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Reducing Urban Runoff Pollution Using Porous Concrete Containing Mineral Adsorbents

Ehsan Teymouri[1*], Sayed-Farhad Mousavi[2], Hojat Karami[3], Saeed Farzin[3] and Maryam Hosseini Kheirabad[4]

[1]Graduated MSc. Faculty of Civil Engineering, Semnan University, Semnan, Iran
[2]Professor, Faculty of Civil Engineering, Semnan University, Semnan, Iran
[3]Assistant Professor, Faculty of Civil Engineering, Semnan University, Semnan, Iran
[4]MSc. Student, Faculty of Civil Engineering, Payame noor University, P.O. Box: 19395-3697, Tehran, Iran

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Abstract

Porous concrete has been used in sidewalks and surface pavements since the last decade for management of urban runoffs. Porous concrete is considered valuable for its hydraulic conductivity, adsorption capacity for pollutants, reduction of turbidity and contaminants, especially heavy metals. The present research examines the effect of adding minerals such as zeolite (Z), perlite (Pe), pumice (Pu) and LECA (L), which are able to adsorb pollutants, at different percentages (0, 5,10 and 15%) and fine-grains (0, 10 and 20%) to porous concrete blocks to evaluate its mechanical characteristics such as compressive strength, permeability and porosity and the ability to improve runoff quality (EC, TDS, NaCl, COD, BOD and turbidity). Results showed that adding fine-grains improved runoff quality and enhanced compressive strength, but led to lower permeability and porosity. All adsorbents enhanced the quality of runoff and the increase was prominent at higher percentages of additives. Porous concrete had little effect on reducing EC, TDS and NaCl contents. The best results belonged to samples containing zeolite and LECA. The L15-0, Z15-10 and L15-20 treatments (containing 0, 10 and 20% fine-grains and 15% adsorbent) had the highest pollution reduction and improved the TSS (75.8, 79.1 and 84.6%), COD (87.1, 82.6 and 89.3%) and BOD (88.1, 87.3 and 90.7%).

Keywords: Porous Concrete; Zeolite; Perlite; Pumice; LECA; Mechanical characteristics; Runoff quality

1 Introduction

Nowadays, achieving new water resources is of great importance for the increasing population, water pollution problems and rising living standards. Urban runoffs can be fitted as an important source of fresh water in developing countries which do not use water optimally and has too many water-related problems [1]. In addition, runoffs on urban streets, roads and parking lots, cause organic and non-organic substances such as oils, salts, dirt and chemicals to be washed away. This can be considered as a runoff pollution problem [2].

Considering the necessity of using runoffs for recharging groundwater and maintaining the environmental balance, the use of light-weight porous pavements in urban areas is of particular importance in different countries. This method can also be effective in improving the water quality, by removing some of the runoff contaminants, which influences the underlying soil layers. Porous concrete (Fig. 1) refers to a mixture of Portland cement, coarse-grained particles, with/without fine-grains, additives and water, with zero slump and open granularity. Porous concrete structure includes interconnected pores, because of little amount of fine particles, which allow quick passage of water. The porosity of this concrete is from 11 to 35 percent, its permeability coefficient is between 1.4 and 12.3 mm/s, and its compressive strength is variable ranging from 3.5 to 28 MPa [3, 4, 5]. Kevern et al. reported that aggregates with high level of adsorption or low specific gravity produced a pervious concrete with low freeze–thaw permanence. In this study, permeability of pervious concrete has been partially decreased by addition of sand. In contrast to round aggregates, angular aggregates were found to produce more actual porosities compared to the intended design porosities [6]. Ćosić et al. studied the influence of aggregate type and size on the properties of porous concrete in five different concrete mixtures which the aggregates were dolomite or steel slag and their diameter was in the range of 4-8 mm to 8-16 mm. Results showed that porosity is the main parameter for estimating porous concrete efficiency which was affected more by the aggregate type than the size [7]. According to the Federal Highway Administration, recycled concrete aggregates (RCA) is mainly used for road base. Currently, only 11 states allow the use of RCA as an aggregate for their

Corresponding author: Ehsan Teymouri, Graduated MSc. Faculty of Civil Engineering, Semnan University, Semnan, Iran. E-mail: teymuri.e91@gmail.com, Cellphone: (+98) 9156906585.

new concrete projects [8]. Yap et al. showed that using recycled coarse aggregates (RCA) decreased compressive strength of the porous concrete [9].

Figure 1: Blocks of porous concrete

It is important to use filters to improve water quality by replacing appropriate materials that can reduce water pollution. Some minerals such as zeolite, fly ash, iron slag, perlite, LECA, pumice, vermiculite, silica and quartz have been used in previous studies to reduce contamination in addition to the cost-effective adsorption of contaminants [10, 11, 12, 13]. Using these mineral adsorbents in porous concrete, that is applicable to urban roads, is important because in addition to preventing the urban storm-runoff, they can have positive effects on the improvement of runoff quality.

