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Influence of aggregate type and size on properties of pervious concrete

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HIGHLIGHTS

- A standard dense concrete mixture and four pervious concrete mixtures were studied.
- A higher amount of small aggregate fractions yielded higher density mixtures.
- A higher amount of small aggregate fractions yielded greater flexural strength.
- Connected porosity was influenced more by the aggregate type than the size.
- Pervious concrete can be used as concrete block paving.

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ABSTRACT

This study investigates the influence of aggregate type and size on the properties of pervious concrete. Five different concrete mixtures were prepared, including a standard dense concrete mixture and four pervious concrete mixtures with varied aggregate types (dolomite or steel slag) and differing proportions of 4–8 mm to 8–16 mm aggregate fractions (30:60 or 60:30). The results suggest that a higher amount of small aggregate fractions (4–8 mm) yielded higher density concrete mixtures and greater flexural strength. However, connected porosity as a main parameter for estimating pervious concrete efficiency was surprisingly influenced more by the aggregate type than the size.

1. Introduction

Pervious concrete has been in use for more than 50 years, especially in the United States and Japan [1,2]. It contains a high amount of pores, with cement paste evenly distributed throughout its structure. The porosity of pervious concrete ranges between 11% and 35% [3–5], which gives it permeability, good drainage properties, and high noise absorption characteristics; however, the high porosity also reduces the concrete's strength. The most important features of pervious concrete in its hardened state are reduced density, permeability of 0.2–1.2 cm/s and compressive strength of 3.5–28 MPa [4]. Compared to regular concrete, pervious concrete has the main advantages of preventing water from pooling on surfaces, positively affecting vegetation by supplying plants with water/rainwater and maintaining groundwater quality [6]. These advantages make pervious concrete appropriate for a wide range of applications including slope stabilization systems, alleys, parking lots [4] and light-traffic roads [7].

Pervious concrete is composed of a mixture of cement, water, and coarse aggregate, with or without a small amount of fine aggregate [2]. Since pore connectivity is essential to pervious concrete function, compaction is restricted [8] because it can result in a layer of cement paste at the bottom of the concrete structure that would negatively affect permeability.

Total porosity of pervious concrete is the sum of closed (isolated) porosity and open (connected) porosity, and it can be calculated by hydrostatic weighing. However, direct insight into porosity would be beneficial since permeability is influenced not only by the number of pores but also by their distribution and interconnectivity. X-ray microtomography has been used to characterize many different types of building materials, including stone, concrete, and lightweight aggregate, and it enables assessing the total porosity, phase

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distribution, voids, and cracks. If supported by suitable image analysis software, X-ray microtomography can yield quantified results about the structure, pores, and pore interconnectivity [9–12]. Ayda et al. [13] previously investigated pervious concrete by means of microtomography (among other techniques) and found that aggregate properties have the strongest effect on the mechanical properties of porous concrete because the coarse aggregates are very effective in forming the skeleton structure. Microtomography scans enabled the researchers to follow crack patterns and determine that they were influenced by the distinct porous structure. The cracks extended into locations based on the geometry of the skeleton structure, which was determined by the aggregate grading. In particular, when the aggregates were fine, the cracks developed through the cement paste; with a larger aggregate size, however, the cracks developed more frequently through the aggregate grain [13].

The current study aimed to evaluate the influence of the aggregate type as well as the size and size distribution of aggregates on the mechanical properties and the overall porosity of pervious concrete and its application in pavement structures. This study was also intended to determine the optimal mixture for pervious concrete to meet the requirements of Croatian legislation for pavements [14]. According to the General Technical Conditions for Roadwork [14], concrete for pavement is classified based on its 28-day compressive and flexural strengths. The required compressive strength for a very heavy traffic load is C 35/45, while flexural strength must be 5.0 MPa. For a heavy traffic load, the required compressive strength is C 30/37 and flexural strength is 4.5 MPa, while the required load compressive strength and flexural strength are C 25/30 and 4.0 MPa, respectively, for other traffic. To quantify pore volume and pore connectivity, X-ray microtomography was used, and microstructural analysis was done using a scanning electron microscope to qualify those results.

As a part of this study, the possibility of using a waste material, steel slag, instead of dolomite aggregate in pervious concrete was investigated. The use of steel slag in pervious concrete helps reduce industrial waste landfills, benefits ecological consciousness, and increases cost-effectiveness.

