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for Renewable Electrical
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within the SMEITS
Prof. dr Zoran Lazarević

Editor
Dr Milica Vlahović

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ULOGA VODOPROPUSNIH PROIZVODA U POPLOČAVANJU URBANIH SREDINA U SVETLU ODRŽIVOG KORIŠĆENJA RESURSA

THE ROLE OF PERMEABLE PRODUCTS IN THE PAVING OF URBAN ENVIRONMENT IN THE LIGHT OF SUSTAINABLE USE OF RESOURCES

Marina AŠKRABIĆ*, Aleksandar RADEVIC, Aleksandar SAVIČ
University of Belgrade, Faculty of Civil Engineering

amarina@imk.grf.bg.ac.rs (*corresponding author),
aradevic@imk.grf.bg.ac.rs, sasha@imk.grf.bg.ac.rs

Apstrakt

Propusni beton i različite vrste propusnih proizvoda za popločavanje su u centru pažnje istraživača iz različitih oblasti: ispitivanja materijala, urbanizma, vodno inženjerstvo, održivi razvoj, obnovljivi izvori energije itd. U radu su prikazani najvažniji parametri koji se odnose na proizvodnju i primenu poroznih betona i načini upotrebe ovih proizvoda u različitim uslovima. Dodatno su prikazane mehaničke osobine poroznih betonskih ploča proizvedenih sa 30 % cementa zamenjenog modifikovanim očvrslim muljem tretiranim otpadnim vodama, kao mogući način održive upotrebe ovih proizvoda.

Ključne reči: *porozni beton, propusni proizvodi za popločavanje, održivi materijali, zeleni betony*

Abstract

Pervious concrete and different types of permeable products for paving are in the spotlight of the researchers from different areas: material engineering, urbanization, water management, sustainable development, renewable energy resources, etc. The paper presents the most important parameters related to production and application of pervious concrete, and the ways of using these products in various conditions. Additionally, mechanical properties of pervious concrete slabs produced with 30% of cement replaced with modified solidified waste water treated sludge are presented, as a possible way of sustainable usage of these products.

Key words: *pervious concrete, permeable pavement, sustainable materials, green concrete*

1 Introduction

Due to great increase in urbanization of green surfaces inside and outside of the cities, the planet is exposed to higher level of flooding than it was the case throughout the history. Scientists from the University of Newcastle have shown, through analysis of 170 scientific studies, that flood occurrence is a direct consequence of the urbanization level and basin size [1]. "Sustainable development of transportation infrastructure in the urban environment requires a transition from energy-intensive construction methods to low impact development (LID) practices". The goal of this policy is to restore as much as possible the natural ability of the surface to absorb stormwater, as shown in Figure 1.

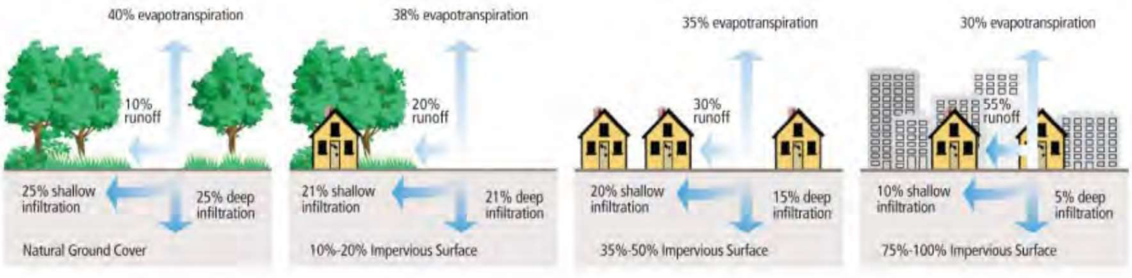

Figure 1 Different runoff possibilities with changes in the level of urbanization [2]

One of the solutions applied, throughout the world, is formation of porous surfaces in urban environments. These surfaces can be divided in two major groups: porous (pervious) asphalt and concrete and permeable interlocking pervious pavements as shown in Figure 2. The difference of these products is based on the mechanism of their permeability: weather the material they are made of contains pores that are able to transport higher amount of rainwater or they are placed on site in a way that allows rainwater to pass through holes between the products used for paving.

Simultaneously, following the goals of sustainable development, the tendency within the civil engineering community, is to use recycled or waste materials in development of new building materials. This led to increased production of so called “green concrete”, or concrete that would be ecologically acceptable. It is produced using recycled or waste materials, with reduction of the amount of cement [3].

This paper presents more detailed insight into the possibilities of green pervious concrete design, especially prefabricated pervious concrete slabs, in the light of sustainable development policies and energy savings.