Tsai et al. used silica to eliminate color from aqueous solution [14]. Al-Anber found that bentonite and quartz could remove Fe(II) from wastewater [15]. Körlü et al. used waste pumice stones to reduce the BOD and COD concentration [16]. Verbinnen et al. indicated that perlite-supported magnetite is suitable for treating real wastewaters by eliminating several oxyanions simultaneously from the considered industrial wastewater [17].

Zhang et al. showed that porous concrete containing pumice was able to reduce COD and BOD up to 60% [18]. Abedi Kupai et al. succeeded in reducing COD, turbidity, TSS and lead (Pb) concentration by adding iron slag to porous concrete and using sand filter. Contaminants concentrations were measured before and after passing the samples through the filter. Results showed that COD, turbidity, lead (2 mg/l), lead (5 mg/l) and TSS were decreased by 11, 38, 44, 42 and 53% and for samples containing iron slag these parameters were decreased by 43, 91, 91, 95 and 70%, respectively [19].

Ong et al. used fly-ash, iron-slag, and limestone powder in porous concrete to improve urban runoff quality [20]. Shabalala et al. eliminated some of the heavy metals from aqueous solution using porous concrete containing fly-ash [21]. Azad et al. by using vermiculite and quartz in porous concrete, managed to reduce TSS, COD and turbidity. Results showed that by adding 30% adsorbents to porous concrete, the quality parameters such as TSS, COD and turbidity were reduced by 45, 14 and 54% for control samples, 85, 43 and 76% for samples containing vermiculite and 78, 45 and 84% for samples containing quartz, respectively [22].

Using porous concrete in large cities and developed countries is a proper method to reduce runoff and prevent urban stormwater events. Adding inexpensive minerals to porous concrete that has a low specific weight and the ability to adsorb contamination, can reduce the volume and improve the quality of runoff. In the present study, in addition to adding 0, 10 and 20% fine-grains, different percentages of mineral adsorbents such as zeolite, perlite, pumice and LECA were added to the mixing design. Mechanical characteristics of porous concrete such as compressive strength, permeability coefficient and porosity, which are important factors in the urban roads, were investigated. Using the results of mechanical characteristics for each percentage of fine grains, 3 samples that had better performance in terms of compressive strength were selected for quality tests. The COD, BOD, TSS, EC parameters, percentage of NaCl and turbidity of selected samples were calculated.

2 Material and Methods

1.2 Concrete and mixing design

To prepare the mixing design for porous concrete, ACI 211.3R standard was used to determine the mixing ratios of zero-slump concrete [23]. The aggregate and cement values were selected to be 1400 and 330 kg/m3, respectively. In order to increase the strength of concrete against sulfate environments, type 5 cement was used. The water to cement ratio was fixed to 0.38 for all samples. Four different percentages of the zeolite, perlite, pumice and LECA adsorbents (0, 5, 10 and 15% w/w), with 0.6 to 1.2 mm average diameter, and three different percentages of fine-grains (0, 10, 20) (0, 140 and 280 kg/m3, respectively) with size of 2.36 to 4.75 mm, were tested. Figure 2 shows the four adsorbents. Figure 3 presents granulometric curves of the aggregates and additives. For each sample, three replicates were considered to ensure the desired accuracy. The adsorbents were saturated before mixing. Chemical characteristics of the adsorbents are shown in Table 1. Each mixing design was encoded using type of adsorbent in it. Letter C is used for control sample, and letters Z, Pe, Pu and L are used for samples containing Zeolite, Perlite, Pumice and LECA, respectively. The percentage of adsorbents and fine-grains is mentioned after the sample's letter. The first number after the letter is percentage of the adsorbent and the second number is percentage of the fine grains. For example, Z15-10 is porous concrete sample containing 15% zeolite and 10% fine-grains.

1.2 Porosity test

Porosity was measured in cubic samples (10×10×10 cm) using the ASTM C1754 standard [24]. Samples were placed in a 105 °C oven for 24 hours. Then, the samples were weighed to get their dry weight. Then, they were immersed in water and their buoyant weight was measured by an Archimedes scale. Porosity of each sample was calculated by the following equation:

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

where, A_t is porosity (%), V is sample volume (cm^3), ρ_w is density of water (g/cm^3), W2 is sample dry weight (gr) and W1 is sample weight in water (gr).

