Mechanics of Advanced Composite Structures 5 (2018) 157 – 163

Semnan University

Mechanics of Advanced Composite Structures

journal homepage: http://MACS.journals.semnan.ac.ir

Improving the Performance of Porous Concrete Composites Using Zeolite as a Coarse Grain

M. Doostmohamadi, H. Karami *, S. Farzin, S.F. Mousavi

Faculty of Civil Engineering, Semnan University, Semnan, Iran

PAPER INFO

Paper history:
Received 2017-12-11
Received in revised form 2018-01-21
Accepted 2018-02-08

Keywords:
Porous concrete
Additive
Zeolite
Physical properties
Groundwater recharge

ABSTRACT

Porous concrete is a mixture of cement and water that may contain fine grains, which play a role in water transfer and permeability. Porous concrete can act as a drain to pass rainwater and recharge groundwater. In this study, 25%, 50%, 75%, and 100% zeolite were used to replace the coarse aggregates in porous concrete. The effects of the zeolite on the compressive strength, permeability coefficient, porosity, and density of the concrete were investigated. The results showed that the zeolite reduced the compressive strength of the concrete samples because of its porous nature. The permeability coefficient and porosity increased with the addition of zeolite. The highest (10.29 MPa) and lowest compressive strength (6.79 MPa) were observed in the 25% and 100% zeolite samples, respectively. The highest porosity (30.97%) and permeability coefficient (1.76 mm/s) were measured in the 100% zeolite sample. For the 25%, 50%, 75%, and 100% zeolite samples, the permeability coefficient increased by 6.99%, 17.39%, 21.3%, and 24.4%, respectively; the density decreased by 7.77%, 10, 15%, and 19.44%, respectively, with respect to the control sample.

1. Introduction

Porous concrete is a special type of concrete that has many economic and environmental benefits. Typically, porous concrete contains no fine aggregates. To form the porous structure in this type of concrete, coarse aggregates are bonded together with cement mortar.

Porous concrete pavement is one of the most rigid pavements because of its unique high permeability due to its porosity. This kind of pavement transfers surface runoff to groundwater aquifers. Reducing surface runoff decreases the risk of flooding and lowers the need for runoff and flood control facilities [1, 2].

Porous concrete also reduces the amount of noise created by vehicles. Because porous concrete pavement reduces the amount of light that is reflected at night, it improves the safety and comfort of drivers [3]. Porous concrete technology has been used in some industrialized countries. Fig. 1 shows porous concrete pavement [4].

Gaedicke et al. [5] found that increasing the porosity of porous concrete decreased its compressive strength. They also stated that, in addition to porosity, the amount of fine aggregates, additives, and density of the pavement affect its compressive strength.

Zaetang et al. [6] used lightweight aggregates to make porous concrete. Their results showed that the density and thermal conductivity of the concrete decreased by 3–4 times relative to the porous concrete containing natural aggregates. Ćosić et al. [7] investigated the effect of aggregate granulation on five types of porous concrete. They found that the compressive strength increased by 20 MPa when fine grains were used in the mix. Joshaghani et al. [8] used the Taguchi method to optimize the mixture design of porous

* Corresponding author. Tel.: +98-9124803350
E-mail address: hkarami@semnan.ac.ir
DOI: 10.22075/MACS.2018.13363.1131

concrete. The results of the study showed that the resistance of the porous concrete sample depended on the porosity of the concrete; the researchers also found that compressive and flexural strengths were inversely related to permeability.

Li et al. [9] evaluated the performance of porous concrete pavement and found that it was difficult to use it extensively because of its low resistance. They made a high-resistance porous concrete and found that its 7-day compressive strength and permeability coefficient was 61.37 MPa and 13.02 mm/s, respectively. The results indicated that this type of porous concrete had optimal performance for a variety of uses.