Figure 2. Mostly applied types of porous surfaces [4]

2 Design and properties of sustainable pervious concrete and pervious concrete slabs

Pervious concrete is a material where the first fraction of aggregate (grains between 0 and 4 mm) quantity is reduced. This material has high percent of pores of greater size than usual concrete, which allows it to quickly transport water to the drainage system. Pervious concrete has been promoted through “American council for green building” in the program known as “Leadership in energetic and ecological design” (LEED). This program states the following advantages of pervious concrete application:

- it improves the runoff of rain, and when possible reduces the contamination of the rainwater before it reaches the drainage system;
- it reflects the sun, and its relatively open structure has lower possibility to warm up than asphalt concrete,
- aggregate in pervious concrete can contain certain amount of recycled materials, and still remain durable and functional,
- if natural aggregate is used in production of pervious concrete, it can be of local origin which will reduce the need for transportation of this important concrete component [5].

Differently from performance criteria defined for typical paving concrete, for pervious concrete most important criteria are porosity, permeability, compressive strength, flexural strength, durability against freeze-thaw cycling, impact loading and abrasion [6].

Methodology of porous slabs design takes into account both structural and hydrological analysis in order to develop integrated approach. Dimensions of the slab and of the base layer are intended to resist the designed loads and to transport the designed amount of water. Two most important properties are the pore size of concrete and compressive strength of paving elements. Higher pore sizes and percent of porosity increase the drainage capacity of the slabs, but usually lead to the reduction of their compressive strength and accordingly, ability of the slabs to resist designed loads [7].

Pore size that enables water transport should be between 2 and 8 mm, while compressive strength ranges between 2,8 to 28 MPa. Water/cement ratio is usually between 0.26 and 0.45 [8]. Aggregate to cement ratio takes values between 4 and 6, by mass, usually between 4.1 to 4.5. Hardened porosity ranges between 15% and 35% [6]. Total porosity of pervious concrete includes approximately 10-20% of closed pores, and 80-90% effective, connected pores. Larger pores influence reduction of ductility, and lead to easier destruction of the concrete structure [9]. Permeability of pervious concrete usually ranges between 0.14-1.22 cm/s [6]. Relationship between performance requirements and mechanical properties (indirect tensile strength – ITS) is presented in Figure 3.

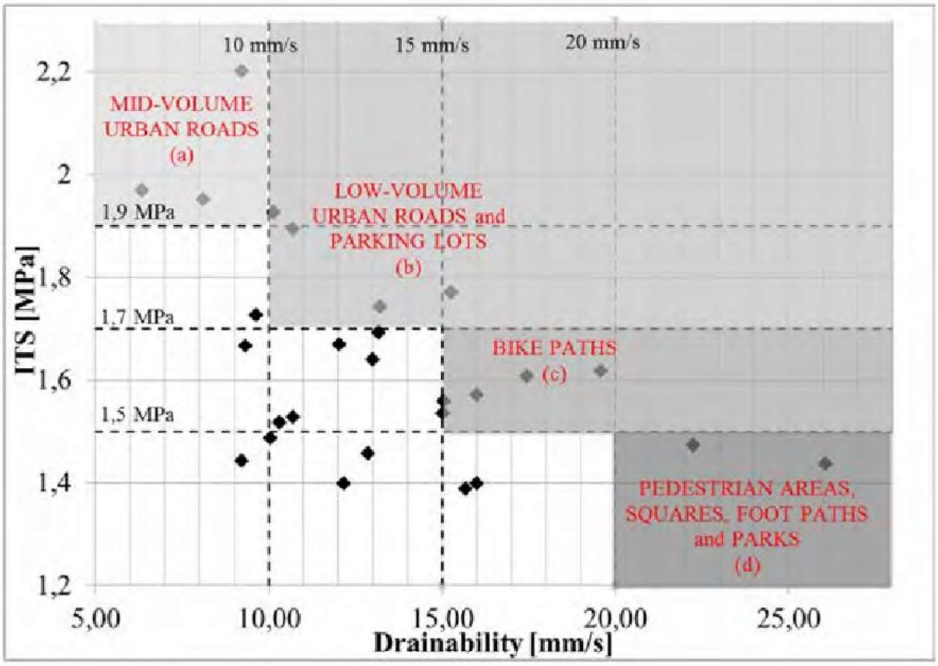

Figure 3 Drainability/ITS relationship where the optimal mixtures and the performance requirements were defined for different urban uses of pervious concrete [10].