Figure 2: Applied additives in porous concrete mixture designs

2.3 Permeability test

To conduct permeability tests, a falling-head type apparatus, 10.1×10.1×80 cm, made of plexiglass (Figure 4), was designed in the Structure Laboratory of Semnan University. The system consists of a 20 cm layer of coarse gravel on the bottom, the porous-concrete sample (sealed tightly to the walls), and 50 cm of water head on the top of the sample. Permeability (hydraulic conductivity) of each sample is calculated by using Eq. (2), which is based on Darcy's Law and similar device has been mentioned in AC 522R standard [25]:

$$K = \frac{aL}{At} \ln(\frac{h_1}{h_2}) \tag{2}$$

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

2.4 Compression strength test

Compressive strength tests were carried out according to the BS 1881 standard [26], on the 15×15×15 cm porous concrete samples which have been cured for 42 days prior to the compressive strength test.

2.5 Runoff-quality tests

To perform the runoff quality tests, some specimens were selected based on higher compressive strength, which is a key factor of pavement's design in urban areas. According to Table 2, for each percentage of fine-grains, three samples that had the highest compressive strength were chosen.

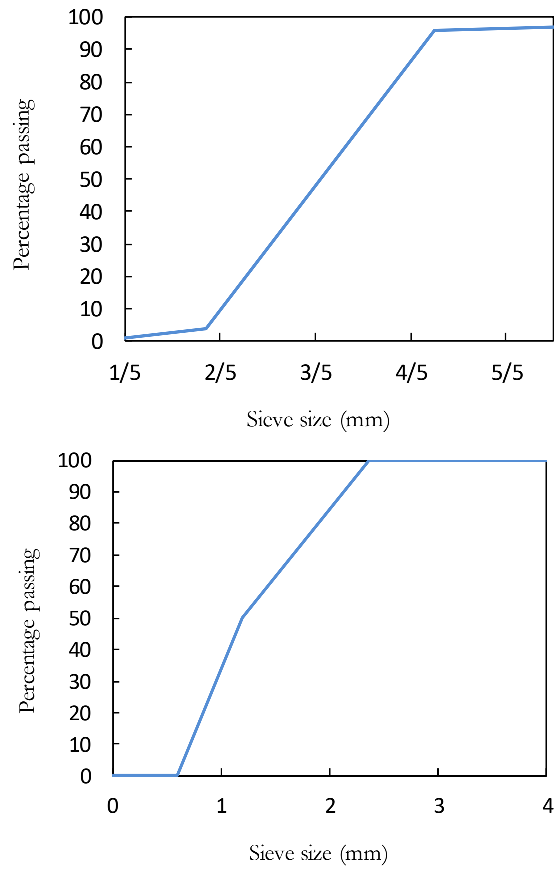

Figure 3: Granulometric curves of the aggregates (above) and additives (below) used in the mixing designs

Table 1: Chemical analysis of Zeolite, Perlite, Pumice, LECA and coarse aggregates

Chemical Feature	Zeolite (%)	Perlite (%)	Pumice (%)	LECA (%)	Coarse aggregates (%)
SiO2	65.15	69.5	48.37	66.05	38.2
Al2O3	11.83	12.8	12.49	16.75	15.4
Fe2O3	1.2	0.94	8.07	7.1	13.6
CaO	2.51	0.8	8.43	2.46	4.3
MgO	0.64	0.5	9.58	1.99	18.2
Na2O	1.96	3.0	4.36	0.69	*
K2O	*	*	*	*	7.0
P2O5	0.27	*	1.79	0.21	*
LOI	12.81	5.1	0.6	20.81	6.8

* Zero or less than 0.1%

Figure 4: The apparatus for measuring permeability coefficient of porous concrete samples

The runoff quality tests were carried out using permeability test apparatus. At the end of the apparatus, a metal net was placed to prevent the obstruction of the drainage valve at the bottom. Due to the fact that there is a sand filter underneath the pavement layer, at the bottom of the apparatus, a 20 cm sand filter was placed. Then, two 10×10×10 cm porous concrete specimens were placed on each other and sealed with foam that was applied on the four sides. The specimens were placed on a sand filter and their sides were sealed with paste in order to prevent runoff passing from the edges. After preparing the samples, the drainage valve was closed at the end and filled with runoff on the samples. For each test, about 8 liters of runoff was used. It took about 30 minutes that runoff was in contact with porous concrete samples. Quality tests for samples were performed with 3 replications. Specifications of the runoff are shown in Table 3. Figure 5 represents the scheme of test conditions.

3 Discussion

3.1 Porosity, Permeability and Compressive Strength

The difference of compressive strength, permeability and porosity with the control sample is shown in Table 4. Results of mechanical characteristics of the porous concrete specimens were analyzed statistically using SAS9.4. Results of LSD test (α=5%) to compare different percentages of fine-grains and mineral adsorbents in all treatments are shown in Table 5.