Natural zeolite is a volcanic material with a three-dimensional structure. It is a natural porous aggregate with a high adsorption capacity. In Iran, zeolite is relatively inexpensive and easily available, which makes it ideal for use in concrete [10]. Ahmadi et al. [10] reviewed the effect of using natural zeolite to improve the mechanical properties and durability of concrete compared with other pozzolanic additives. Najimi et al. [11] determined that concrete containing 15% natural zeolite had improved compressive strength. Valipour et al. [12] observed a decrease in the compressive strength of the concrete as the amount of zeolite was increased (10–30% of the mass of Portland cement). Ghourchian et al. [13] investigated the effect of zeolite aggregates on the internal curing of concrete. Vejmelkova et al. [14] studied the properties of con-crete covering natural zeolite as complementary ce-mentitious material in the blended Portland-cement based binder up to 60% by mass. Nagrockienė et al. [15] investigated the effect of mineral additives on the properties of concrete. According to the results of the study, the freeze–thaw resistance of samples containing natural zeolite increased 3.32 times. Samimi et al. [16] examined the effect of pumice and zeolite on compressive strength when used in self-compacting concrete. The results showed that the substitution of 15% pumice or 10% zeolite in Portland cement is economical in all aspects.

Previous studies have shown that porous concrete has a high potential for use in pavements because it reduces urban runoff. It also reduces the costs of urban runoff control facilities. Using mineral additives, which are abundant and cost-effective, can improve some of the properties of concrete. The type, quality, and quantity of mineral additives greatly affect the properties of porous concrete. Previous research has not investigated zeolite as a coarse-grained alternative for improving the performance of porous concrete. Therefore, the purpose of this study was to evaluate the effect of substituting a zeolite additive for concrete aggregates on the compressive strength, porosity, permeability, and density of the porous concrete.

2. Materials and Methods

2.1. Aggregates and Zeolite

The aggregates used in the experiments are shown in Fig. 2; they were supplied by a mine in Semnan, Iran.

The grading method proposed by the American Concrete Institute (ACI) was used to make the porous concrete [17]. Type 5 Portland cement supplied from a cement factory in Tehran, Iran was used in the experiment; its chemical characteristics are given in Table 1. Fig. 3 shows the zeolite that was used as the additive. This additive was bought from a mine in Semnan, Iran. Some of the chemical characteristics of the zeolite are presented in Table 2. The sizes of the aggregates and zeolite additive ranged from 4.75 mm to 9.5 mm.

Figure 1. Porous concrete pavement [4]

Figure 2. Aggregates used in the experiment

2.2. Zeolite Treatments

According to the ACI standard [17], the amount of aggregates and cement used in this study were 1,330 kg/m^3 and 340 kg/m^3, respectively; the water to cement ratio was constant and equal to 0.38. Table 3 shows the percentage of zeolite used in the porous concrete samples.

2.3. Making the Porous Concrete Samples

The samples of porous concrete were made at the Concrete Technology Laboratory of Semnan University in Iran. Cubic samples that were 100 mm × 100 mm × 100 mm were used to measure the porosity and permeability, while 150 mm × 150 mm × 150 mm cubic samples were used for the compressive strength tests.

Figure 3. Zeolite additive used in the experiment

Table 1. Chemical composition of type 5 Portland cement (data provided by the factory)

Composition	Weight (%)
Si_2O_2	20.68
Al_2O_3	4.48
Fe_2O_3	4.62
MgO	3.11
SO_3	1.91
K_2O	0.66

Table 2. Some chemical composition of zeolite (data provided by the seller)

Composition	Weight (%)
SiO_2	65.15
Al_2O_3	11.83
Fe_2O_3	1.2
MgO	0.64
P_2O_5	0.27
LOI	12.81

Table 3. Designed treatments for porous concrete samples

Treatment	Code	Additive content (% w)
Control	C	0
25% zeolite	Z-25	25
50% zeolite	Z-50	50
75% zeolite	Z-75	75
100% zeolite	Z-100	100

To easily separate the hardened concrete from the molds, the inner surfaces of the molds were lubricated with oil. The materials used in the concrete were weighed according to the mix design. After thorough mixing in a concrete mixer machine, the concrete was poured into the molds and compacted in 3 layers with a standard percussion hammer using 25 strokes per layer. The mold surface was smoothed using a trowel. After 24 hours, the samples were removed from the molds and transferred to a water pond for curing. Because type 5 Portland cement was used, the curing time of the samples was 42 days.

