USE OF SECONDARY AGGREGATES FOR CONCRETE PRODUCTION

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Abstract

The properties of concretes based on different types of secondary coarse and fine aggregates were studied experimentally with a view to their potential for the construction of pavement layers. Namely, the prototypes were tested for compressive and flexural strengths, water absorption, and frost resistance. The results show that these concretes are characterized by fairly high tensile strength and frost resistance, which is an important requirement for road pavements. Thus, the use of secondary coarse and fine aggregates in pavement concretes could be a plausible solution from the viewpoint of both construction and environmental sustainability.

Keywords

Secondary concrete aggregates, secondary crushed stone, secondary sand, pavement bases, concrete

1 INTRODUCTION

The development of effective methods of using the remains of dismantled buildings and structures has been an urgent task for most countries of the world for many years. The volume of newly formed construction waste due to the dismantling and destruction of buildings and structures increases annually [1], [2].

During the destruction and dismantling of buildings and structures, many different types of remains emerge, the type of which depends primarily on the type of construction. The remains of reinforced concrete structures and brick walls are the most suitable for reuse are [3]. These residues are sufficiently high-quality raw materials for the production of secondary concrete aggregates, such as secondary crushed stone and sand. The widespread use of secondary aggregates in concrete will solve the problem of recycling most of the remains from buildings and structures. However, a significant disadvantage of secondary aggregates is their relatively low homogeneity [4]. Sorting and additional processing of secondary crushed stone or sand is a complex process that requires unreasonably high costs. Accordingly, such aggregates can be effectively used in concrete structures that have a large volume with relatively low requirements for strength and frost resistance [5].

The most rational approach is to use secondary aggregates for concrete production for building the basis layers of road pavements, especially for pavements with cement-concrete surfaces. It is expedient from a technical, economic and ecological point of view. Accordingly, the task of developing effective road concretes with the maximum possible use of secondary aggregates is urgent [6].

According to the strength requirements of the Ukrainian state standard GBN B.2.3-37641918-557, the base layers of rigid pavements should be made from low grade cement concrete, mainly with the class of flexural strength B_{tb} 1.0 and B_{tb} 1.2 [7]. According to the strength requirements of state standard DBN B.2.3-4:2015, the frost resistance of these concretes should be at least F25 or F50, depending on the temperature of the coldest month [8]. The standards require only necessary strength characteristics for concrete used in basis layers of pavement; they do not require its composition. Thus, these concretes can be made from secondary aggregates, subject to the required strength.

In recent years, the volume of waste from the dismantling of buildings and structures has been constantly increasing [9]. Storing of construction waste in landfills is very expensive and inappropriate from ecological point of view [10]. This stimulates the development of technologies for processing construction waste into secondary crushed stone and sand [11].

Secondary aggregates are widely used in road construction, in particular in the production of concrete pavements and bases. For example, in research [12], waste from the dismantling of buildings was effectively used in concrete for the bases of highways, which were laid using the rolling method. In [13], when using only waste, namely secondary aggregates and blast furnace slag as a binder, concrete for the base of pavement with a strength of up to 6 MPa was obtained. In [14], when up to 30% of granite crushed stone was replaced by secondary concrete, the strength of concrete remained sufficient for the construction of rigid pavements. In [15], the use of dispersed

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reinforcement made it possible to achieve the strength of concrete with secondary aggregates, which met the requirements for the installation of rigid pavements.

The analysis carried out in this way shows that concrete with secondary aggregates can be effectively used for pavement bases. This confirms the relevance of the task of improving the composition and technology of preparing such concrete [16].

The purpose of the work is to determine the effect of secondary crushed stone and sand of various types on the strength and frost resistance of the concrete for pavement bases.

2 METHODOLOGY

As part of the research, the properties of concrete containing ordinary and secondary aggregates were compared. Three types of coarse aggregate of fraction size 8–16 mm were used for the production of samples:

- Granite river gravel, Danube. Bulk density of gravel 1570 kg/m^3, water absorption 0.70% (see Fig. 1.a).
- Secondary crushed stone from recycled reinforced concrete structures. The bulk density of this crushed stone is 1260 kg/m^3, water absorption is 5.94% (see Fig. 1.b).
- Secondary crushed stone from recycled brickwork and ceramic tiles. The bulk density of this crushed stone is 1150 kg/m^3, water absorption is 8.53% (see Fig. 1.c).