Table 2: Selected treatments for quality tests

Fine grains (%)	Treatment
0	Z5-0 L15-0 Pu15-0
10	Z-15-10 Pe10-10 Pu10-10
20	Z10-20 L5-20 L15-20

Table 3: Concentration of quality parameters in the runoff

Runoff quality parameter	EC (μS/cm)	TDS (mg/l)	TSS (mg/l)	NaCl (%)	COD (mg/l)	BOD (mg/l)	Turbidity (NTU)
Control mixture	2231	1121	182	4.3	542	236	278

Figure 5: Scheme of test conditions for performing quality tests

According to Tables 4 and 5 for all samples regardless of their type and percentage of additives, adding fine grains to porous blocks decreased porosity and coefficient of permeability, and increased the compression strength. These results are similar to what Jiang et al. found in their research. Treatments with no-fine-grain have shown no special compressive strength variation trend [27]. Due to filling of the pores by the additives, in all samples with 10 and 20 percent fine-grains, the compressive strength was increased by raising the percentage of additives.

Table 4: Designations for mixing the additives and fine grains with porous concrete

Treatment code	Average compressive strength difference (%)	Average permeability difference (%)	Average porosity difference
Pe5-0*	-5.64*	-3.56	-2.14
Pe10-0	0.17	-9.03	-10.73
Pe15-0	-4.5	-6.59	-15.79
Pu5-0	7.29	-3.95	4.94
Pu10-0	5.74	-1.31	-9.06
Pu15-0	1.84	-5.93	-5.15
L5-0	-2.96	-1.97	9.26
L10-0	14.39	-3.95	-16.5
L15-0	-4.84	-7.71	-4.96
Z5-0	19.89	-5.93	-9.63
Z10-0	1.08	-1.12	1.73
Z15-0	2.87	-3.09	-14.21
Pe5-10	2.3	-4.29	-17.92
Pe10-10	-4.22	-17.46	-41.21
Pe15-10	8.28	-19.82	-69.28
Pu5-10	-2.19	-4.08	-16.21
Pu10-10	4.93	-11.02	-35.20
Pu15-10	7.6	-14.1	-52.94
L5-10	-4.73	-1.93	-23.7
L10-10	6.29	-17.46	-45.69
L15-10	10.2	-20.75	-52.29
Z5-10	2.51	-6.23	-25.64
Z10-10	15.09	-8.87	-41.15
Z15-10	21.3	-20.54	-46.1
Pe5-20	-3.05	-24.17	-22.64
Pe10-20	1.82	-26.46	-30.41
Pe15-20	7.07	-30.09	-47.26
Pu5-20	-11.19	-11.49	10.21
Pu10-20	0.71	-15.21	-3.61
Pu15-20	1.88	-15.72	-33.04
L5-20	-11.09	-13.52	0.54
L10-20	2.32	-14.87	-28.87
L15-20	11.82	-19.1	-52.18
Z5-20	5.38	-20.37	-14.66
Z10-20	12.6	-24.17	-31.07
Z15-20	20.01	-30.86	-42.45

* The first number after the letter is percentage of the additive and the second number is percentage of fine grains.
C = control, Pe = perlite, Pu = pumice, L = LECA, Z = zeolite

Porous concrete samples containing zeolite and perlite had the highest and lowest compressive strength, respectively, which is justifiable due to their specific weight. Moreover, no significant difference was seen between majority of samples with various fine-grain percentage for different types and percentage of additives. Because of filling role of the fine additives, the permeability and porosity of all samples were decreased compared with the control sample for each percentage of fine-grains. For instance, a section of porous concrete containing perlite and zeolite with no-fine-grains after compressive strength test is shown in Figure 6. Here, the filling role of fine additives is obvious. In addition, according to Table 6, by increasing the percentage of the additives, the permeability and porosity have decreased for 10 and 20% fine-grains treatments. However, no specific trend was found for no-fine-grains samples. Furthermore, by changing the type and percentage of additives, significant differences were seen between some samples. Porous concrete samples containing pumice and perlite had the highest and lowest permeability which is explained by porous structure of pumice and high-water intake of perlite particles. Also, it should be noted that the porosity and permeability results have similar trends for all porous concrete samples.

Figure 6: Section of porous concrete containing zeolite (above) and perlite (below)

3.2 Improvement of runoff quality

As mentioned before, due to the insignificant differences in permeability and porosity of porous concrete containing adsorbents with the control sample, the criteria to select the samples for performing the quality tests are the compressive strength parameter. A synthetic runoff was made to run the quality tests. This runoff's quality was assessed by measuring such parameters as electrical conductivity (EC), total dissolved solids (TDS), percentage of NaCl, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD) and turbidity, before and after conducting the tests.

