of cement mass according to the recommendation of the manufacturer. The superplasticiser was used for increasing the stiffness of fresh concrete without adding extra water. The main characteristics of superplasticiser Berament HT28 are: density at 20 °C is 1,080 kg/m³ and pH is

6. This additive is effective in increasing the self-compacting ability of concrete. This is especially important when working with stiff concrete mixtures, as in this study (the cone slump was 1 – 2 cm, which corresponds to stiffness grade S1). Thus, the mixtures developed have a high degree of stiffness, which allows them to be used only by concrete pavers with sliding formwork, which is optimal for the arrangement of road surface layers.

Two types of coarse aggregates of 8/16 mm size and two types of fine aggregates of 0/4 mm size were used for the production of the experimental concretes: river gravel (RG) (Fig. 1a), recycled concrete aggregate (RCA) (Fig. 1b), quartz sand (Fig. 1c), and fine fraction recycled concrete aggregate (RCA-f) (Fig. 1d). Their properties are given in Table 1. In Western and Central Europe, river gravel is used as the main type of coarse aggregate for concrete production since there are large local natural deposits (Schmidt and Fehling, 2005); therefore, the reference concrete composition was made from that type of aggregate. The RCA used contained extracted granite gravel and rubble from demolished concrete structures with a low cement-sand matrix content.

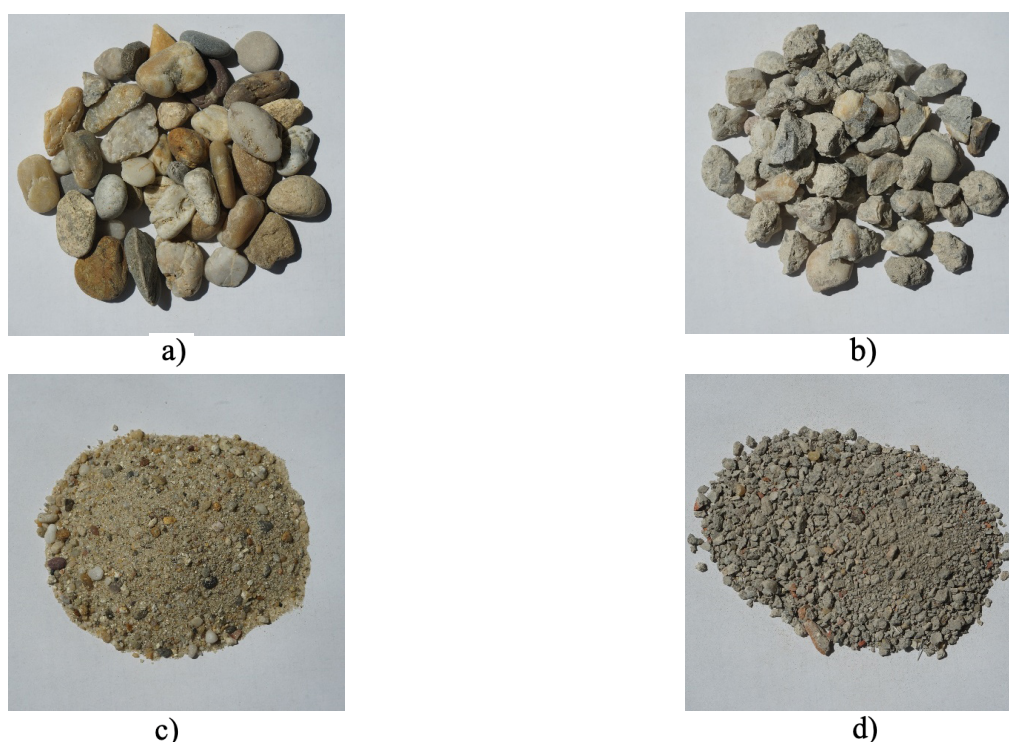


Fig. 1 Coarse and fine aggregates used: (a) river gravel 8/16 mm; (b) recycled concrete aggregate 8/16 mm; (c) quartz sand 0/4 mm; (d) recycled concrete aggregate of fine fraction 0/4 mm

Tab. 1 Properties of coarse and fine aggregates used

Aggregate	Bulk density [kg/m ³]	Water absorption [%]	Aggregate crushing value [%]	Dustiness [%]	Fineness modulus
RG	1570	0.7	1	1.0	-
RCA	1260	5.9	1	0.5	-
Quartz sand	1835	-	-	-	3.19
RCA-f	1500	-	-	-	3.53

For dispersal reinforcement of the experimental concretes, three types of fibre were used:

- EGIBI PP 34 $\mu\text{m}/12\text{ mm}$ polypropylene fibre. The fibre length is 12 mm with an equivalent diameter of 34 μm , produced by the Czech company EGIBI. The recommended amount of fibre in the concrete mixture is 0.9 kg/m^3 (Fig. 2a).
- BeneSteel 55 polypropylene fibre. The fibre length is 55 mm with an equivalent diameter of 0.2 – 0.5 mm, manufacturer SKLOCEMENT BENES, Czech Republic. The tensile strength according to EN 14889-2 is 610 MPa (Fig. 2b).
- ANTI-CRAK HP 12 alkali-resistant glass fibre. The fibre length is 12 mm, the equivalent diameter is 0.48 mm, the manufacturer is Owens Corning, NY, USA. The tensile strength is 1000 – 1700 MPa (Fig. 2c).



a)



b)



c)

Fig. 2 Fibres used in the research: (a) EGIBI PP 34 $\mu\text{m}/12\text{ mm}$ polypropylene fibre, (b) BeneSteel 55 polypropylene fibre, (c) ANTI-CRAK HP 12 glass fibre

2.2 Methods of research

For the experiment, the samples of the concrete were prepared. Before testing, the specimens were kept in a special chamber for strength gain of concrete at a relative humidity of $(90 \pm 5) \%$. The concretes were tested at the ages of 3 and 28 days. The experimental program included the determination of the density, water absorption, frost resistance, compressive strength, and flexural strength. A more detailed description of the test methodology is presented in the paragraphs below.

Density. The tests were carried out according to STN EN 12390-7 at the ages of 3 and 28 days on cubic samples sized $100 \times 100 \times 100\text{ mm}$. The dimensions of the samples were measured by a calliper, while the weight of the samples was determined by Radwag PS 1000.R2 scales with a mesh of 0.01 g and a maximal load of 3,000 g.

Water absorption. The water absorption of the concrete samples was determined in accordance with STN 73 1316 on cubic samples sized $100 \times 100 \times 100\text{ mm}$ at the age of 28 days. The samples were placed in a container filled with water so that the water level in the container was 50 mm higher than the top face of the samples. The samples were weighed every 1 hour for the first 24 hours and then every 24 hours. The test was carried out until the results of two consecutive weightings differed by no more than 0.1 %. Drying of the samples was carried out during a period of 24 hours at a temperature of $102\text{ }^{\circ}\text{C}$ in a BUKOTHERM BK-50 drying cabinet. The water absorption by mass was determined and measured in percentages.

Frost resistance. Determination of the frost resistance of the concretes at the age of 28 days was carried out according to STN P CEN/TS 12390-9 using the accelerated method in a 5 % sodium chloride solution at a freezing temperature of $-50\text{ }^{\circ}\text{C}$ and a thawing temperature of $20\text{ }^{\circ}\text{C}$ in a BINDER Model MKF 720 climatic chamber. The samples were previously soaked in a 5 % sodium chloride solution for 5 days. The frost resistance grade was determined according to STN P CEN/TS 12390-9. Five cycles of freezing and thawing were conducted that corresponded to the frost resistance grade F100. The studied concretes were tested only for compliance with this frost resistance grade F100; the concretes were not tested for higher frost resistance grades.

Compressive strength. The testing of the concretes for their compressive strength was carried out on cubic samples by central-axial compression according to STN EN 12390-4 after 3 and 28 days of curing using a Controls MCC8 150/600/1000 kN hydraulic press machine. The samples had dimensions of $100 \times 100 \times 100\text{ mm}$. The method of determining the compressive strength consisted of loading a concrete sample under compressive forces until its destruction, while recording the maximum load indicator. The compressive strength is calculated using Formula (1) below and is measured in MPa.

$$f_{c.cube} = \frac{\alpha \cdot F}{A} \quad (1)$$

where α is the scaling factor coefficient ($\alpha = 0.95$ for cube specimens with the edge size of 100 mm from heavy concretes); F is the breaking load (N); and A is the working cross-sectional area of the sample ($A = 10000 \text{ mm}^2$ for cube samples with the edge size of 100 mm).

Flexural strength. The testing of the concretes for flexural strength was carried out on beam samples with dimensions of $100 \times 100 \times 400$ mm after 3 and 28 days of curing using a three-point bending test on the VEB Werkstoffprüfmaschinen Leipzig 280 press machine. The test was conducted according to STN EN 12390-5. The method of determining the flexural strength consisted of loading a concrete beam-shaped specimen in a three-point loading system and subjecting it to bending forces until its destruction, while recording the maximum load indicator. The flexural strength was calculated using Formula (2) below and is measured in MPa.

$$f_{c.ft} = \frac{\delta \cdot F \cdot l}{b \cdot a^2} \quad (2)$$

where δ is the scaling factor coefficient ($\delta = 0.92$ for prism specimens with the edge size 100 mm from heavy concretes); F is the breaking load (N); l is the distance between the

supporting rollers when testing prism specimens under tension in bending (300 mm); b is the height of the cross section of the prism (100 mm); and a is the width of the cross section of the prism (100 mm).