Sustainability in pervious concrete is present in partial replacement of cement or aggregates with recyclable materials or industrial by-products. It was shown that replacement of cement in amounts between 5% and 15% with fly ash leads to the improvement of mechanical properties of this type of concrete [8,9]. Also, when pozzolans are used for partial replacement of cement, in higher percent, it is necessary to leave more time for reaching the final strength values.

Several authors performed trials with high-volume fly ash pervious concrete. The compressive strength from different mixtures ranged between 5.4 to 11.4 MPa in one study [11] and between 2.9 to 10.3MPa in another study [12]. The splitting tensile strength was between 0.7 and 1.4 MPa [11].

When aggregates are concerned, types with sharp edges are favoured, due to better adhesion to cement paste. This led to possible applications of recycled concrete aggregates, crushed brick aggregate, copper slag, steel slag, etc. [13]. One of the studies dealt with the possibility of replacing natural aggregate with recycled aggregate from 0 to 100%, using GGBFS as 50% replacement of cement. Results indicate that permeability improved by 12-43%, while compressive strength was reduced for 10-12% and tensile strength also reduced by 6.2-11.3% with 10% increase of recycled aggregate in the pervious concrete [14]. Another study found that an optimal replacement level of aggregates with recycled rubber aggregates (in amount of 18% and 14%) led to the increase by 12% in compressive strength and 30% in flexural strength [15].

Another aspect of the sustainability in the case or pervious concrete systems is the type of sub-base used. Usually only drainage layer is applied which is composed of untreated granular aggregate. Studies show that the energy consumption is about 81% lower for this type of sub-base, than for the base course in asphalt concrete [16].

Producing a holistic green design framework for permeable surfaces involves interconnection between the design, environmental engineering, material selection, low impact development and porous pavements [4].

Research needs for the future projects combine necessity for standard mixture design methods, standardized testing methods, resolving failures of the pervious concrete due to the low strength and durability and database of field tests [6].

3 Application of pervious concrete in various conditions

Large number of research have been performed regarding the application of pervious concrete in cold and hot climate. Researchers in Canada defined that the most problems emerge when concrete becomes completely saturated, and then frozen. If the snow is removed from the slab surface, low amount of ice on the top of the concrete should not present a problem. Importantly, researchers recommend reduction of the application of de-icing salts, when this type of concrete is in question [17].

Pavements are recognized as major contributors to urban heat island effect, since they represent 20-40% of the landcover in urban environment [18].

Researchers in hot and wet climate, as in Brazil, have found many positive aspects when pervious concrete is applied. Scientists from Lamar University and Laboratory from Brazil have replaced smaller part of a parking with pervious concrete with depth of 15 cm, over 20 cm of the base aggregate. They have concluded that in the case of pervious concrete, temperature of water that reaches lower layers of the system becomes lower than when impermeable layers are used, as water evaporates from the surface of the pervious concrete and enables cooling of the slabs and remaining water [19]. Similar conclusion was drawn in the paper comparing the heat development in the depth of pavement between permeable and impermeable paving sections [20].

When the climate is warm and dry, temperature of the pervious concrete can reach around 6 degrees celsius higher than the nonpermeable concrete [21].

Charlesworth et al. [22] prepared a combination of ground water heating pump, pervious paving system and rainwater harvesting. This was the first project of this kind, built to provide means of heating to Hanson Ecohouse built on the Innovation Park at the Garston near Watford, UK. Due to the ground conditions on site, the pervious paving system could be escavated to the depth of 350, which was shown to be insuficient. The total surface area of the system was 65 m^2 which was considered suitable for production of 6 kW of heating or cooling energy. Cross section through the proposed system is shown in Figure 4.

The authors concluded that since this was a pilot study, the problems encountered were to be expected. Still, they find that the potential for using these kind of combined systems appears to be substantial.

4 Pervious concrete with addition of modified solidified waste water treated sludge (MSWWTS)

One of the sustainable solutions for pervious concrete production, as it was mentioned before, is use of different materials as a partial replacement of cement. One of these materials, with ever increasing production, is water treated sludge, formed as a by-product of waste or drinking water purification. In this paper, cement in pervious concrete slabs was replaced in amount of 30% with solidified waste water treated sludge (SWWTS), mixed with additional components chosen to improve its binding capacity. Detailed characterization of the SWWTS used can be find in [23]. Modification procedure assumed mixing SWWTS (90%) with Al_2O_3 (6.3%), $Mg_3Si_4O_{10}(OH)_2$ (3%), and sealant (0.7%). Reference mixture contained only cement as a binder. Both types of concrete slabs were produced with crushed aggregate of natural origin, in two fractions – 2/4 mm and 4/8 mm.

