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Article

Using Waste Vermiculite and Dolomite as Eco-Friendly Additives for Improving the Performance of Porous Concrete

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Abstract. The present study investigated the applicability of waste vermiculite and dolomite as fine aggregate, known as appropriate mineral adsorbents to enhance the quality of urban runoff, for improving the mechanical properties of porous concrete. 180 samples were mixed by adding 5-30% vermiculite and dolomite, as fine aggregate, and combining them with ordinary sand; lime sand (combining of 5-15% of each). Results showed that although adding dolomite culminated in a minor reduction of permeability– average of about 30%-, the average of compressive strength was augmented by 120%. Results of compressive strength of dolomite samples were repeated in mixtures containing vermiculite (an increase of 57%). While exploiting vermiculite in high percentages (20, 25, and 30) resulted in an extensive decrease in the permeability (94%), it was improved to an acceptable level (about 40%) after using vermiculite in combination with ordinary sand (lime sand). All dolomite and improved vermiculite mixtures, after combining vermiculite with ordinary sand, had appropriate performance in draining storm-urban runoff; such that in the weakest case, stimulated storm runoffs with heights of 10, 20, 30 and 40 cm were completely drained only after 17, 36, 59 and 87 seconds, respectively. Also, using vermiculite resulted in reducing the concrete weight (about 100 kg). Generally, although a little reduction in the permeability was seen, but using waste vermiculite and dolomite improved the mechanical properties of porous concrete significantly.

Keywords: Porous concrete, dolomite, waste vermiculite, floods and urban runoff management, lightweight aggregates.

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1. Introduction

Every year, floods and urban runoff cause damages and high costs. Porous concrete is one of the eco-friendly methods for disposing and even retrieval of floods and urban runoff. This system is a special concrete with continuous voids (ACI 522R). Due to the existence of many voids, porous concrete can be used as a suitable system for drainage of urban runoff [1]. This kind of concrete, also, has several advantages such as temperature and sound insulation, useful for recharging groundwater resources, reducing thermal gradient, decreasing inflation due to freezing, etc. [2-5].

In recent years, many researches have been done for improving the structural performance of concrete [6]. Chindaprasirt et al. (2006) investigated the effect of using various levels of cement on the compressive strength of porous concrete [7]. According to their report, adding superplasticizer and reducing the water/cement ratio culminated in a significantly increases of the compressive strength. Yang et al. (2008) examined the effects of cementitious material and aggregate size on the compressive strength and void ratio of porous concrete. Results indicated that even in the most optimal mixture, the compressive strength was very low and less than 10 MPa. [8]. In some other studies, various kinds of fiber were used to increase the porous concrete strength. Hesami et al. (2014) used glass, PPS and steel fibers to improve the performance of porous concrete. Results showed that these additives had suitable impact on improving porous concrete resistance [9]. It is noteworthy that the mentioned additives are not appropriate for wide use in public places due to their high costs. For this reason, other studies applied some recyclable materials such as latex, car tires, waste concrete and building materials to reduce the costs. [10-13]. These recycled materials, despite the numerous advantages, have environmental pollution which if used in the porous concrete, the pollutant would be transferred to the runoff.

Existence of pollutants in urban runoff has harmful effects on water and amphibious ecosystems, such as depletion of dissolved oxygen and increase of turbidity and toxicity. In numerous studies, various adsorbents (herbal, chemical, mineral) have been used to improve the quality of wastewater [14, 15]. Among these adsorbents, minerals such as dolomite, zeolite, pumice and vermiculite, are gained acceptable usage because of availability and economic justification [16, 17]. Recently, studies have been conducted on the probability of using adsorbents as part of porous concrete in order to improve the quality of wastewater. Abedi-Koupai et al. (2016) compared the ability of iron slag for enhancing porous concrete in order to improve the quality of urban runoff. Results suggested the better ability of mixtures containing iron slag [18]. Zhang et al. (2015) investigated the applicability of porous concrete containing pumice for enhancing river water quality. According to their research, pumice could increase the concrete ability in removing COD and BOD up to 60% [19]. Ong et al. (2016) using fly ash, slag and limestone powders as cementitious material, improved the ability of porous concrete for reducing the pollutants of urban runoff [20]. In other studies, furthermore, Holmes et al. (2017) and Shabala et al. (2017) used porous concrete containing fly ash to remove some of the heavy metals from water. Results suggested the capability of mentioned system in reducing heavy metals [21, 22]. Another study showed that using pumice and LECA as fine aggregate was able to be helpful in improving the structural behavior of porous concrete. This mineral also could have significant effects on the performance of porous concrete in reducing the water pollution [23].