3 RESULTS AND DISCUSSION

3.1 Concrete compositions

Optimal concrete compositions from natural and recycled aggregates with dispersal reinforcement were developed within the research using analytical calculations and laboratory approbation. The concrete compositions are presented in Table 2. For a complete comparison of properties of the concrete, a series of reference compositions without the addition of any fibre was developed. Thus, concretes labelled 1F – 3F (the reference compositions without dispersal reinforcement), 1EG – 3EG (with polypropylene fibre EGIBI PP 34 $\mu\text{m}/12 \text{ mm}$), 1BS – 3BS (with polypropylene fibre BeneSteel 55), and 1AC – 3AC (with alkali-resistant glass fibre ANTI-CRAK HP 12) were developed. The amount of fibre added was calculated according to the recommendation of the manufacturer. The stiffness of all the concrete mixtures was S1, which corresponded to 1 – 2 cm of the cone slump; the water/cement ratio (w/c) was regulated to ensure constant stiffness of the concrete mixtures.

Tab. 2 Compositions of concretes developed

Label	Cem., [kg]	Coarse aggregate,		Fine aggregate,		Fibre,		Additive, [kg]	Water, [l]	w/c
		Type	[kg]	Type	[kg]	Type	[kg]			
Reference series without dispersal reinforcement										
1F	300	RG	1250	quartz	750	-	-	3.6	130	0.43
2F		RCA	1100						138	0.46
3F		RCA	1050	RCA-f	745				168	0.56
Series with polypropylene fibre EGIBI PP 34 um/12 mm										
1EG	300	RG	1250	quartz	749	EGIBI PP	0.9	3.6	130	0.43
2EG		RCA	1100						138	0.46
3EG		RCA	1050	RCA-f	744				168	0.56
Series with polypropylene fibre BeneSteel 55										
1BS	300	RG	1240	quartz	735	BeneSteel 55	4.0	3.6	149	0.50
2BS		RCA	1090						158	0.53
3BS		RCA	1040	RCA-f	730				190	0.63
Series with alkali-resistant glass fibre ANTI-CRAK HP										
1AC	300	RG	1245	quartz	745	AN-TI-CRAK	1.0	3.6	137	0.46
2AC		RCA	1095						148	0.49
3AC		RCA	1045	RCA-f	740				178	0.59

The water/cement ratio was determined to ensure the equal workability of the fresh concrete are presented in Table 2 and in the graphs in Fig. 3. Considering that the stiffness of all the concrete mixtures was the same, i.e. from 1 to 2 cm of cone slump, only the type of coarse aggregate and fibre have an effect on the w/c of the concrete mixtures studied. Also, because of the matrix of the concrete compositions, it is possible to make a clear assessment of the effect of both the coarse aggregates and fibre on the w/c of the mixture. The EGIBI PP polymer micro-fibre does not have any effect on the w/c of the concrete mixture. The ANTI-CRACK HP glass fibre sufficiently increased the water consumption of the concrete mixture by 5 – 7 %. The BeneSteel 55 polymer fibre had a strong effect on the water consumption of the concrete mixture to ensure the same stiffness of the mixture; the w/c increased by 13 – 15 %, compared to the same concrete composition without any fibre. At the same time, the types of coarse and fine aggregates used to produce the dispersal reinforced concretes also had a sufficient effect on the w/c of the concrete mixture to ensure the equal workability (much higher than the effect of the fibre). Thus, using RCA increased the w/c of the mixture by 6 – 7 % compared to the river gravel mixtures; using RCA as a coarse aggregate in combination with RCA-f as a fine aggregate increased the w/c of the mixture by 26 – 30 %, compared to on the river gravel and quartz sand mixtures. Generally, it can be concluded that the use of fibre can increase the w/c of the mixture; moreover, the increase in water consumption is directly proportional to the increase in fibre size and it is at a maximum for BeneSteel 55 fibre, with dimensions of 55 mm length and a diameter of 0.48 mm. The large fibre, probably, increased the stiffness of the concrete

mixtures, which required a larger amount of water to achieve the same stiffness of fresh concrete.

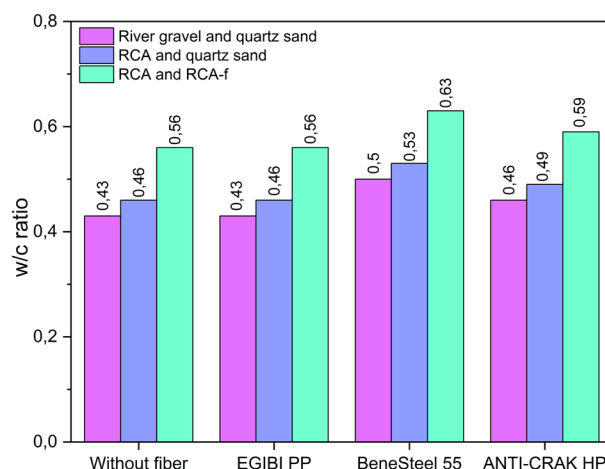


Fig. 3 W/c determined to ensure equal workability of the fresh concrete

3.2 Characteristics of the concretes

The density, compressive and flexural strength at the age of 3 and 28 days, the water absorption by mass, and the frost resistance at the age of 28 days were determined for all the types of concrete compositions. The test results are given in Table 3.