2.4. Compressive Strength Tests

Compressive strength is considered to be one of the most important properties of concrete. It plays an important role in the quality control of concrete. One may notice that modifying the preparation of concrete can affect its compressive strength. According to the British Standard [18], 150 mm × 150 mm × 150 mm samples should be used for testing compressive strength.

After being cured for 42 days in the water, the samples were exposed to fresh air for 24 hours to dry. A load jack, shown in Fig. 4, was used to measure the compressive strength. This device was connected to a computer to determine the compressive strength of the cubic and cylindrical concrete samples in accordance with international and national standards.

2.5. Permeability Tests

To measure the permeability (hydraulic conductivity) of the porous concrete samples, a falling head device made of plexiglass was built at the Concrete Technology Laboratory of Semnan University. Each porous concrete sample was placed in a cylinder in which water entered from the top surface and exited from the opposite side. Foam and glue were used to seal the four sides of the cubic samples.

The permeability coefficient was calculated using Equation (1), which is based on Darcy's law and the laminar flow assumption. The average test result for 3 100 mm × 100 mm × 100 mm cubic samples was reported as the permeability coefficient of each treatment.

$$K = \frac{aL}{At}\ln(\frac{h1}{h2}) \quad (1)$$

where K is the permeability coefficient (mm/s), a is the cross-section area of the plexiglass cylinder (mm^2), A is the cross-section area of the sample (mm^2), t is the time of water-head drop from h_1 to h_2 (s), h_1 is the initial height of the water column (mm), and h_2 is the final height of the water column (mm).

2.6. Porosity Test

The ASTM standard [19] was used to measure the porosity of the porous concrete samples. First, the samples were placed in an oven at 105°C for 24 hours. Then the samples were weighed (W_2). To obtain the immersion weight (W_1), an Archimedes scale was used. Finally, the porosity of the samples was calculated using Equation (2):

$$A_t = (1 - \frac{W_2 - W_1}{\rho_w V}) \times 100 \quad (2)$$

where A_t is the total porosity (%), W_2 is the dry sample weight (g), W_1 is the immersion weight of the sample (g), V is the sample volume (cm^3), and ρ_w is the density of water (g/cm^3).

2.7. Density of the Samples

The density of each porous concrete sample was calculated by dividing its weight by its volume.

2.8. Statistical analysis

In this study, SAS 9.4 software was used for the statistical analysis. The statistical design of the experiment was a completely randomized block design. The means were compared using the least significant difference (LSD) test at a 5% probability level.

3. Results and Discussion

The results of the analysis of variance for compressive strength, permeability coefficient, porosity, and density are shown in Tables 4, 5, 6, and 7, respectively.

Figure 4. Load jack used to measure compressive strength

Table 4. Results of the analysis of variance of compressive strength

Source of change	Degree of freedom	Sum of squares	Mean squares	F value	P	Coefficient of variation	R^2
Sample	4	257.1927	64.2981	202.54	< 0.0001	-	-
Block	2	0.2529	0.1264	0.40	0.6840	-	-
Error	8	2.5396	0.3174	-	-	5.2631	0.9902
Total	14	259.9853	-	-	-	-	-

Table 5. Results of the analysis of variance of the permeability coefficient

Source of change	Degree of freedom	Sum of squares	Mean squares	F value	P	Coefficient of variation	R^2
Sample	4	0.3930	0.0982	77.85	< 0.0001	-	-
Block	2	0.0204	0.0102	8.11	0.0119	-	-
Error	8	0.0100	0.0012	-	-	2.2709	0.9761
Total	14	0.4236	-	-	-	-	-

Table 6. Results of the analysis of variance of porosity

Source of change	Degree of freedom	Sum of squares	Mean squares	F value	P	Coefficient of variation	R^2
Sample	4	225.3987	56.3896	24.91	< 0.0001	-	-
Block	2	10.1010	5.0505	2.23	0.1696	-	-
Error	8	18.0962	2.2620	-	-	5.4936	0.9286
Total	14	253.5960	-	-	-	-	-

