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Properties of pervious concretes partially incorporating acidic pumice as coarse aggregate

Hatice Öznur Öz

Department of Civil Engineering, Niğde Ömer Halisdemir University, Niğde, Turkey

HIGHLIGHTS

- Pervious concrete with acidic pumice aggregate (PCAP) was studied.
- Two concrete groups with varying cement dosage were produced.
- Replacement of crushed stone with acidic pumice reduced the strength of concretes.
- Resistance to water permeability, total void ratio, and surface abrasion enhanced.

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ABSTRACT

Using pervious concrete (PC) as a pavement material in low-volume road applications has gained great importance since its positive environmental benefits. The paper presented herein addresses the prospective use of acidic pumice aggregate in pervious concrete. At a constant water/cement ratio of 0.30, two control concretes were produced with only crushed stone aggregates with cement contents of 300 and 420 kg/m^3, respectively. Thereafter, the acidic pumice were replaced with the crushed stone at 10%, 20%, 30%, 40% and 50%, respectively by total aggregate volume. A total of 12 pervious concretes (PC) were produced and tested for the compressive, splitting tensile, and flexural strengths as well as the total void ratio and permeability at 28 and 90 days. Additionally, the surface abrasion resistances of PCs incorporating pumice were tested at 90-day. Test results have revealed that the PCs incorporating pumice had better water permeability and surface abrasion resistance, irrespective of the replacement level. However, the compressive, splitting tensile and flexural strengths of PCs decreased with increasing the replacement level of pumice.

1. Introduction

Using conventional concrete as a pavement material has caused some problems for the management of stormwater runoff. [1]. Considering the negative impacts of the conventional concrete pavement, pervious concrete (PC) (also called porous concrete or enhanced porosity concrete) have reinvigorated interest in the free-draining systems of pavements. Such concretes have a reduced density of about 2000 kg/m^3, porosity of 11 to 35%, permeability of 0.2–1.2 cm/s, and a compressive strength of 3.5–28.0 MPa [2–6]. Pervious concrete has been increasingly used due to its benefit in improving water quality by removing the total suspended solids from stormwater, decreasing the stormwater runoff, and enhancing skid pavement resistance of during storm events by rapid drainage of water [1,7–9]. Therefore, PC can be used as an environmental friendly material in paving applications such as walkways, parking areas, tennis courts, slope stabilization systems, shoulders, alleys, light traffic roads, and low-grade roads [4,10–12]. The Environmental Protection Agency (EPA) of the United States has accepted the utilization of PC as one of the best management applications in decreasing storm-water runoff even though both the high porosity and the low strength restrict its popularity [9].

Pervious concrete consists of a mixture water, cement and coarse aggregate, with or without a small amount of fine aggregate [2,13]. Since pore connectivity is one of the basic parameters of PC, compaction energy of the concrete that play a main role between strength resistance, suitable permeability, and density of PCs should be limited [13–16]. Considering the studies performed on PCs it was seen that the water/cement ratio changed in the range of 0.28 and 0.40 [4,14,17], the aggregate/cement ratio varied in the range of 4:1 to as high as 6:1 as well as the total aggregate volume of about 50–65% [14]. The particle size of coarse aggregate

E-mail address: oznuroz@ohu.edu.tr

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appeared to be much more effective on the permeability as well as the porosity of PC. The aggregate gradation of PC characteristically consists of single-sized coarse aggregates/binary mixture [14]. In some studies summarized in Table 1, aggregate with the grain size in the range of 2.36–9.5 mm have been utilized in order to improve the strength of PC [18–22]. However, the grain sizes of 9.5–19 mm were applied to provide sufficient voids [23]. Additionally, K. Cosic et al. [2] showed that the connected porosity as a main parameter for estimating the efficiency of PC were surprisingly influenced more by the type of aggregate than its size. Furthermore, the higher amount of small aggregate, the higher density of the concrete mixtures which inturn provided the greater flexural strength. The study of Y. Zaetang et al. [8] indicated that the recycled concrete block aggregate and the recycled concrete aggregate increased the compressive strengths of PCs except for the high replacement level of 100%. However, the addition of recycled concrete aggregate improved the surface abrasion resistance of PC. Moreover, M. Gesoglu et al. [11] found that the tire rubber utilization possessed positive effect on the pervious concrete against the abrasion so that pervious concrete with rubber had the superior abrasion resistance. The cement content, w/c ratio, type of finish, and curing method seemed to have marked influence on the surface abrasion more than on the strength [15,24]. In the literature, however, lightweight aggregates such as pumice and diatomite have not taken adequate attention as much as natural, crushed, recycle aggregates and waste rubber to be used in the production of PC.