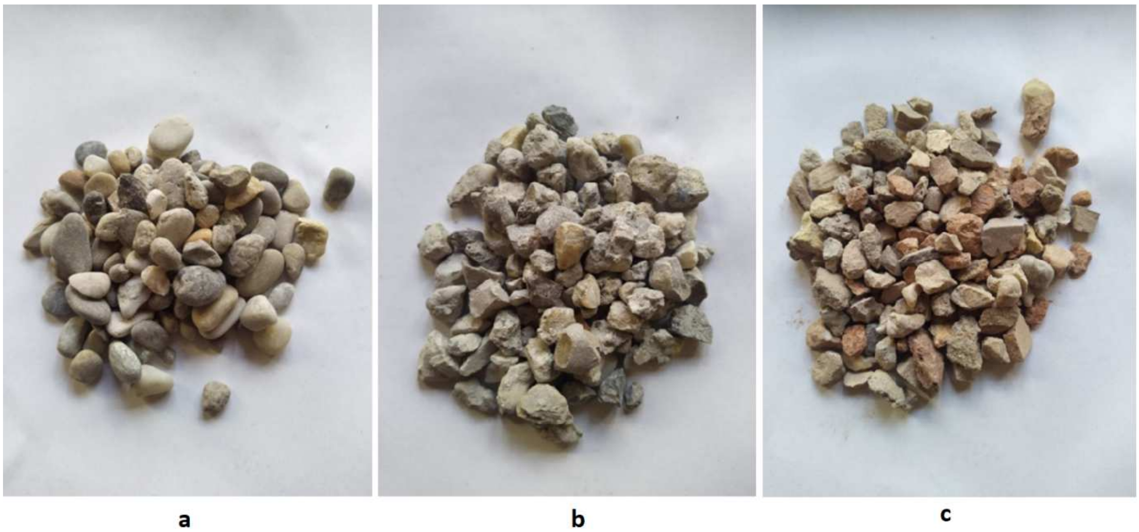

Fig. 1 Types of coarse aggregates used in the production of experimental concrete.

Three types of sand fraction size 0–4 mm were also used:

- Quartz sand with fineness modulus 3.19, bulk density 1935 kg/m^3 (see Fig. 2.a).
- Secondary sand from recycled reinforced concrete structures. The fineness modulus of this sand is 3.83; the bulk density is 1500 kg/m^3 (see Fig. 2.b).
- Secondary sand from recycled brickwork and ceramic tiles. The fineness modulus of this sand is 3.72; the bulk density is 1375 kg/m^3 (see Fig. 2.c).

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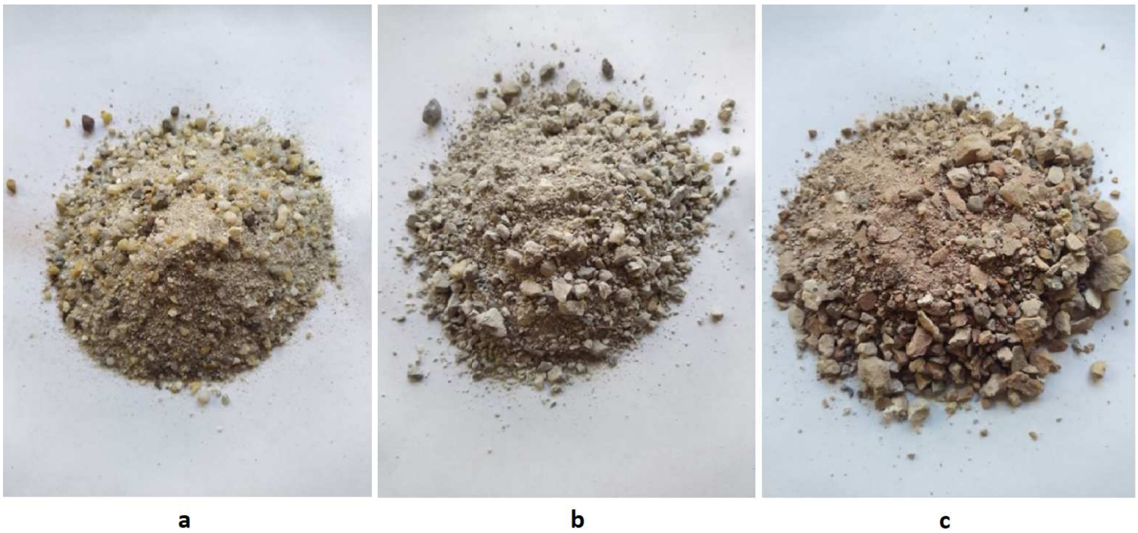

Fig. 2 Types of fine aggregates used in the production of experimental concrete.