Table 7. Results of the analysis of variance of density

Source of change	Degree of freedom	Sum of squares	Mean squares	F value	P	Coefficient of variation	R^2
Sample	4	0.2095	0.0523	138.48	< 0.0001	-	-
Block	2	0.0001	0.00008	0.23	0.8003	-	-
Error	8	0.0030	0.0003	-	-	1.2071	0.9857
Total	14	0.2127	-	-	-	-	-

The F value for the samples and the block was significant at the 1% level, which showed that there was a significant difference between the treatments. The coefficient of determination for all four parameters was greater than 0.92.

In Table 8, the average values of compressive strength, permeability coefficient, porosity, and density for the different zeolite treatments are compared using the LSD method at the 5% probability level. According to this table, there was no significant difference between the mean compressive strength of the Z-25 and Z-50 samples. However, the average compressive strengths of the other samples were significantly different from each other and the control sample. In general, due to the low specific gravity and the high porosity of zeolite, the compressive strength of the samples decreased with the replacement of aggregates by zeolite. According to Table 8, the difference between the average permeability coefficients of the treatments was significant, and the Z-100 treatment had the highest permeability coefficient (1.763 mm/s).

Table 8 also shows that the average porosity of the samples containing zeolite was significantly different from the control sample. However, there was no significant difference between the zeolite treatments. As the percentage of zeolite increased in the samples, no significant change was observed in the porosity.

Table 8 shows that the average density of the samples containing different percentages of zeolite were significantly different from each other and the control sample. As the zeolite percentage increased in the samples, the density decreased; the Z-100 sample had the lowest density (1.45 g/cm^3).

Fig. 5 shows the relationship of the compressive strength of the porous concrete samples with/without zeolite and porosity. As the percentage of zeolite increased, the porosity of the samples increased, while the compressive strength decreased. The control sample had the highest compressive strength (18.54 MPa) and the lowest porosity (19.84%).

By replacing the aggregates in the porous concrete with 25% zeolite, the compressive strength decreased by 44.49% and the porosity increased by 29.84%. The reasons for these changes are associated with the structure and high porosity of the zeolite. Ćosić et al. [7] investigated how the use of different types of aggregates affected the porosity of concrete samples.

The compressive strength and porosity of the Z-50 treatment were relatively similar to that of the Z-25 sample. When more than 50% zeolite was used in the porous concrete samples, such as in the Z-75 and Z-100 treatments, there was a decrease in average compressive strength: 7.77 MPa and 6.79 MPa, respectively. The equation depicted in Fig. 5 could be used to estimate the compressive strength of porous concrete samples with varying percentages of zeolite and porosity.

Fig. 6 lists the permeability coefficient and the porosity of the porous concrete samples. As the percentage of zeolite increased, the permeability coefficient and the porosity increased compared with the control sample. The control sample had the permeability coefficient of 1.33 mm/s.

Table 8. Comparison of the average physical parameters in the different zeolite treatments

Treatment	Average compressive strength (MPa)	Average permeability coefficient (mm/s)	Average porosity (%)	Average density (g/cm^3)
C	18.53^a	1.333^e	19.84^b	1.80^a
Z-25	10.29^b	1.424^d	28.27^a	1.65^b
Z-50	10.13^b	1.607^c	28.80^a	1.62^c
Z-75	7.77^c	1.693^b	28.99^a	1.52^d
Z-100	6.793^c	1.763^a	30.97^a	1.45^e

In each column, values with at least one common letter are not significantly different at the 5% level.