Tab. 3 Characteristics of the concretes

Label	Density at the age of: [kg/m³]		Compressive strength at the age of: [MPa]		Flexural strength at the age of: [MPa]		Water absorption by the mass, [%]	Frost resistance grade
	3 days	28 days	3 days	28 days	3 days	28 days		
Reference series without dispersal reinforcement								
1F	2350	2320	13.8	28.1	1.60	3.12	3.8	F100
2F	2260	2230	15.0	29.2	1.58	3.18	5.4	F100
3F	2220	2190	14.8	27.8	1.51	2.78	5.3	F100
Series with polypropylene fibre EGIBI PP 34 um/12 mm								
1EG	2340	2320	13.5	27.9	1.81	3.25	4.4	F100
2EG	2250	2230	15.1	29.0	1.78	3.31	5.0	F100
3EG	2220	2200	15.0	27.7	1.61	2.81	5.2	F100
Series with polypropylene fibre BeneSteel 55								
1BS	2330	2300	13.5	27.4	1.50	2.93	6.9	F100
2BS	2230	2190	14.9	29.0	1.62	3.04	7.8	F100
3BS	2130	2090	13.8	26.3	1.33	2.65	10.1	F100
Series with alkali-resistant glass fibre ANTI-CRAK HP								
1AC	2340	2320	16.7	29.8	1.87	3.41	3.7	F100
2AC	2230	2210	17.7	32.7	1.78	3.39	5.5	F100
3AC	2180	2150	14.8	28.9	1.57	2.78	5.4	F100

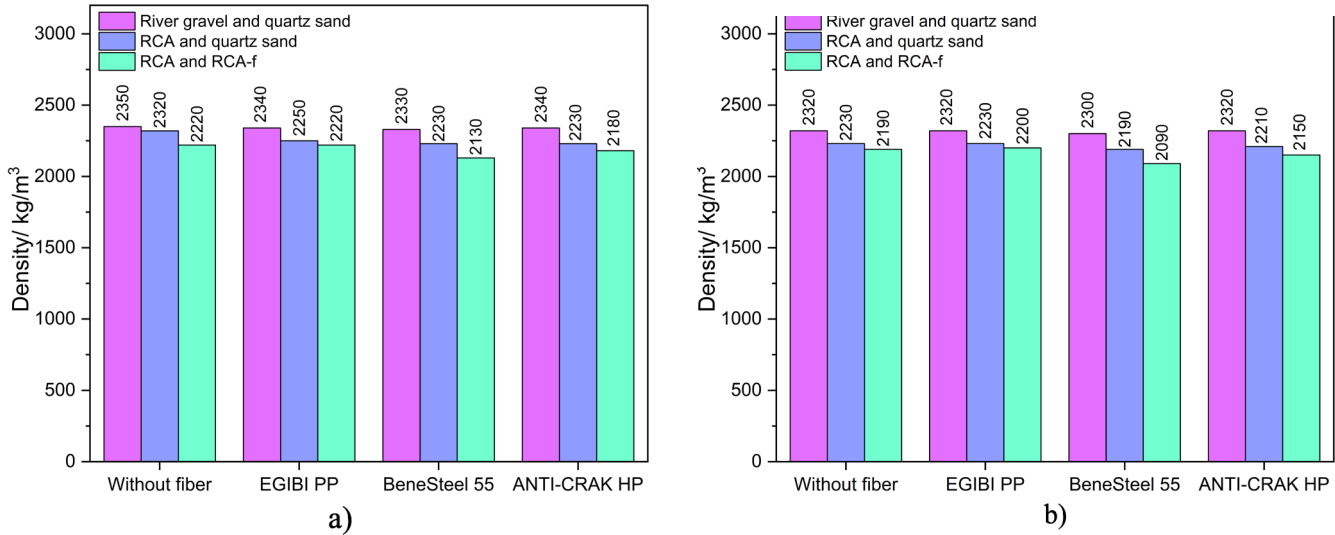


Fig. 4 Density of the dispersal reinforced concretes at the age of: (a) 3 days; (b) 28 days

