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ABSTRACT

Pervious/permeable/no-fines concrete is a material with the same basic components as the standard concrete but designed to have high porosity. The typical properties of pervious concrete are: good drainage properties, high noise absorption properties, ability to reduce urban heat islands, poor mechanical properties, low abrasion and freeze-thaw resistance. A pervious concrete mixture is composed of cement, water, and coarse aggregate, with or without a small amount of fine aggregate. 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 increase of the amount of cement in pervious concrete will reduce or even completely prevent its ability to infiltrate water, which is its main advantage. Pervious concrete as a material was used for the first time in 1852 and patented in 1980. Although it is not a new technology, pervious concrete is receiving renewed interest today. Namely, poor mechanical properties, low abrasion and freeze-thaw resistance are characteristics of pervious concrete interesting to scientists even today. Therefore, this paper deals with improving mechanical properties of pervious concrete by using polymer. Four mixtures of pervious concrete without and with polymer incorporated were prepared and their properties in hardened state compared to each other. It was concluded that polymer can significantly improve compressive strength of pervious concrete.

Keywords: pervious concrete, mechanical properties, polymer, porosity, compressive strength.

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% (Putman and Neptune, 2011; Schaefer et al., 2006). A pervious concrete mixture is composed of cement, water, and coarse aggregate, with or without a small amount of fine aggregate (Huang et al., 2010). 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 increase of the amount of cement in pervious concrete will reduce or even completely prevent its ability to infiltrate water, which is its main advantage. Since pore connectivity is essential for the pervious concrete function, its compaction is restricted (ACI Committee 522, 2010) because it can result in a layer of cement paste at the bottom of the concrete structure that would negatively affect permeability. Pervious concrete as a material was used for the first time in 1852 (Ghafoori and Dutta, 1995a) and patented in 1980 (Hodson, 1980). 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 (Schaefer et al., 2006; Tennis et al., 2004). Using aggregate of sharp grain edges in pervious concrete will allow the water to pass smoothly through the pore system and positively influence its draining capability (Netinger Grubeša et al., 2018a).

b) High noise absorption properties. 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. 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 (Neithalath et al., 2006). Marolf et al. (2004) 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 (Marolf, 2004). In Netinger Grubeša et al. (2018b) was concluded that the higher total porosity of pervious concrete will result in its higher capacity to absorb the traffic noise.

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 (Hirano and Fujita, 2012; Kolokotroni et al., 2006; Santamouris et al., 2007). Many recent studies have shown that paved surfaces play a determinant role in the overall urban thermal balance (Menon et al., 2010; Gaitani et al., 2007). 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 MPa to 28 MPa (Tennis et al., 2004; Selvaraj and Amirthavarshini, 2016; Aoki, 2009) and flexural strengths generally ranging between 1 MPa and 3.8 MPa (Tennis et al., 2004). 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 (Huang et al., 2010; Pindado et al., 1999; Deo and Neithalath, 2010).

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 (Scott and Safiuddin, 2015). 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 (Liu et al., 2005; Abdelbary and Mohamed, 2016). Test results shown in (Wu et al., 2011; Wu et al., 2016) have confirmed that adding latex to concrete mixtures will improve the compressive strength thus result in improving its abrasion resistance too. 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 (Kevern et al., 2015), as does the usage of an air-entraining admixture (Ghafoori and Dutta, 1995b), silica fume with super plasticizers (Yang and Jiang, 2003) or tire chips and crumb rubber (Gesoglu et al., 2014).

This paper deals with improving mechanical properties of pervious concrete by using commercially available synthetic rubber emulsion, latex.

Methodology

In this study, four mixtures of pervious concrete were prepared with two different types of aggregate (crushed clay brick and dolomite), fraction 8-16 mm. Crushed clay brick used here is coming from the local brick factory and it was generated by crushing brick of insufficient quality to be placed in the market. 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 (Technical Committee CEN /TC 154, 2012), and the aggregate fractions were classified according to HRN EN 12620:2013 (Technical Committee CEN /TC 154, 2013a), as follows: fractions 8-16 mm of crushed brick and dolomite as GC 85/15 and sand (0-2 mm) as GF85. The densities of the used crushed brick, dolomite aggregate and sand were 1.92, 2.75 and 2.65 kg/dm^3, respectively, according to EN 1097-6:2013 (Technical Committee CEN /TC 154, 2013b). For all mixtures, the effective water to cement ratio was 0.33, and it was prepared with tap water. The cement was ordinary Portland cement, CEM II/A-M(S-V) 42.5 N according to EN 197-1:2011 (Technical Committee CEN /TC 51, 2011), with a density of 3.0 kg/dm^3 according to EN 196-6:2010 (Technical Committee CEN /TC 51, 2010). The cement content was 300 kg/m^3 for all mixtures. Table 1 presents the proportions of all constituents in the mixtures.