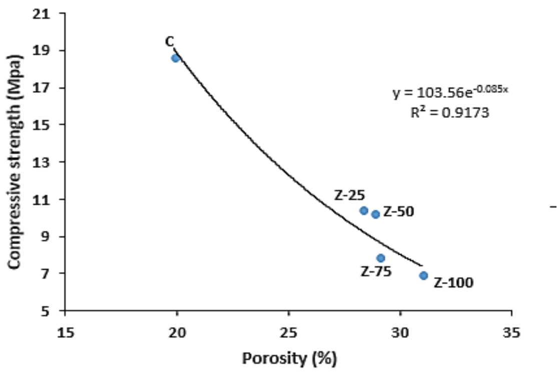

Figure 5. Relationship between compressive strength and porosity of various concrete samples

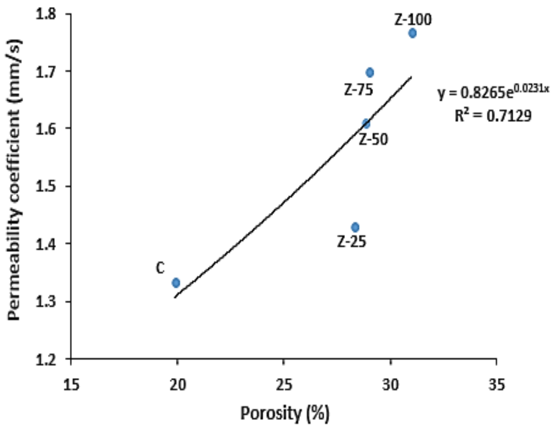

Figure 6. Relationship between permeability coefficient and porosity of various concrete samples

Fig. 7 shows the density and porosity of the porous concrete samples. According to the figure, increasing the percentage of zeolite increased the porosity and decreased the density. The reduction for the Z-25, Z-50, Z-75, and Z-100 treatments was 7.77%, 10%, 15%, and 19.44%, respectively. The density of the porous concrete samples with different percentages of zeolite could be estimated by the equation given in Fig. 7.

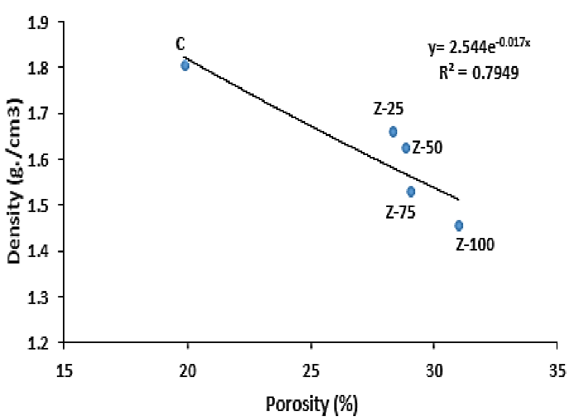

Figure 7. Relationship between density and porosity of various concrete samples

For the 25% zeolite treatment, the porosity and permeability coefficient increased by 29.84% and 6.99%, respectively. The permeability coefficient of the Z-50, Z-75, and Z-100 treatments increased by 17.39%, 21.3%, and 24.43%, respectively. The Z-100 sample had the highest porosity (30.97%) and permeability (1.76 mm/s). The coefficient of permeability could be estimated from the equation shown in Fig. 6.

4. Conclusion

This study investigated the effect of replacing coarse aggregates with 25%, 50%, 75%, and 100% zeolite on some of the physical properties of porous concrete. Porosity and permeability are important and effective parameters that affect the performance of porous concrete; thus, replacing the aggregates in porous concrete with zeolite increased and improved these parameters. The results are summarized as follows.

1- By replacing the aggregates in porous concrete with zeolite, the compressive strength of the samples was reduced due to the high porosity of the zeolite. The highest compressive strength (10.29 MPa) was observed in the sample containing 25% zeolite (Z-25). The lowest compressive strength (6.79 MPa) was observed in the 100% zeolite sample (Z-100).

2- The permeability coefficient of the samples increased in the samples containing 25%, 50%, 75%, and 100% zeolite by 6.99%, 17.39%, 21.3%, and 24.43%, respectively.

3- The average porosity of the samples containing zeolite was greater than the control sample. The increase was 29.84%, 31.11%, 31.58%, and 35.93%for the Z-25, Z-50, Z-75, and Z-100 treatments, respectively.