The density of the concretes at the ages of 3 and 28 days is shown in graphs in Fig. 4. The graphs show that the type of aggregate had a high degree of influence on the density of the concretes, which was also connected with the w/c ratio of those concretes. Generally, the application of the dispersal reinforcement does not have a high degree of influence on the w/c of the concrete mixtures, because of the addition of the EGIBI PP polymer micro fibre, density of the concrete did not change; the addition of the ANTI-CRAK HP glass fibre insufficiently decreased the density of the concrete by 0 – 2 %; the addition of the BeneSteel 55 polymer fibre decreased the density of the concretes to the greatest extent for the all the compositions tested, i.e. by 1 to 5 % compared to the reference compositions without any fibre. Such dependencies

are also applicable to the w/c ratio of the concrete mixtures. When analysing the Table 3 data, it is possible to conclude that the density of the concretes at the age of 28 days is 1.2 – 2 % lower than the density of the same concretes at the age of 3 days, which is explained by the evaporation of water from the concrete mass during its curing. Thus the density of the concrete array decreased despite the growth of cements hydration products.

The graphs in Fig. 5 demonstrate the dependencies between the w/c of the concretes (which was regulated to ensure equal stiffness of the mixtures) and the density of the concrete at 28 days. The graph illustrates a decrease in the concrete’s density with an increase in the w/c ratio.

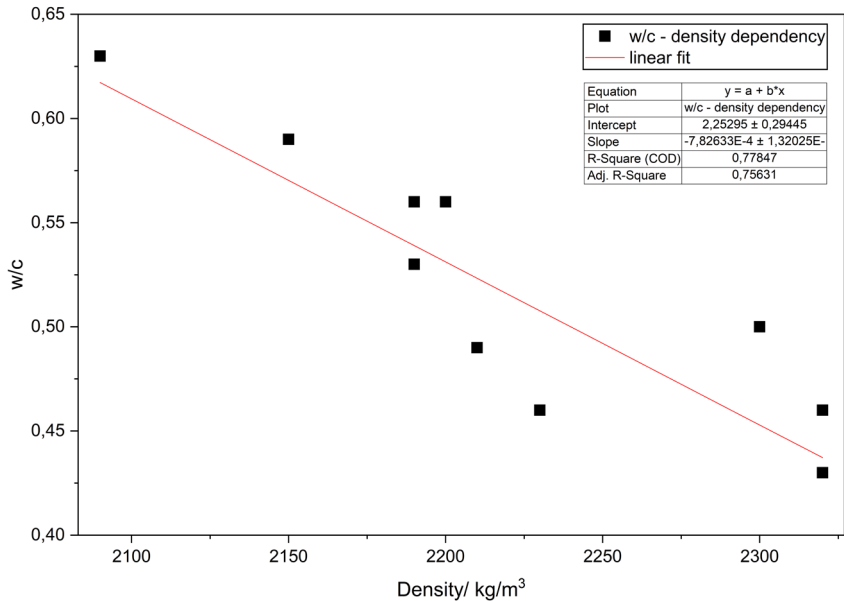


Fig. 5 Effect of w/c on the density of the concretes at the age of 28 days

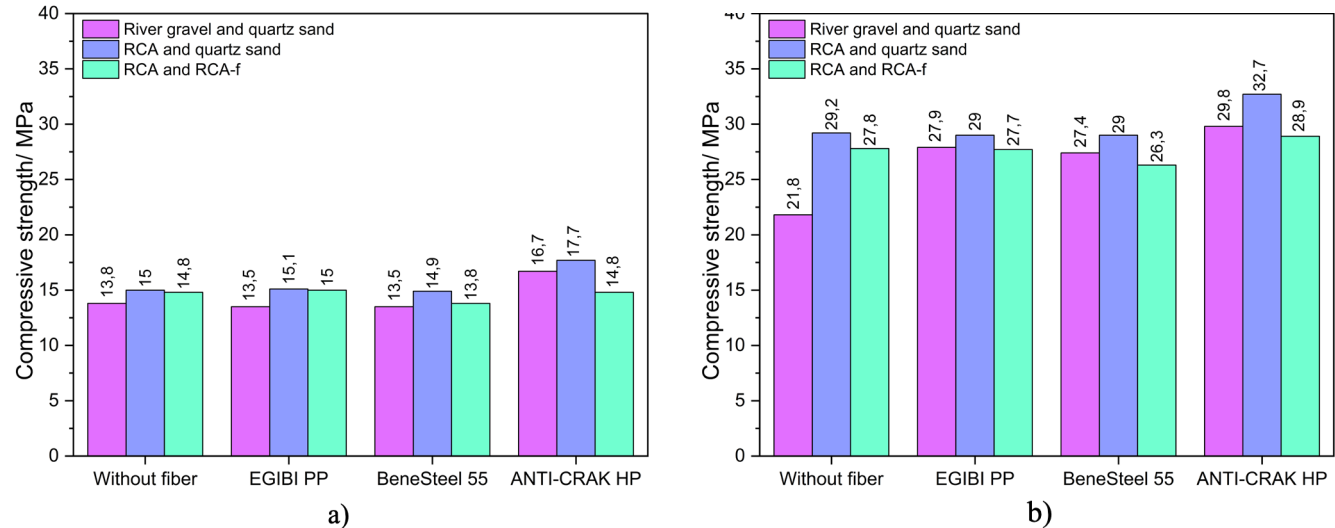


Fig. 6 Compressive strength of the dispersed reinforced concretes at the ages of: (a) 3 days; (b) 28 days