Table 1. *Mixture Compositions*

Constituents/mixtures	**M1**	**M2**	**M3**	**M4**
(Water+polymer)/cement proportion - (w+p)/c	0.33	0.33	0.33	0.33
Cement [kg]	300	300	300	300
Water [kg]	99	99	99	99
Polymer [kg]	-	1,95	-	1,95
Aggregate [kg]	1406	1406	2183	2183
Sand 0-2 mm [%-kg]	10-140.6	10-140.6	10-178.7	10-178.7
Crushed brick 8-16 mm [%-kg]	90-1265.4	90-1265.4	-	-
Dolomite 8-16 mm [%-kg]	-	-	90-1605.4	90-1605.4

The aggregates used for preparing concrete were first saturated and then surface-dried. This was achieved in an artificial way, by dipping the aggregates into a water tank for 24 h, taking them out, and then wiping excess water from their surface. A synthetic rubber emulsion (latex) usually used for adding to cement mortar or concrete when good adhesion is required was blended here with water and sprayed over aggregate by using water sprayer (Figure 1). Cement and water were mixed together for 2 minutes in a pan mixer (DZ 100VS, Diemwerke). Aggregate coated with latex was added into the cement paste and all the constituents were mixed for additional 3 minutes. Three specimens were prepared to determine the mechanical properties. The specimens of all concrete mixtures were cast with a compacting rod by rodding 25 times. All specimens were extracted from the mounds 24 h after casting and placed in a water tank for 27 days at a temperature of 20 °C ± 5 °C according to EN 12390-2:2009 (Technical Committee CEN /TC 104, 2009a).

At 28 days, the properties of the hardened pervious concrete specimens were tested as follows:

- The compressive strength was tested on cube specimens of 15-cm edge length with a constant loading rate of 0.5 MPa/s according to EN 12390-3:2009 (Technical Committee CEN /TC 104, 2009b).
- The density and void content (total porosity) were tested on the same specimens as compressive strength, according to the standard ASTM C1754/C1754M-12:2012 (ASTM International, 2012).

Figure 1. *Spraying of Latex over the Aggregate*

Findings/Results

The results of the testing are given in Table 2 and Figures 2-4. Results are presented as an average value of three tested specimens of each mixture.

Table 2. *Results of Hardened Concrete Tests* (Kljajić, 2017)

Property/Mixture	**M1**	**M2**	**M3**	**M4**
Compressive strength [MPa]	7.64	9.36	25.04	29.64
Density [kg/m^3]	1889	1900	2350	2365
Total porosity [%]	18.8	19.6	15.3	15.9