3.2.1 EC and TDS

Variations of EC for selected porous concrete samples are shown in Figure 7. As can be seen, increasing fine-grains have no significant impact on reducing EC. Adding the additives led to better effect on reducing EC. In Figure 8, variation of the TDS parameter is observed, which has the same trend as the EC changes. However, no significant changes were found in the removal of EC and TDS.

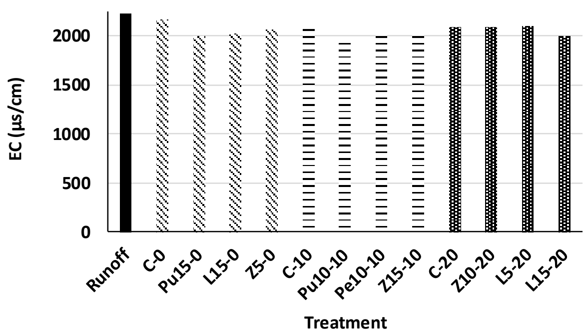

Figure 7: Variation of runoff EC for selected porous concrete samples

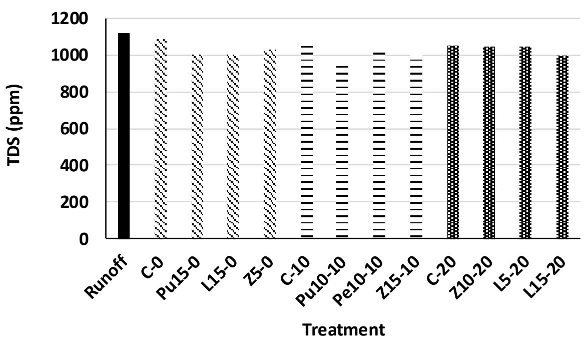

Figure 8: Variation of runoff TDS for selected porous concrete samples

3.2.2 Percentage of NaCl

As shown in Figure 9, the variation of percentage of NaCl is not significant. At best, the amount of NaCl was decreased by 11%.

3.2.3 TSS

TSS is the most important parameter in urban runoff pollution. TSS elimination can lead to reducing total phosphorus, heavy metals, and turbidity from urban runoff. The effect of porous concrete containing adsorbents is very noticeable in reducing the values of TSS parameter. As shown in Figure 10, due to the increase in the percentage of fine-grains in the selected samples, the removal ratio has been increased. For mixing design with no-fine-grains, 10 and 20% fine-grains, L15-0, Z15-10 and L15-20 had the highest reduction rate, and in general, the L15-20 sample had the highest reduction percentage (84.6%). Among the selected samples, the sample containing perlite had the lowest percentage of reduction.