Pumice which is used as the aggregate and/or the mineral admixture in the production of concrete is identified as a natural pozzolanic material of volcanic origin [25,26]. It has come out because of the gas release during the solidification of lava [26–28]. Due to a sudden release of the gases in the structure of pumice during its cool down and formation, the connectivity of the pore structure of pumice may range from completely closed to completely open [27,29]. There are two types of pumice known as acidic and basic. While acidic pumice is a lightweight aggregate, specific gravity of basic pumice is close to that of natural aggregate. Also, basic pumice has higher rough surface when compared to the acidic pumice. Acidic pumice, which possesses a porous structure, provides superior advantages of low weight, high heat and sound insulation, and easy workability [27]. Total pumice reserve found in Turkey forms approximately 40% of total pumice reserve located in the world (18 billion m^3) [28]. However, Italy, Greece, Saudi Arabia, Chile and the other world countries (i.e., USA, Spain, France, Equator, New Zealand, Algeria etc.) have approximately 22%, 9%, 7%, 6% and 17% of the total pumice reserves, respectively. Y. Zaetang et al. [26] identified that the PC incorporating pumice and recycled aggregate showed lower mechanical properties associated with higher thermal conductivity and water permeability than those with diatomite aggregate. It can be concluded that the use of materials with high porosity and low specific gravity such as pumice in the design of PC is vital to provide sufficient drainage conforming the purpose of PC. To the knowledge of authors, however, there is a shortage in the literatures related to the usage of lightweight aggregate (especially acidic pumice) in the production of PC.

This study covers an experimental program in which the effects of acidic pumice on the mechanical, durability, and permeability properties of pervious concretes were investigated. For this, a total of 12 mixtures in two different groups of PC were designed to have cement dosages of 300 and 420 kg/m^3, respectively. The control mixtures were made with full crushed stone aggregates while the rest of the mixtures were generated by the crushed stone with the acidic pumice at 10%, 20%, 30%, 40% and 50% by total aggregate volume. The pervious concretes with and without acidic pumice were tested for the porosity, permeability, compressive, flexural and splitting tensile strengths at 28 and 90-day. Additionally, the abrasion resistances of PC incorporating pumice were tested at 90-day.

2. Experimental study

2.1. Materials

An Ordinary Portland cement (CEM I 42,5R) with Blaine fineness of 326 m^2/kg and specific gravity of 3.15 was used. Physical and chemical properties of the cement used in the production of pervious concrete are listed in Table 2. In this study, 10–12 mm sizes crushed limestone and/or acidic pumice were used as the coarse aggregate (Fig. 1). Specific gravity of the crushed stone and the acidic pumice were 2.65 and 0.99, respectively. The water absorption of acidic pumice was measured to be 33.2% according to ASTM C127 [30]. Slake durability test was also conducted with respect to ASTM D4644-16 to determine the stability of pumice against fragmentation and weakening [31]. The test identified the slake durability of acidic pumice as 98.35%.

2.2. Concrete mixture proportioning and casting

In this study, it was aimed to determine the maximum and minimum cement dosage by considering the limitation for compressive strength and water permeability coefficient as well as the aggregate/cement ratio for PCs. At first, test batches were generated by using the varying amounts of cement dosage and ratio of aggregate/cement until the limiting value were reached in the design of PCs incorporating acidic pumice. Then, it was decided that two groups of pervious concretes with 300 and 420 kg/m^3 cement dosages were designed which consisted of two control and ten acidic pumice mixtures. In this manner, a total of 12 mixtures were produced at a constant water/cement ratio of 0.30. The control concretes were made of full crushed stone aggregates while the rest of mixtures for given cement content were generated by replacing the crushed stone with the acidic pumice at 10 to 50%

Table 1
The details of the literature studies.

References	Grain size (mm)	Maximum compressive strength (MPa)
Deo and Neithalath [20]	2.36	20–21
	4.75	22–23
	9.5	19–20
	12.5	18–19
Huang et al. [21]	4.75	10–12
	9.5	12–14
	12.5	14–16

Table 2
Chemical compositions and physical properties of Portland cement.

Chemical Analysis (%)	Cement
CaO	62.58
SiO_2	20.25
Al_2O_3	5.31
Fe_2O_3	4.04
MgO	2.82
SO_3	2.73
K_2O	0.92
Na_2O	0.22
Loss of Ignition	2.96
Specific Gravity	3.15
Blaine Fineness (m^2/kg)	326