The compressive strength of the concretes at the ages of 3 and 28 days is shown in the graphs in Fig. 6. As can be seen from the test data, using polymer fibre did not increase the compressive strength of the concretes; on the contrary, their strength was decreased. The compressive strength of the dispersed reinforced concrete using EGIBI PP polymer micro fibre (fibre length is 12 mm, equivalent diameter is 34 μ m) was 0.3 – 1 % lower, depending on the composition, when compared to the reference concrete’s composition without any dispersal reinforcement. The compressive strength of the dispersed reinforced concrete using BeneSteel 55 polymer fibre (fibre length is 55 mm, equivalent diameter is 0.2 – 0.5 mm) was 1 – 5 % lower, compared to the reference concrete’s composition without any dispersal reinforcement. Only the use of the ANTI-CRAK HP alkali-resistant glass fibre (fibre length is 12 mm, equivalent diameter is 0.48 mm) increased the compressive strength of the concretes by 4 – 12 %, compared to the reference concrete’s composition without any dispersal reinforcement. According to the data analysis, it can be concluded that, unlike glass fibre, polymer fibre does not increase the compressive strength of concrete. On the contrary,

due to the need to increase the w/c ratio of the concrete mixture when using fibre to ensure the specified stiffness of the fresh mixture, the compressive strength of concrete decreases. RCA concretes have approximately a 4 % higher compressive strength compared to the reference composition; RCA and RCA-f concretes have approximately a 2 % lower compressive strength compared to the reference composition. That increase in strength is explained by the rough shape of RCA, which ensures better adhesion and interconnections with the cement-sand matrix, compared to the streamlined shape of river gravel. In addition, the recycled aggregate concretes studied have a typical compressive strength gain rate. Thus, on the third day, concretes have, on average, 50 – 56 % from the project strength on 28th day.

The graphs in Fig. 7 demonstrate the effect of the w/c ratio of concretes on their compressive strength at the age of 28 days. Increasing the w/c and decreasing the density because of the addition of fibre decreased the compressive strength of the concretes studied.

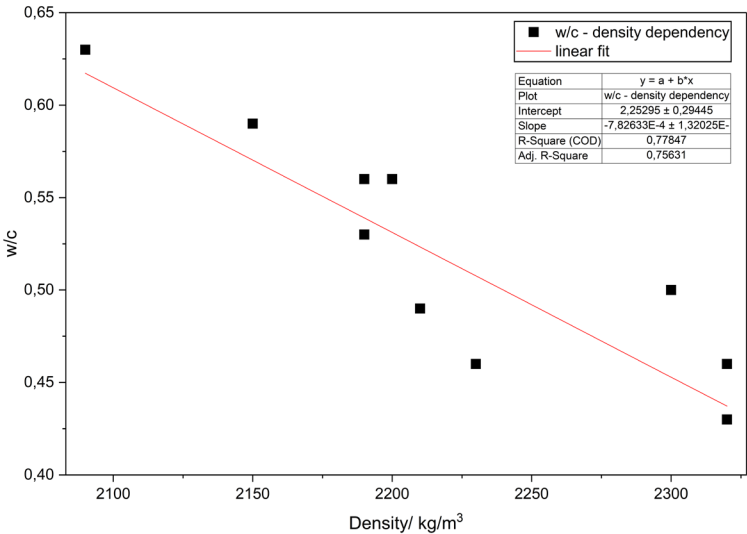


Fig. 7 Effect of w/c on the compressive strength of the concretes at the age of 28 days