Figure 2. *Pervious Concrete Compressive Strength Test Results*

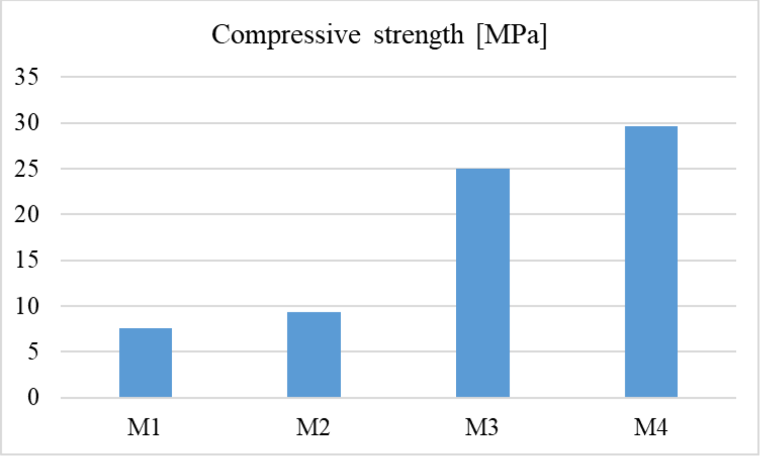


Figure 3. *Pervious Concrete Density Test Results*

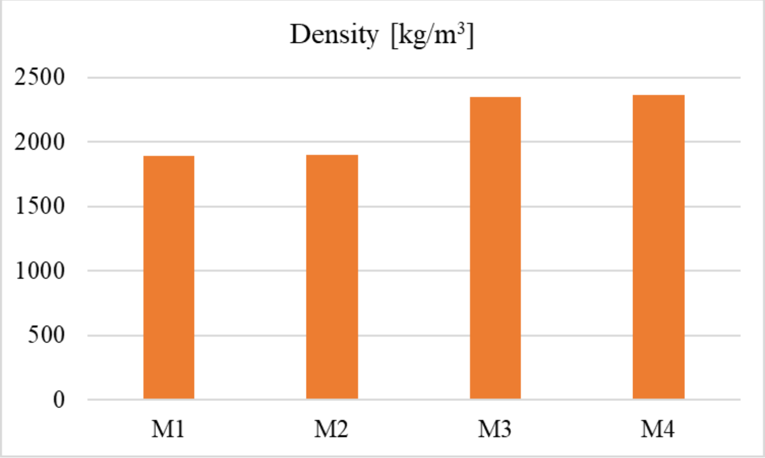
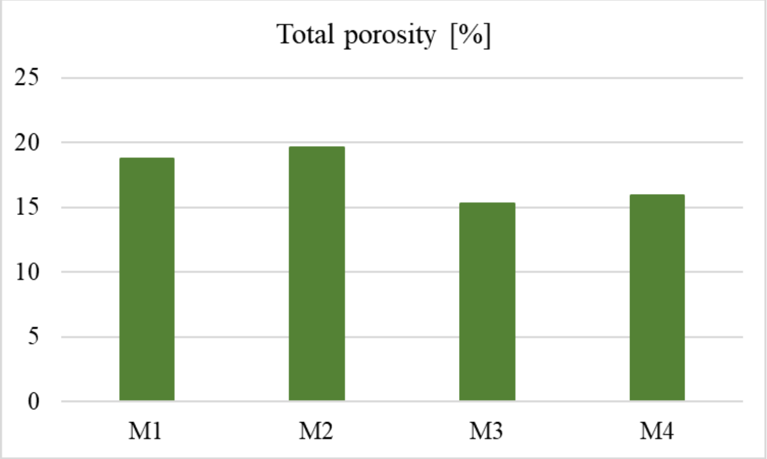


Figure 4. *Pervious Concrete Total Porosity Test Results*



Discussion

Comparing the results listed in Table 2 and Figures 2-4, it is visible that the compressive strength of mixture M2 is higher than the compressive strength of mixture M1 and, again, that the compressive strength of mixture M4 is higher than the compressive strength of mixture M3. Out of this can be unanimously concluded that latex improved compressive strength of pervious concrete mixtures. This increase in pervious concrete with crushed brick and dolomite aggregate is 23% and 18% respectively. Such result might be an outcome of improved quality of interfacial zone between cement paste and aggregates which is usually the weakest area in terms of mechanical properties. Regarding porosity and density there is no significant differences between mixtures with and without latex. Increase in density and total porosity is 1% and 4% respectively regardless of thy aggregate type. Therefore, there is no general conclusion in relation to whether latex used in this way in concrete influences these two properties. However, it can be assumed that since it is not proven for latex to significantly influence total porosity and density of tested mixtures, it would not significantly influence pervious concrete drainage properties. This is to be investigated in more details in further research also taking into account different aggregate types.

Conclusions

Latex, usually used for adding to cement mortar or concrete when good adhesion is required was used in this paper with the aim to improve the quality of interfacial zone between cement paste and aggregates which is expected to positively influence the compressive strength of concrete. Four mixtures of pervious concrete with and without latex incorporated were prepared and their properties in hardened state compared to each other. It was concluded that latex can significantly improve compressive strength of pervious concrete without influencing its porosity and density. Even though latex has improved pervious concrete compressive strength, achieved values are still insufficient for its usage in heavy traffic areas or in structural concrete. So, its potential usage could be analyzed in a view of a paving material for pedestrian areas where its drainage properties and reduced urban heat island effect will be emphasized and exploited.

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