Portland cement CEM II/B-S 42.5 N manufactured by Cementaren Ladce (contains 21% blast furnace slag) and additive superplasticizer polycarboxylate type Berament HT28, manufactured by Beton Racio, were used. The amount of additive was 1.2% of the cement mass. The mobility of all mixtures was S1, cone draft was 1–2 cm, which meets the requirements of DBN B.2.3-4:2015 [8] for laying technologies using a concrete paver with sliding formwork.

Five types of concrete compositions were investigated: based on granite gravel and quartz sand (as control compositions), two compositions using two types of coarse secondary aggregates and quartz sand, and two compositions using two types of coarse secondary aggregates and two types of secondary sand. The exact compositions of the studied concretes for bases of pavements are shown in Tab. 1. The concrete compositions of were designed according to Ukrainian state standard DSTU B V.2.7-43-96 [17] and modified based on the density and other characteristics of secondary concrete aggregates.

Tab. 1 Compositions of the studied concretes.

№	Cement (kg/m^3)	Coarse aggregate (type, kg/m^3)	Sand (type, kg/m^3)	Additive (kg/m^3)	Water (l/m^3)	W/C
1a	*300*	*granite gravel, 1252*	*quartz, 762*	*3.6*	*124*	*0.413*
2a		*secondary from reinforced concrete constructions, 1122*			*138*	*0.460*
3a		*secondary from brickwork, 982*			*175*	*0.583*
4a		*secondary from reinforced concrete constructions, 1070*	*secondary from reinforced concrete constructions, 755*		*168*	*0.560*
5a		*secondary from brickwork, 803*	*secondary from brickwork, 765*		*229*	*0.762*

For the production of concrete mixtures using all types of aggregates, mixing was carried out in a forced-type laboratory mixer. The studies were carried out on cube concrete samples with dimensions of 100 mm × 100 mm × 100 mm. After removing from the metal forms, the samples were hardened under normal conditions at a temperature of (20 ± 2) °C and humidity (95 ± 5)% in a special cabinet.

During the research, the density of concrete samples was determined by their weighing and measuring. Concrete was tested for water absorption; samples were soaked in water for 5 days and then weighed. Afterwards, the samples were dried in a drying oven for 24 hours under temperature of 102 °C and weighed. Based on the difference in the weight of the samples in water-saturated state and in an absolutely dried state, the water absorption of concrete by mass and volume was determined.

All concrete compositions were tested for compressive strength on samples with dimensions 100 mm × 100 mm × 100 mm on the 3rd day (at this age concrete acquires approximately half of design strength) on a Controls MCC8 150/600 press (see Fig. 3). The test is planned to be carried out also on the 28th day, after the concrete has reached its design strength. The equipment undergoes annual accuracy testing.

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Fig. 3 Controls MCC8 150/600.

3 RESULTS

For all studied compositions, their average density, water absorption and compressive strength at the age of 3 days were determined in experimental methods. The data obtained from the testing of the concretes are presented in Tab. 2.

Tab. 2 Properties of the studied concrete for pavement bases.

No.	Average density, kg/m^3	Water absorption, %	Compressive strength at age of 3 days, MPa
1a	*2458*	*6.2*	*28.28*
2a	*2341*	*7.6*	*29.45*
3a	*2238*	*9.7*	*21.29*
4a	*2288*	*7.8*	*15.61*
5a	*2061*	*13.9*	*13.04*

4 DISCUSSION

The conditions of preparation and laying of the concrete mixtures during of the experiment were close to real technological features of arranging concrete bases of pavements. It was confirmed that the water cement ratio (further W/C) of the mixtures directly depended on their composition (see Tab. 1). Concretes based on granite gravel and quartz sand are expected to have the lowest W/C. When using secondary crushed stone, the W/C increased due to the absorption of part of the water by the coarse aggregate. At the same time, the use of rubble from brickwork and ceramic tiles necessitated a greater increase in W/C compared to the use of rubble from reinforced concrete structures. When secondary crushed stone was used simultaneously with secondary sand, the W/C of the mixtures was additionally increased. It is known that a significant part of the water in concrete on secondary aggregates is absorbed by them during saturation, which has an ambiguous effect on the structure. An increase in W/C raises the total porosity of the composite material, but at the same time the saturation of the aggregate improves the conditions of concrete hardening and the adhesion between the aggregate and the cement matrix [18], [19].

