Construction and Building Materials 169 (2018) 252–260

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Draining capability of single-sized pervious concrete

Ivanka Netinger Grubeša [a,*], Ivana Barišić [a], Vilma Ducman [b], Lidija Korat [b]

[a] Faculty of Civil Engineering Osijek, Josip Juraj Strossmayer University of Osijek, Vladimira Preloga 3, 31000 Osijek, Croatia
[b] ZAG Ljubljana, Dimičeva 12, 1000 Ljubljana, Slovenia

HIGHLIGHTS

- Hydrologic and mechanical properties of pervious concrete were studied.
- The optimal aggregate type from the hydrologic point of view is diabase.
- An aggregate of sharp grain edges allows the water to pass smoothly through the pore system.
- A coarser aggregate fraction results in better hydraulic and mechanical properties.

ARTICLE INFO

Article history:
Received 21 August 2017
Received in revised form 17 February 2018
Accepted 3 March 2018

Keywords:
Pervious concrete
Porosity
Hydrologic properties
Mechanical properties
X-ray microtomography
SEM analysis

ABSTRACT

Six mixtures of single-sized pervious concrete were prepared with three different types of aggregates (dolomite, diabase, and steel slag from a Croatian landfill near the town of Sisak) and with two different aggregate fractions (4–8 mm and 8–16 mm). Each pervious concrete mixture contained 10% of sand from the Drava River. The hydrologic properties of the pervious concrete mixtures are compared in order to define the aggregate type that will ensure the best drainage properties. The draining capability was tested by three methods: the constant head and falling head methods on the small samples, and the standard test method for testing the infiltration rate of in-place pervious concrete by ASTM C 1701-09. The possibility of pervious concrete application as a surface layer in pavement construction in the European area is estimated according to the achieved mechanical properties. The optimal aggregate type for preparing pervious concrete from the hydrologic point of view is diabase because of its sharp grain edges, which allow the water to pass smoothly through the pore system. None of the studied mixtures satisfied the set criteria on the mechanical properties of concrete for the surface layer of pavements in the European area. However, it is observed that the coarser aggregate fraction will result in better hydraulic and mechanical properties of pervious concrete.

1. Introduction

Pervious/permeable/no-fines concrete is a material with the same basic components as the standard concrete but designed to have high porosity, with void content between 11% and 35% [1,2]. A pervious concrete mixture is composed of cement, water, and coarse aggregate, with or without a small amount of fine aggregate [3]. Since pore connectivity is essential for the pervious concrete function, its compaction is restricted [4] because it can result in a layer of cement paste at the bottom of the concrete structure that would negatively affect permeability. The installation of pervious concrete into the pavement is similar to the installation of asphalt. However, unlike the asphalt, pervious concrete needs to be cured until reaching the required strength. Pervious concrete as a material was used for the first time in 1852 [5] and patented in 1980 [6]. Although it is not a new technology, pervious concrete is receiving renewed interest today. The typical properties of pervious concrete presented below are based on recent and older literature, which reflects the continuous interest of researchers in this topic.

a) Good drainage properties. The permeability of pervious concrete, because of its high porosity, is in the range of 2–6 mm/s [2,7]. Contrary to regular concrete, pervious concrete prevents water from pooling on horizontal surfaces and, if properly designed, positively affects the surrounding soil and groundwater quality [8]. Owing to its drainage properties, pervious concrete is used in the construction of shoulders, bases, and subbases of roads.

* Corresponding author.
E-mail address: nivanka@gfos.hr (I.N. Grubeša).

https://doi.org/10.1016/j.conbuildmat.2018.03.037
0950-0618/

b) High noise absorption properties. Owing to its high porosity, pervious concrete is able to reduce environmental noise. Noise and noisy environment can cause various kinds of diseases related to living in such an unpleasant environment. This has been widely researched and many studies have proved the connection between traffic noise and cardiovascular, neuro-vegetative, and other diseases [9,10]. The noise resulting from the interaction between tire and pavement is being increasingly recognized as a significant environmental issue, and it has become a major problem in urban areas. The noise produced by a moving vehicle largely depends on the geometrical properties of the road surface. This is the main reason why current research is focused on finding new methods for reducing noise at its place of origin, the road surface, through the observation of the behavior of different pavement types and their composition. The studies have shown that modification of the type and/or texture of pavement surface can result in significant tire/pavement noise reductions and that the proper selection of the pavement surface can be an appropriate noise abatement procedure [11]. Concrete pavements are generally a worse choice compared to asphalt pavements considering the tire/road noise impact. The only type of concrete surface course that can be considered as "quiet" is pervious concrete. The key factors that determine the efficiency of pervious concrete in absorbing sound are the porosity that can be accessed by the sound waves, pore size, pore aperture size, and thickness of the porous layer. An acoustically efficient material is that with smaller pore sizes and high pore confinement [12]. Marolf et al. studied the effect of aggregate size and gradation on the acoustic absorption of pervious concrete and they reported that pervious concrete mixtures with single-sized aggregates provide substantial improvement in sound absorption compared to conventional concrete [13].