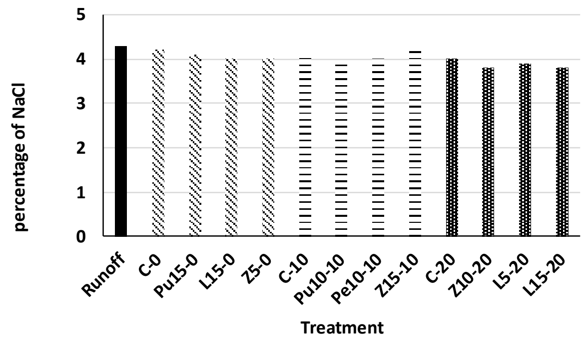

Figure 9: Variation of percentage of NaCl for selected porous concrete samples

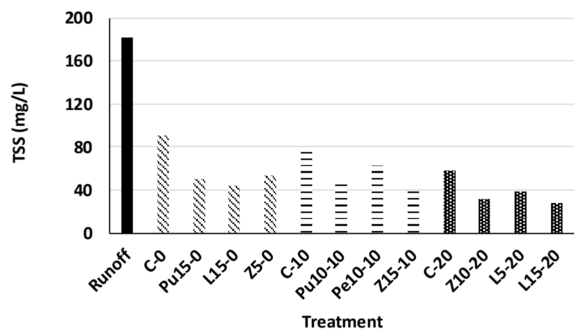

Figure 10: Variation of runoff TSS for selected porous concrete samples

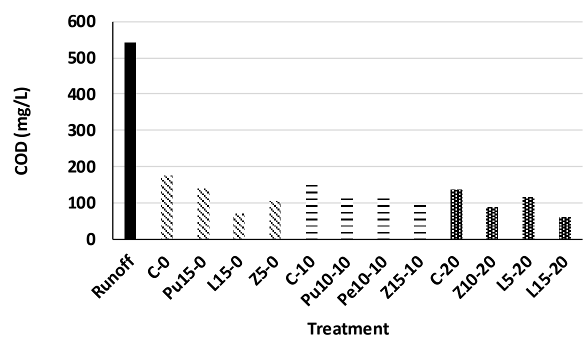

Figure 11: Variation of runoff COD for selected porous concrete samples

3.2.4 COD and BOD

Based on Figures 11 and 12, increasing the percentage of fine-grains was effective in COD and BOD reduction. For mixing designs with no-fine-grains, 10 and 20% fine grains, the highest percentage of reduction of COD and BOD was for samples L15-0, Z15-10 and L15-20, respectively. Utilizing adsorbents had effective role in removal of COD and BOD, and removal percentage was increased by raising the percentage of adsorbents. The major part of the reduction of COD and BOD is due to the removal of TSS.

Table 5: Results of LSD test (α=5%) to compare different percentages of fine-grain and mineral adsorbents

Treatment	Average compressive strength (MPa)	Average permeability (mm/s)	Average porosity (%)	Treatment	Average compressive strength (MPa)	Average permeability (mm/s)	Average porosity (%)	Treatment	Average compressive strength (MPa)	Average permeability (mm/s)	Average porosity (%)
C-0	17.55^{cd}	1.517^{a}	20.96^{bcd}	C-10	23.68^{cde}	1.397^{a}	16.96^{a}	C-20	30.73^{efg}	1.183^{a}	9.14^{a}
Pe5-0	16.56^{d}	1.463^{c}	20.51^{cde}	Pe5-10	24.27^{cde}	1.337^{bc}	13.92^{b}	Pe5-20	29.79^{efg}	0.897^{f}	7.07^{b}
Pe10-0	17.58^{cd}	1.38^{f}	18.71^{efg}	Pe10-10	22.68^{e}	1.153^{g}	9.97^{de}	Pe10-20	31.3^{fg}	0.87^{fg}	6.36^{bc}
Pe15-0	16.76^{d}	1.417^{e}	17.65^{g}	Pe15-10	25.82^{bcd}	1.12^{h}	9.14^{g}	Pe15-20	33.07^{cde}	0.827^{h}	4.82^{cd}
Pu5-0	18.93^{bc}	1.457^{cd}	22.05^{b}	Pu5-10	23.16^{de}	1.34^{bc}	14.21^{b}	Pu5-20	27.29^{g}	1.047^{b}	10.17^{a}
Pu10-0	18.62^{bcd}	1.5^{ab}	19.06^{defg}	Pu10-10	24.91^{be}	1.243^{e}	10.99^{cd}	Pu10-20	30.95^{efg}	1.003^{cd}	8.81^{b}
Pu15-0	17.88^{cd}	1.42^{de}	19.8^{cdef}	Pu15-10	25.63^{be}	1.2^{f}	7.98^{f}	Pu15-20	31.32^{def}	0.977^{de}	6.12^{cd}
L5-0	17.03^{cd}	1.487^{abc}	23.1^{a}	L5-10	22.56^{e}	1.37^{ab}	12.94^{b}	L5-20	27.32^{g}	1.023^{bc}	9.19^{a}
L10-0	20.5^{ab}	1.45^{abc}	17.5^{efg}	L10-10	25.27^{be}	1.153^{g}	9.21^{def}	L10-20	31.46^{bcd}	1.007^{c}	6.51^{d}
L15-0	16.7^{d}	1.4^{ed}	19.92^{bcde}	L15-10	26.37^{bc}	1.107^{h}	8.09^{ef}	L15-20	34.85^{cf}	0.957^{e}	4.37^{d}
Z5-0	21.91^{a}	1.427^{de}	18.9^{defg}	Z5-10	24.29^{cde}	1.31^{d}	12.61^{bc}	Z5-20	32.48^{cde}	0.942^{gh}	8.7^{cd}
Z10-0	17.74^{cd}	1.49^{ab}	21.33^{bc}	Z10-10	27.89^{ab}	1.273^{e}	9.98^{de}	Z10-20	35.16^{bc}	0.897^{h}	6.3^{d}
Z15-0	18.07^{cd}	1.47^{b}	17.98^{fg}	Z15-10	30.09^{a}	1.11^{h}	9.14^{def}	Z15-20	38.42^{a}	0.82^{h}	5.26^{cd}

In each column, values of physical characteristics with at least one common letter are not significantly different by the LSD method (α=5%).

Hence, COD and BOD changes have the same trend as TSS variations. Perlite had the least removal percentage among the adsorbents.