In Fig. 4, a diagram of the average density of the tested concretes for pavement bases is shown. The analysis of the diagram shows that concretes from granite gravel and quartz sand have the highest density. When using secondary rubble from reinforced concrete structures, the average density decreases by 3%–5%; and when using secondary rubble from brickwork and ceramic tiles, it decreases by 8%–9%. The concretes based on secondary crushed stone and sand from reinforced concrete structures have a 6%–9% lower average density compared to the reference compositions (labelled 1a). Concretes based on secondary crushed stone and sand from recycled brickwork and ceramic tiles have the lowest average density (14%–17% less than the average density of the reference concretes). This influence of aggregates is explained by their own average density and porosity. This is confirmed by the determined water absorption value of the studied concretes, which is actually their open porosity and is given in Tab. 2.

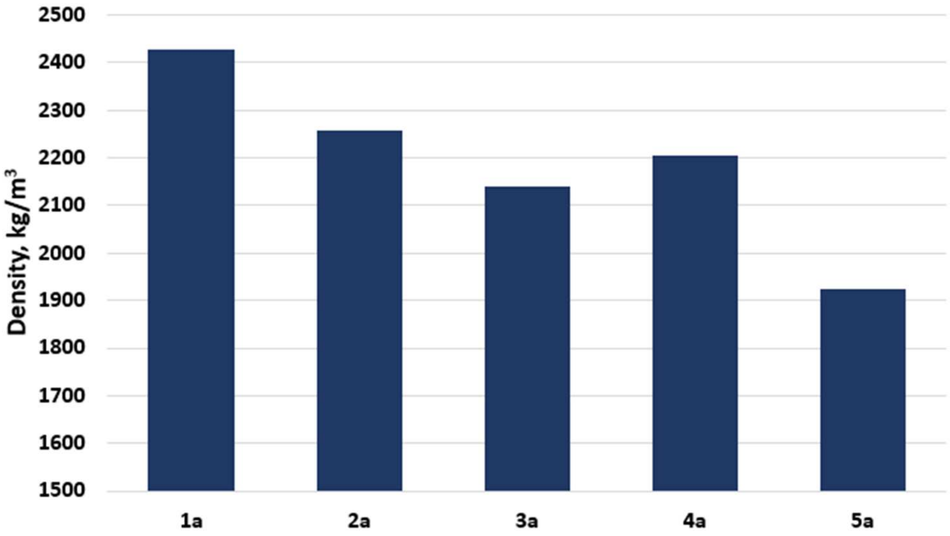

Fig. 4 The average density of the studied concretes.

For the studied concrete, the influence of the type of aggregate on the strength of concrete was proportional to their density and characteristics of the aggregates (see Fig. 5 and Fig. 6). When quartz sand was used, concretes on crushed stone from reinforced concrete structures (labelled 2a) had the highest compressive strength. The strength of concrete on this secondary crushed stone at the age of 3 days is 2%–6% higher than the strength of concrete on granite gravel. This difference is explained by the use of granite gravel with smooth edges in the reference concrete. When using secondary crushed stone from brickwork and ceramic tiles and quartz sand (labelled 3a), the strength of concrete on 3rd day becomes lower by 7%–15% compared to the concrete made from granite gravel. For concretes based on secondary crushed stone from reinforced concrete structures and secondary sand (labelled 4a), the compressive strength is reduced by 40%–45% compared with concrete from the reference concrete. When using secondary rubble and sand from brickwork and ceramic tiles (labelled 5a), the compressive strength of concrete is 44%–46% lower than the strength of similar reference concretes. Thus, concretes with secondary aggregates and quartz sand are characterized by sufficiently high compressive strength, which is due to the rough surface of the aggregate. This structure provides high adhesion to the sand-cement matrix and contributes to increased resistance to compressive stresses [19].