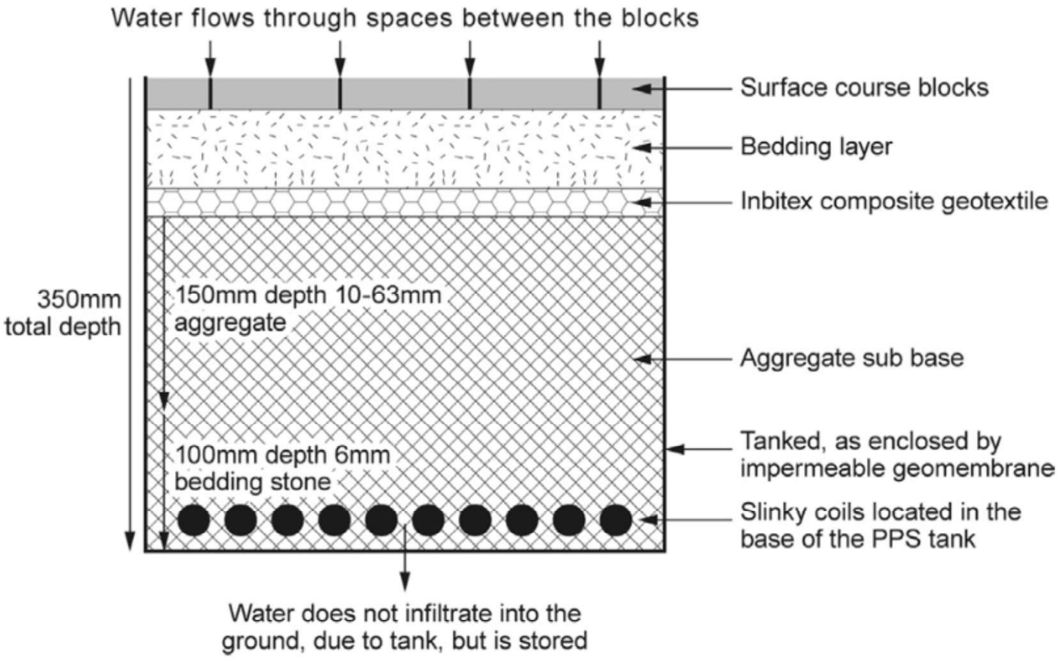

Figure 4 Cross section through the system applied at the Ecohouse [22]

Results of mechanical tests performed on the concrete slabs at the age of 28 days are presented in Table 1. Average abrasion resistance of reference slabs was 18.71 $cm^3/50\ cm^2$, while for the slabs containing MSWWTS this value was 26.44 $cm^3/50\ cm^2$.

Table 1. Results of mechanical tests performed on the two types of concrete slabs

	Ref. mix	*30% MSWWTS*
Compressive strength (MPa)	4.21	3.17
Splitting tensile strength (MPa)	1.44	0.95
Flexural strength (MPa)	1.58	0.85
Pull-off strength (MPa)	1.33	1.18

According to the presented results, the addition of MSWWTS in amount of 30% (as a cement replacement) led to deterioration of all mechanical properties. If the values of splitting tensile strength are compared with the categorization presented in Figure 3 (ITS values), it can be concluded that reference mixture could be used for pedestrian areas, squares, footpaths and parks, which is not the case for mixture 30%MSWWTS. Nevertheless, lower percent of cement replacement, together with more trials on the mixtures, will result in higher compressive and tensile strength, and lead to formation of pervious concrete slabs with appropriate properties for pedestrian areas.

5 Conclusion

The paper presents application of one type of waste material (modified waste water treated sludge) in the production of pervious concrete slabs, as a partial cement replacement. Although the results showed drop in the mechanical properties of the products tested, there is a potential of using this type of material in lower percent, for pedestrian paths and parks.

Pervious concrete has been in the spotlight of the researchers from different scientific areas during the last ten years, although it has been first produced and used during the second half of the twentieth century. They have been recognized as a possible sustainable and green solution for paving of the urban areas, especially in warm and wet climates. Their role in lowering air temperatures is recognized in the reduction of the urban heat island effect. Also, permeable interlocking pavements were recommended as a part of the system for renewable energy production for heating and cooling of smaller family homes.

Still, there are open questions that need to be resolved in the future in order to improve the possibilities for the application of these products. There is a need for standardization of the mixtures development and even more importantly for their testing in hardened state. When these questions are resolved the possibility of using different waste materials and industrial by-products in the production of pervious concrete will be even higher.

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