2. Experiment

2.1. Preparation of specimens

In this study, five different concrete mixtures were prepared. The first one was a standard dense concrete mixture, while the others were pervious concrete mixtures with two different types of aggregates and different proportions of aggregate fractions (Table 1). Crushed dolomite stone was used as a natural material, and steel slag from Croatian landfills near the town of Sisak was used as a substitute aggregate material. The relevant properties of the aggregates are given by Netinger et al. [15].

Steel slag from Croatian landfills has already been proven to be a good substitute for natural aggregate in regular concrete mixtures [16–18]; therefore, this investigation did not focus on substitute aggregate properties. Pervious concrete mixtures M2 and M4 were prepared from coarse dolomite aggregate (fractions of 4–8 mm and 8–16 mm) and sand from the Drava River (fractions of 0–2 mm); the mixtures M3 and M5 were prepared from a coarse steel slag aggregate (fractions of 4–8 mm and 8–16 mm) and sand from the Drava River (fractions of 0–2 mm); and the reference mixture (M1) was prepared entirely from dolomite (fractions of 0–4, 4–8, and 8–16 mm). Each pervious concrete mixture contained 10% sand from the Drava River. The grain size distribution of all aggregate fractions is shown in Fig. 1, and the cumulative sieving curves of aggregates in specific concrete mixtures are shown in Fig. 2. The grain size distribution of the aggregates was determined according to EN 933-1:2012 [19]. The designations M1–M5 in Fig. 2 correspond to concrete mixtures M1–M5.

Table 1
Mixture compositions.

Characteristics	Mixture									
	M1		M2		M3		M4		M5	
Water/cement proportion (w/c)	0.33		0.33		0.33		0.33		0.33	
Cement (kg)	350.0		300.0		300.0		300.0		300.0	
Water (kg)	115.5		99.0		99.0		99.0		99.0	
Superplasticizer (kg)	3.5		0.0		0.0		0.0		0.0	
Aggregate (kg)	2034.0		1783.7		2053.3		1783.7		2053.3	
Components										
Sand 0–2 mm (%-kg)	–	–	10	178.4	10	205.3	10	178.4	10	205.3
Dolomite 0–4 mm (%-kg)	40	813.6	–	–	–	–	–	–	–	–
Dolomite 4–8 mm (%-kg)	30	610.2	60	1070.2	–	–	30	535.1	–	–
Dolomite 8–16 mm (%-kg)	30	610.2	30	535.1	–	–	60	1070.2	–	–
Steel slag 4–8 mm (%-kg)	–	–	–	–	60	1232.0	–	–	30	616.0
Steel slag 8–16 mm (%-kg)	–	–	–	–	30	616.0	–	–	60	1232.0
Total (kg)	2503.0		2182.7		2452.3		2182.7		2452.3	

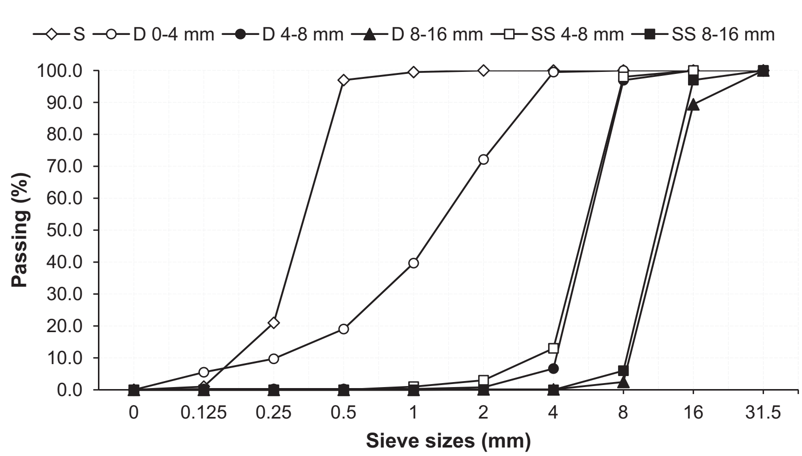

Fig. 1. Sieving curves of aggregate fractions (S = sand, D = dolomite, SS = steel slag).