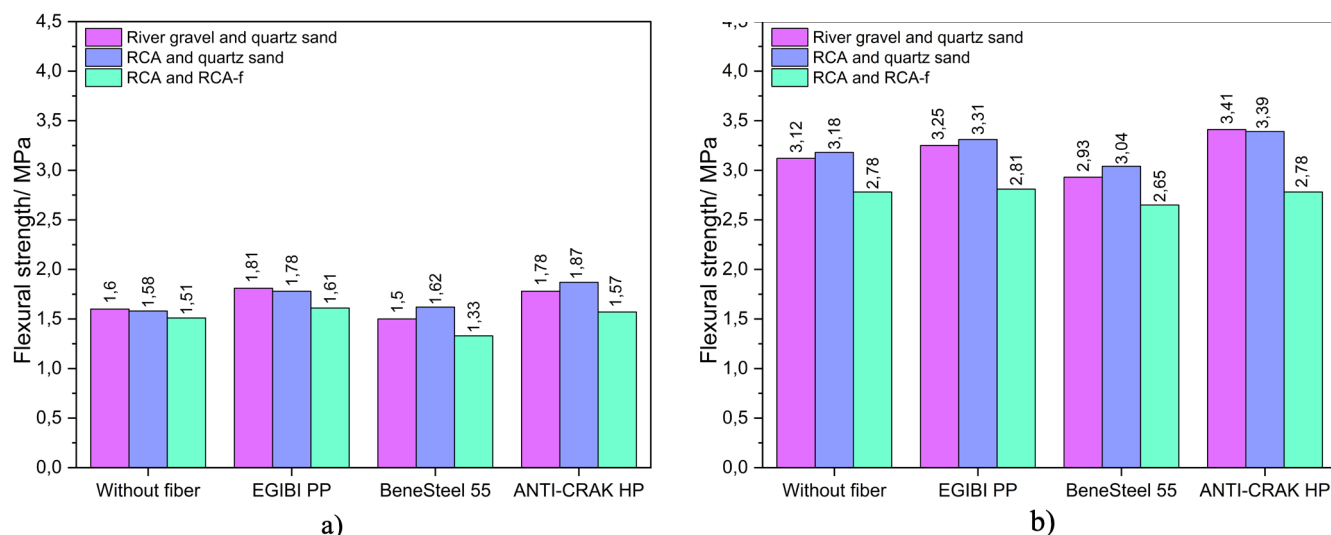


Fig. 8 Flexural strength of the dispersed reinforced concretes at the ages of: (a) 3 days; (b) 28 days

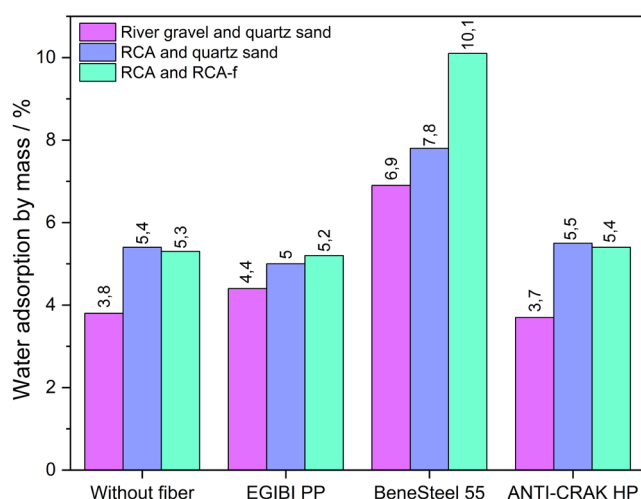


Fig. 9 Water adsorption by mass of the dispersal reinforced concretes at the age of 28 days: (a) 3 days; (b) 28 days

The graphs in Fig. 8 show the flexural strength of the concretes after curing of the samples for 3 and 28 days. The results show that all the fibres, except for the BeneSteel 55, increased the flexural strength of the concretes. The concrete composition with the BeneSteel 55 polymer fibre has a 5 – 6 % lower compressive strength compared to the concretes without any dispersal reinforcement. Such a decrease in flexural strength, despite the addition of the fibre, which technically should increase the flexural strength, is explained by the increase in w/c of the mixture because of the addition of such a type of fibre. This demonstrated that using a large polymer fibre (55 × 0.5 mm) is not effective in recycled aggregates concretes with a high degree of stiffness of the mixture. Using EGIBI PP polymer microfibre insufficiently increased the flexural strength of the concretes by 1 – 4 % compared to the reference compositions. The greatest increase in the flexural strength was for concretes with the addition of the ANTI-CRAK HP glass fibre, by 6 and 9 % for compositions on river gravel and RCA, respectively, and for compositions based on RCA and

RCA-f, flexural strength was not changed after adding glass fibre. Generally, it is possible to conclude that using dispersal reinforcement does not have a high degree of efficiency for recycled aggregates concrete, especially on fillers of fine sizes. In analogue to compressive strength, concretes have the same flexural strength gain rate, i.e. at the age of 3 days the concretes have approximately 50 – 55 % of the project's flexural strength (on 28th day).

The water adsorption by mass of the concrete with dispersal reinforcement at the age of 28 days is shown in the graphs in Fig. 9. The water adsorption of the concretes has direct dependencies with the w/c ratio of those concretes, which is affected by the type of fibre and aggregate used. The highest water adsorption was for concretes with the BeneSteel 55 polymer fibre because of the high w/c and the lowest density, and varied from 6.9 % to 10.1 % (maximum for compositions on RCA and RCA-f simultaneously). The water adsorption of the reference compositions, i.e. the compositions with the EGIBI PP polymer microfibre and the ANTI-CRAK HP glass fibre did not differ significantly and amounted to 3.7 – 5.5 %, depending on the aggregate composition.