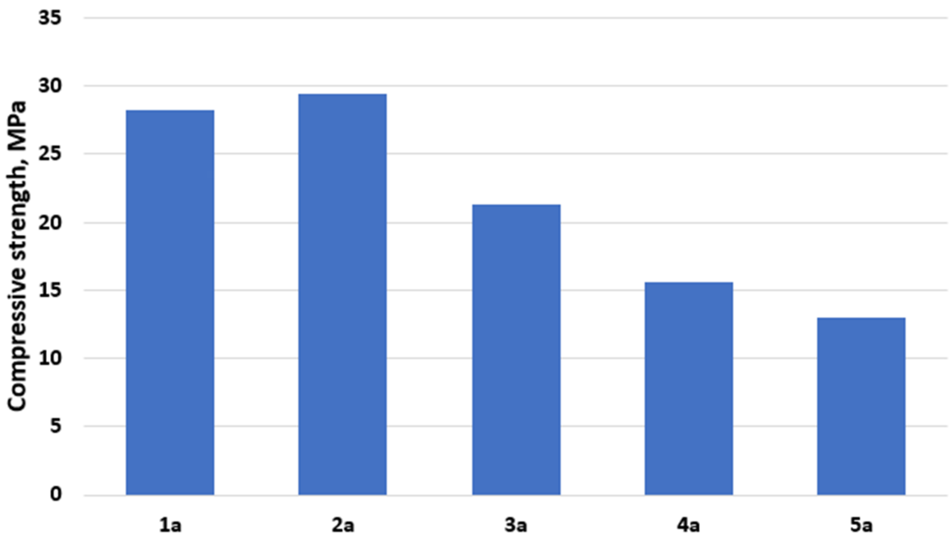

Fig. 5 Compressive strength of the studied concretes at the age of 3 days.

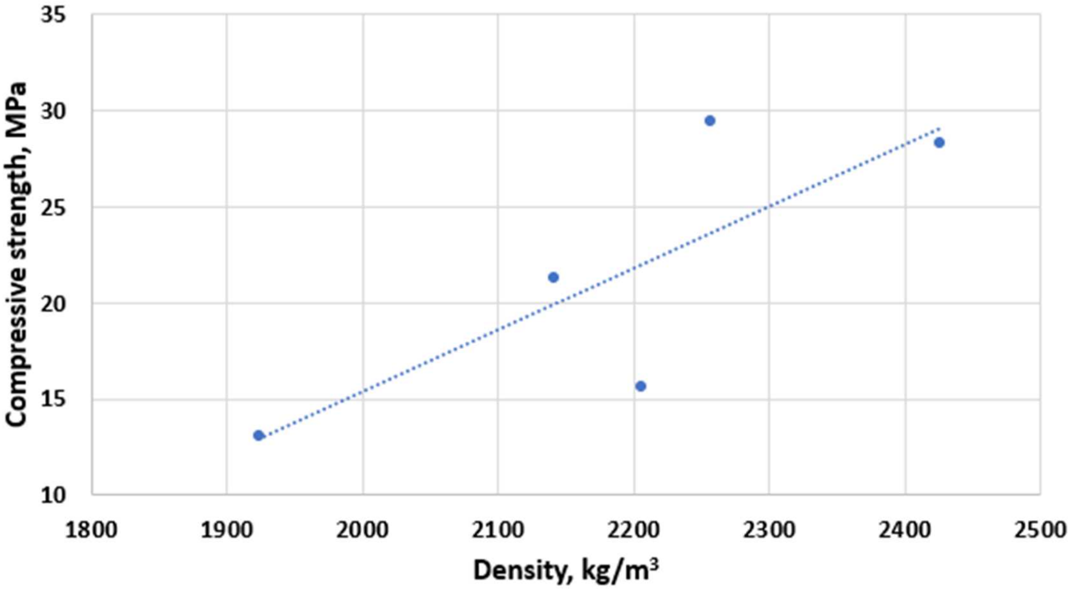

Fig. 6 Relations between density and compressive strength of studied concretes at the age of 3 days.

As observed from the graphs in Fig. 7 and Fig. 8, the average water absorption by volume of studied samples is directly related to the density of concretes. It is expected that samples with a lower density have higher water absorption. This is explained by a higher number of pores in concrete, which are filled with water during the water absorption test. This corresponding dependence also affects to the compressive strength of the concretes.