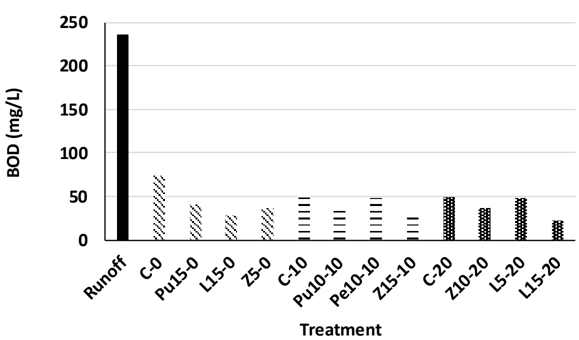

Figure 12: Variation of runoff BOD for selected porous concrete samples

3.2.5 Turbidity

Figure 13 illustrates that the turbidity is decreased as the fine-grains percentage is increased. There is no significant difference in the turbidity reduction between different adsorbents and only increasing the percentage of fine-grains led to more turbidity elimination. In other words, in order to reduce runoff turbidity, adsorbent type does not matter, but the porosity has the important role to trap suspended solids. Also, the presence of a filter is very important and increases the reduction efficiency.

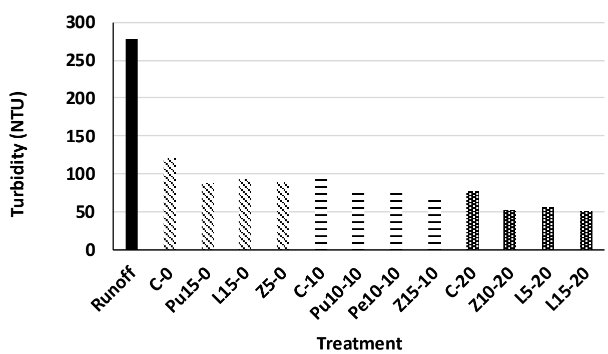

Figure 13: Variation of runoff turbidity for selected porous concrete samples

4 Conclusion

Porous concrete is usually used in low-traffic urban road systems, pavements and parking lots to reduce or delay urban runoffs. The results of this experiment represent that using zeolite, perlite, pumice and LECA as mineral adsorbents was effective in increasing the ability of porous concrete to reduce urban runoff pollution. In general, adding fine-grains and increasing the percentage of adsorbents to porous concrete enhanced the compressive strength in some cases, reduced the permeability and porosity in all cases and improved the performance of samples in reducing contamination. Moreover, results showed that zeolite and LECA were more effective in both mechanical characteristics and runoff quality and perlite had a poor performance among the adsorbents in all tests. For quality tests, L15-0, Z15-10 and L15-20 had the best outcomes in reducing TSS (75.8%, 79.1% and 84.6%), COD (87.1%, 82.6% and 89.3%) and BOD (88.1%, 87.3% and 90.7%) among selected samples. Finally, utilizing mentioned adsorbents on economic basis showed that the use of reasonable percentage of mentioned adsorbents with fine-grain regard to application field could be considered in future.

References

1 Salimi, A.; Karami, H.; Farzin, S.; Hassanvand, M.; Azad, A.; Kisi, O. Design of water supply system from rivers using artificial intelligence to model water hammer. ISH Journal of Hydraulic Engineering 2018, 1–10. Doi: 10.1080/09715010.2018.1465366

2 Bannerman, R.T.; Owens, D.W.; Dodds, R.B.; Hornewer, N.J. Sources of pollutants in Wisconsin storm water. Water Science Technology 1993. 28(3-5), 241-259. Doi:10.2166/wst.1993.0426

3 Tennis, P.D.; Leming, M.L.; Akers, D.J. Pervious concrete pavements. Portland Cement Association, Maryland 2004.

4 Schaefer, V.R.; Wang, K.; Suleiman, M.T.; Kevern, J. Mix design development for pervious concrete in cold climates. National Concrete Pavement Technology Center, Iowa State University, Ames, Iowa 2006.

5 Putman, B.J.; Neptune, A.I. Comparison of test specimen preparation techniques for pervious concrete pavements. Construction and Building Materials 2011, 25, 3480-3485. Doi: 10.1016/j.conbuildmat.2011.03.039

6 Kevern, J.T.; Wang, K.; Schaefer, V.R. effect of coarse aggregate on the freeze-thaw durability pf pervious concrete. Journal of Material of Civil Engineering 2010, 22 (5) 469-475. Doi: 10.1061/(ASCE)MT.1943-55330000049

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. Doi: 20.1016/j.conbuildmat.2014.12.073

8 Federal Highway Administration (FHWA). State of the practice national review, Transportation Applications of Recycled Concrete Aggregate 2004, page 47.