According to the test results, the frost resistance of the concrete with dispersal reinforcement corresponds to the frost resistance grade F100. The concretes were tested only for compliance with the frost resistance grade F100, since the concretes developed for the arrangement of the lower layers of two-layer rigid pavements, the frost resistance requirements for which are relatively low. The concretes studied may have a higher frost resistance grade.

When analysing the research data, it is possible to assess the possibilities of using recycled concrete aggregates, of fine fraction including, for road concrete production and the effectiveness of using the fibres studied for dispersal reinforcement of those concretes. The compositions on RCA and quartz sand have even higher compressive and flexural strength compared to the compositions on river gravel and quartz sand. The composites with RCA of coarse and fine sizes showed a decrease in strength but still have good properties,

i.e., 28.9 – 32.7 MPa of compressive strength and 2.65 – 3.41 MPa of flexural strength. This totally meets the requirements of STN 73 6123 for lower layers of rigid pavements, namely minimum classes of concretes, i.e., C12/15 – C20/25 and frost resistance grade F50 – F100, depending on the road class. However, the concretes studied concerning recycled aggregates and dispersed reinforcement did not reach the strength of concretes with similar compositions as seen in previous research (Kroviakov et al., 2026; Kryzhanovskiy et al., 2026), the compressive strength of which amounted to 40 – 50 MPa, the flexural strength to 4.5 – 5.0 MPa, depending on the composition, and the frost resistance grade – F200. First of all, this can be explained by the locally available raw materials and the type of recycled concrete aggregate used in the study. In the research mentioned, RCA was extracted granite rubble from concrete scrap; in the current research, as described in the article, the RCA was river gravel extracted from the concrete. That river gravel normally has a lower strength compared to the granite rubble, which affects the RCA from that raw material and the concrete from it, respectively. In addition, pretreatment of the aggregate for concrete production and the use of chemical additives also affects the concrete's characteristics significantly.

Moreover, it was established that using fibre for dispersal reinforcement has an ambiguous effect on the mechanical characteristics of concretes: the EGIBI PP polymer microfibre increased the flexural strength insignificantly, and the compressive strength was not changed. The BeneSteel 55 polymer macrofibre decreased all the mechanical parameters of the concrete because increasing w/c for ensuring the constant stiffness of fresh concrete. Only the ANTI-CRAK HP glass fibre has a effect on strength characteristics of the concretes on recycled aggregates, but it was insignificant. Generally, the use of dispersal reinforcement for recycled aggregates concretes for lower layers of rigid pavements does not have a high degree of efficiency.

4 CONCLUSIONS

According to the research results of investigations of recycled aggregates concretes with dispersal reinforcement using fibres of different types and cement with a high content of blast furnace slag for the construction of lower layers of rigid pavements, the following conclusions are possible to make:

- The effect of EGIBI PP 32 µm/12 mm polypropylene fibre and BeneSteel 55 polymer fibre as a dispersal reinforcement material on the properties of concrete for lower layers of rigid pavements using recycled aggregates was determined. The low efficiency of the dispersed reinforcement with the mentioned fibres to produce concrete based on recycled aggregates was established. The use of BeneSteel 55 polypropylene fibre caused a decrease in the strength of the concrete, which is due to the need to significantly increase the w/c when using this fibre. This shows the inexpediency of using the mentioned fibres in recycled aggregates concretes

for dispersal reinforcement, taking into account the economic factor.

- It has been established that dispersal reinforcement with the ANTI-CRAK HP 12 alkali-resistant glass fibre increases the compressive strength of concrete for road pavement bases by 4 – 12 %. At the same time, the flexural strength of concrete on river gravel and quartz sand increases by 9.3 %, but for RCA concrete only by 3.5 %. Fibre of this type can be used for dispersed reinforcement of concrete on recycled aggregates when it is necessary to increase the mechanical characteristics of concrete.
- The possibility of using recycled aggregates concretes and cement with a high slag content for lower layers of rigid pavements was proven. Such composites, including fine size RCA, have a compressive strength of 26.3 to 28.9 MPa, a flexural strength from 2.65 to 2.81 MPa and a frost resistance grade F100. This meets the minimum requirements for the strength and frost resistance of concrete for a monolithic lower layer of road pavements, as specified in STN 73 6123 (concrete of classes C12/15 – C20/25 and frost resistance grade F50 – F100, depending on the road class).

Acknowledgments

This research was funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the Project No. 09I03-03-V01-00141 and Project VEGA No. 1/0597/25 “Research of transport properties of rocks for environmental use”.

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