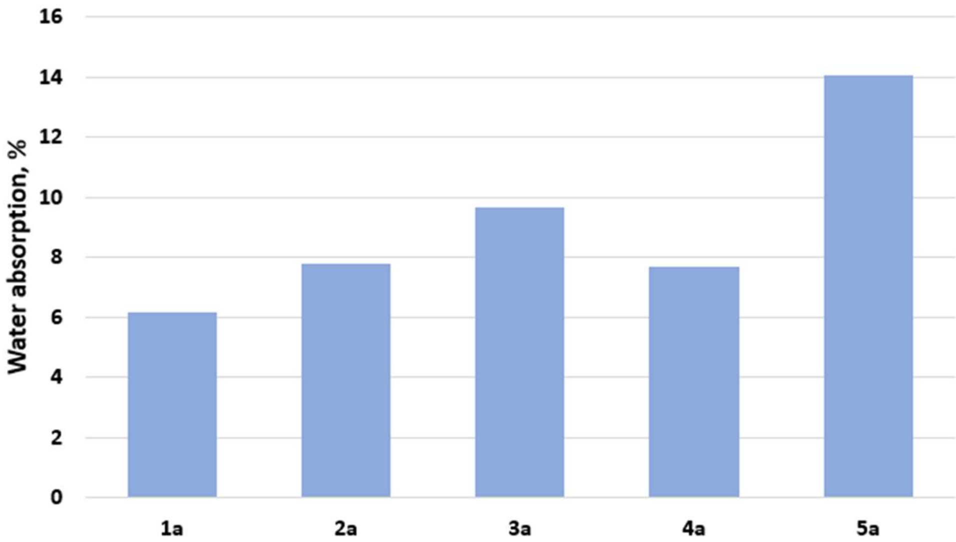

Fig. 7 Water absorption of researched concretes.

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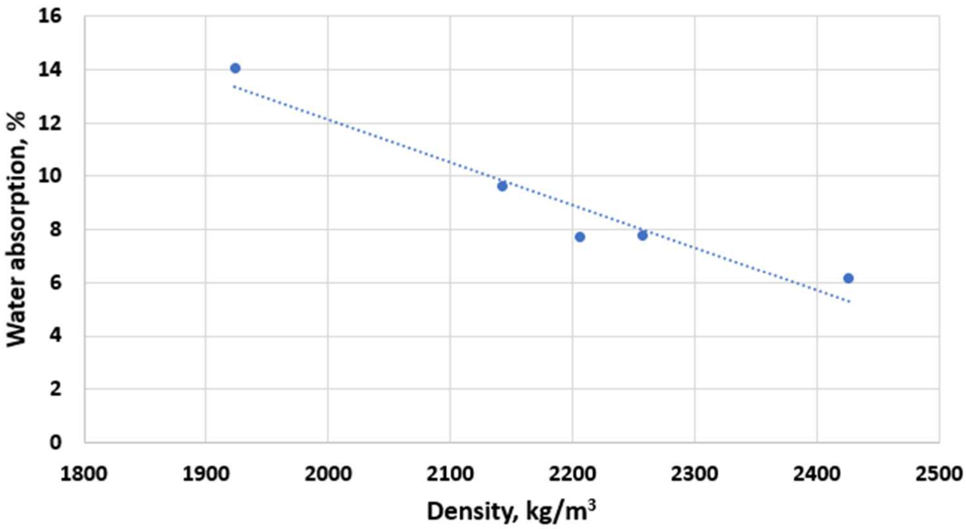

Fig. 8 Relations between density and water absorption of studied concretes.

5 CONCLUSION

The results of our research imply the following observations:

- Tested concretes based on secondary aggregates were characterized by a sufficiently high compressive strength on the 3rd day, enabling their use for a range of purposes after reaching the design strength of concrete, including the construction of pavement bases.
- The use of secondary concrete aggregates can contribute to solving important problems related to the disposal of construction waste and landfilled reclamation.
- All raw materials used for the production of concrete are available throughout Europe.

This allows us to draw the conclusion that concretes based on secondary aggregates have the strength that enables such materials to be considered as an alternative to traditional concretes for the bottom layer of rigid pavements. However, in order to identify the technical feasibility of such a solution, additional studies should be conducted. In particular, the compressive strength, flexible strength and frost resistance [20] on the 28th day must be determined. Moreover, the research should move towards exploring the increased use of other secondary and recycled materials, such as geopolymers, to completely or partially replace cement as a binder material. For pavements, flexural strength and frost resistance are more important indicators than the compressive strength. The calculation of the structure of roads with a rigid pavement is based on these indicators simultaneously with the modulus of elasticity of concrete [21].

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