9 Yap, S.P.; Chen, P.Z.C.; Goh, Y.; Ibrahim, H.A.; Mo, K.H.; Yuen, C.W. Characterization of pervious concrete with blended natural aggregate and recycled concrete aggregate. Journal of Clean Production 2018, 181, 155-165. Doi: 10.1016/j.jclepro.2018.01.205

10 Aghakhani, A.; Mousavi, S.F.; Mostafazadeh-Fard, B.; Rostmian, R.; Seraji, M. Application of some combined adsorbents to remove salinity parameters from drainage water. Desalination 2011, 275(1-3), 217-223. Doi: 10.1016/j.desal.2011.03.003

11 Malekian, R.; Abedi-Koupai, J.; Eslamian, S.S.; Mousavi, S.F.; Abbaspour, K.C.; and Afyuni, M. Ion-exchange process for ammonium removal and release using natural Iranian zeolite. Application Clay Science 2011, 51 (3), 323-329. Doi: 10.1016/j.clay.2010.12.020

12 Malamis, S.; And Katsoi, E. A review on zinc and nickel adsorption on natural and modified zeolite, bentonite and vermiculite: Examination of process parameters, kinetics and isotherms Journal of Hazard Mater 2013, 252, 428-461. Doi: 10.1016/j.hazmat.2013.03.024

13 Bilardi, S.; Calabro, P.S.; Moraci, N. Simultaneous removal of CuII, NiII and ZnII by a granular mixture of zero-valent iron and pumice in column system. Desalination of Water Treatment 2015, 55(3), 767-776. Doi: 10.1080/19443994.2014.916234

14 Tasi, W.T.; Hsien, K.J.; Yang, J.M. Silica adsorbent prepared from spent diatomaceous earth and its application to removal of dye from aqueous solution. Journal of Colloid Interface Science 2004, 275 (2), 428-433. Doi: 10.1016/j.jcis.2004.02.093

15 Al-Anber, M.A.; Removal of high-level Fe3+ from aqueous solution using natural inorganic materials: Bentonite (NB) and quartz (NQ). Desalination 2010, 250(3), 885-891. Doi: 10.1016/j.desal.2009.06.071

16 Körlü, A.E.; Yapar, S.; Perineck, S.; Yilmaz, H.; Bagiran, C. Dye removal from textile waste through the adsorption by pumice used in stone washing. Autex Research journal 2015, 15 (3), 158-163. Doi: 10.1515/aut-2015-0012

17 Verbinnen, B.; Block, C.; vandecasteele, C. Adsorption of oxyanions from industrial wastewater using perlite-supported magnetite. Water Environmental Research 2016, 88 (5), 408-414. Doi: 10.2175/106143015x14362865226932

18 Zhang, R.; Kanemaru, K.; Nakazawa, T. Purification of river water quality using precast concrete products. Journal of Advanced Concrete Technology 2015, 13(3), 163-168. Doi: 10.3151/jact.13.163

19 Abedi Koupai, J.; Saghaian Nejad, S.; Mostafazadeh-Fard, S.; Behfarnia, K. Reduction of urban storm-runoff pollution using porous concrete containing iron slag adsorbent. Journal of Environmental Engineering 2016, 142(2), 1-7. Doi: 10.1061/(ASCE)EE.1943-7870.0001025

20 Ong, S.K.; Wang, K.; Ling, Y.; Shi, G. Pervious concrete physical characteristics and effectiveness in storm water pollution reduction. Final Report, MTC, Iowa State University, Ames, Iowa, USA 2016, page 47.

21 Shablala, A.N.; Ekolu, S.O.; Diop, S.; Solomon, F. Pervious concrete reactive barrier for removal of heavy metals from acid mine drainage-column study. Journal of Hazard. Mater 2017, 323, 641-653. Doi:10.1016/j.hazmat.2016.10.027

22 Azad, A.; Mousavi, S.F.; Karami, H.; Farzin, S.; Singh, V.P.; The effect of vermiculite and quartz in porous concrete on reducing storm-runoff pollution. ISH Journal of Hydraulic Engineering 2018, 1-9. Doi: 10.1080/09715010.2018.1528482.

23 ACI Committee 211. Guide for selecting proportions for no-slump concrete, ACI 211.3R Report 2006.

24 ASTM C1754/C1754M-12. Standard test method for density and void content of hardened pervious concrete. ASTM International 2012, USA.

25 ACI Committee 522. Pervious concrete, ACI522R-06 Report 2006.

26 British Standard, Testing Concrete Method for making test cubes from fresh concrete 1983, BS 1881, Part 108.

27 Jiang, W.; Sha, A.; Xiao, H.; Li, Y.; Huang, Y. Experimental study on filtration effect and mechanism of pavement runoff in permeable asphalt pavement. Construction and Building Material 2015, 100, 102-110. Doi: 10.1016/j.conbuildmat.2015.09