4- The density of the samples containing 25%, 50%, 75%, and 100% zeolite decreased by 7.77%, 10%, 15%, and 19.44%, respectively, as compared with the control sample.

5- Porous concrete samples containing zeolite could be used in areas with low traffic loads, such as parking lots, sidewalks, greenhouses, and airport runways.

6- Because porous concrete samples containing zeolite have a high porosity, this type of concrete is suitable for reducing the volume of urban runoff and directing it to recharge the groundwater.

References

[1] ACI Committee 522R-10. Pervious concrete. American Concrete Institute. 2010.

[2] Henderson, V. Evaluation of the performance of pervious concrete pavement in the Canadian climate. PhD Thesis, University of Waterloo, Ontario, Canada 2012.

[3] Yang, J and Jiang, G. Experimental study on properties of pervious concrete pavement materials. Cement and Concrete Research 2003; 33(3): 381-386.

[4] https://challenge.abettercity.org/toolkits/climate-resilience-toolkits/flooding-and-sea-level-rise/paving-and-asphalt?toolkit=229.

[5] Gaedicke C, Marines A, Miankodila F. A method for comparing cores and cast cylinders in virgin and recycled aggregate pervious concrete. Construction and Building Materials 2014; 52: 494-503.

[6] Zaetang Y, Wongsa A, Sata V, Chindaprasirt P. Use of lightweight aggregates in pervious concrete. Construction and Building Materials 2013; 48: 585-591

[7] Ćosić K, Korat L, Ducman V, Netinger I. Influence of aggregate type and size on properties of pervious concrete. Construction and Building Materials 2015; 78: 69-76.

[8] Joshaghani A, Ramezanianpour A. A, Ataei O, Golroo A. Optimizing pervious concrete pavement mixture design by using the Taguchi method. Construction and Building Materials 2015; 101: 317-325.

[9] Li J, Zhang Y, Liu G, Peng X. Preparation and performance evaluation of an innovative pervious concrete pavement. Construction and Building Materials 2017; 138: 479-485.

[10] Ahmadi B, Shekarchi M. Use of natural zeolite as a supplementary cementitious material. Cement and Concrete Composites 2010; 32(2):134–141.

[11] Najimi M, Sobhani J, Ahmadi B, Shekarchi M. An experimental study on durability properties of concrete containing zeolite as a highly reactive natural pozzolan. Construction and Building Materials 2012; 35: 1023-1033.

[12] Valipour M, Pargar F, Shekarchi M, Khani S. Comparing a natural pozzolan, zeolite, to metakaolin and silica fume in terms of their effect on the durability characteristics of concrete: A laboratory study. Construction and Building Materials 2013; 41: 879–888.

[13] Ghourchian S, Wyrzykowski M, Lura P, Shekarchi M, Ahmadi B. An investigation on the use of zeolite aggregates for internal curing of concrete. Construction and Building Materials 2013; 40: 135-144.

[14] Vejmelková E, Koňáková D, Kulovaná T, Keppert M, Žumár J, Rovnaníková P, Černý R. Engineering properties of concrete containing natural zeolite as supplementary cementitious material: Strength, toughness, durability, and hygrothermal perfomance. Cement and Concrete Composites 2015; 55: 259-267.

[15] Nagrockienė D, Girskas G, Skripkiūnas G. Properties of concrete modified with mineral additives. Construction and Building Materials 2017; 135: 37-42.

[16] Samimi K, Kamali-Bernard S, Maghsoudi A. A, Maghsoudi M, Siad H. Influence of pumice and zeolite on compressive strength, transport properties and resistance to chloride penetration of high strength self-compacting concretes. Construction and Building Materials 2017; 151: 292-311.

[17] ACI Committee 211. Guide for Selecting Proportions for No-slump Concrete. ACI 211.3R Report. 2006.

[18] British Standard, Testing Concrete, Method for Making Test Cubes from Fresh Concrete. BS 1881, 1983; Part 108.

[19] ASTM C1754/C1754M-12. Standard Test Method for Density and Void Content of Hardened Pervious Concrete. ASTM International, USA 2012.