c) Ability to reduce urban heat islands. Heat island refers to the development of higher urban temperatures within an urban area, compared to the temperatures of the surrounding suburban and rural areas. This phenomenon has an important impact on the energy consumption of buildings for cooling purposes. Various studies have shown that the cooling energy consumption of buildings may have doubled because of the significant increase in urban temperatures [14–16]. Many recent studies have shown that paved surfaces play a determinant role in the overall urban thermal balance [17,18]. In permeable pavements, water passes to the soil through the material voids/pores. It evaporates when the temperature of the material increases, contributing to a lower temperature of the pavement surface.

d) Poor mechanical properties. Pervious concrete mixtures can develop compressive strengths in the range of 2.8–28 MPa [7,19,20] and flexural strengths generally ranging between 1 MPa and 3.8 MPa [7]. The low strength of pervious concrete is the reason for its limited application in construction of high traffic highways. In order to address this issue, research with different, new components in pervious concrete is being conducted worldwide [3,21,22].

e) Low abrasion and freeze-thaw resistance. Pervious concrete has some durability issues related to abrasion and freeze-thaw cycles, which deter its wider application. The abrasion resistance of concrete depends on its paste hardness, aggregate hardness, and aggregate/paste bond [23]. Many researchers agree that there is a general relation between abrasion resistance and compressive strength—by increasing the strength of concrete, the effects of abrasion are reduced [24,25]. Test results shown in [26,27] have confirmed that adding latex to concrete mixtures is a way of improving their strength and, consequently, their abrasion resistance. Further, runoff water that flows into pervious concrete in cold weather and freezes can lead to pressure build up on the thin cement paste coating area, which makes pervious concrete not suitable for dry-freeze conditions. Studies on the improvement of the resistance of pervious concrete to freeze-thaw cycles have found that the addition of long macrofibers increases its freeze-thaw (F-T) resistance [28], as does the usage of an air-entraining admixture [29], silica fume with super plasticizers [30] or tire chips and crumb rubber [31]. In exploitation, when small material such as dirt and fine sand are carried by storm water in the exploitation through the pores of pervious concrete, the debris can eventually reduce the effectiveness of the drainage and permeability of the concrete. Such clogging could then lead to flooding and the concrete being susceptible to extensive freeze-thaw cycles [32].

Although the composition of pervious concrete seems simple, it is not easy to achieve good mechanical properties and a satisfactory pore system at the same time. Decreasing the water to cement ratio and increasing the cement amount in the concrete mixture will result in better mechanical properties in the case of regular concrete. However, the increment of the amount of cement in pervious concrete will reduce or even completely prevent its ability to infiltrate water, which is its main advantage. This paper studies the possible application of pervious concrete as a surface pavement layer in Europe. Guided by the idea that single-sized aggregates in pervious concrete will result in high sound absorption capacity [13], the authors focus on single-sized aggregate pervious mixtures with three different aggregate types. The hydrologic properties of six pervious concrete mixtures are compared in order to determine the aggregate type that will ensure the best drainage properties. The potential of pervious concrete application as a surface layer in pavement construction in the European area is evaluated according to the achieved mechanical properties.

2. Experimental program

2.1. Material characterization

In this study, six mixtures of pervious concrete were prepared with three different types of aggregate (dolomite, diabase, and steel slag from a Croatian landfill near the town of Sisak) and with two different aggregate fractions (4–8 mm and 8–16 mm). The porosity and pore size distribution of the prepared aggregates were determined by means of mercury intrusion porosimetry (MIP). Particles having a size of approximately 1 cm^3 of each of the prepared aggregates were dried in an oven for 24 h at 110 °C, and then analyzed by means of a MIP Autopore IV 9500 equipment (Micrometrics). The results are presented in Table 1. The appearance of the aggregate grains is shown in Fig. 1.

Each pervious concrete mixture contained 10% sand from the Drava River. The grain size distribution of the aggregates was determined according to EN 933-1:2012 [33], and the aggregate fractions were classified according to HRN EN 12620:2013 [34],

Table 1
Porosity and medium pore size of the three used aggregates.

Aggregate	Porosity (%)	Average pore size (μm)	Density (excluding pores) (g/mL)
Slag	7.0019	0.1204	3.8924
Diabase	1.2241	0.1428	2.8969
Dolomite	1.1221	1.0032	2.8322