Mineral adsorbents are modern materials to be used as a portion of porous concrete to improve the structural performance as well as enhance the urban runoff quality. But, at first, it is necessary to investigate the effect of these materials on the structural performance of porous concrete. In this study, effects of using vermiculite and dolomite adsorbents as minerals, which are able to improve the quality of urban runoff, on the structural performance of porous concrete were examined. Hence, this study followed four goals: 1) checking the effects of adding different percentages of vermiculite and dolomite on the compressive strength, permeability and porosity of porous concrete; 2) examining the effects of adding different percentages of lime sand on the performance of concrete containing vermiculite and dolomite; 3) reviewing the function of all mixtures in draining various heights (10, 20, 30 and 40 cm) of urban runoff, and 4) checking the ability of vermiculite as a light grain in reducing special weight of the porous concrete.

2. Materials and Methods

2.1. The Used Materials

2.1.1. Cement and aggregates

In this study, Portland cement type 5 was used to make the porous concrete blocks. This cement is produced by Tehran Cement Factory, Iran, and its chemical characteristics are given in Table 1. The reason for using this cement is possible exposition of porous concrete to sulfated environments.

Table 1. Chemical analysis of cement, dolomite and vermiculite.

Chemical Parameters	Cement	Dolomite	Vermiculite
SiO_2	22.6	>0.01	38.2
Al_2O_3	4.4	>0.01	15.4
Fe_2O_3	4.4	0.02	13.6
CaO	63.1	33.1	4.30
MgO	1.70	20.6	18.2
SO_3	1.50	>0.01	---
Na_2O	0.2	>0.01	-----
K_2O	0.5	>0.01	0.7
L.O.I	---	44.2	6.8

2.1.2. Additives

2.1.2.1. Vermiculite

Vermiculite with chemical formula of (MgFe 3+ Al)3 [(OH)2 - Al 1.25 Si 2.75 O10]. Mg 0.33 $(H2O)_4$ is a mineral with layered texture and relatively low stiffness (1.5 in the Mohs table). The raw vermiculite has been less used and intentionally was consumed in expanded form. In building materials, vermiculite is used for production of light concrete and cement because of its low special weight (about 450 kg/m^3). On the other hand, this material is applied as an insulator for steam pots and construction of furnaces owing to the high thermal resistance (about 1100 °C). Also, because of its special features, vermiculite was used for insulation of steel pipes and audio and acoustic insulations [24]. In recent years, extensive studies have been done on the applicability of this material for improving runoff and industrial wastewater [26-28]. SEM picture of vermiculite is shown in Fig. 1. It should be noted that in this study, waste vermiculite was used. The waste vermiculite has no usage in common purposes after expansion operations. This vermiculite is mainly used for nutrition of the agricultural soil. The chemical analysis of vermiculite is given in Table 1.

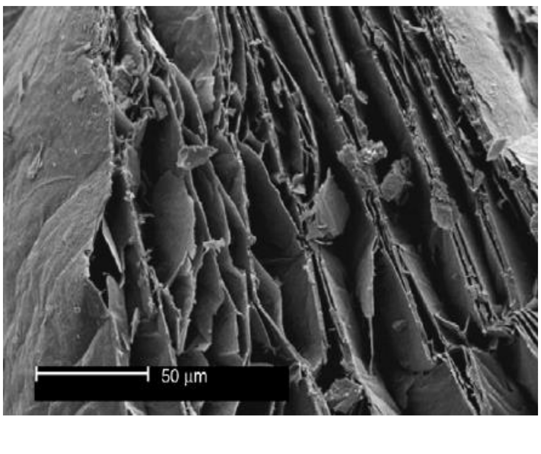

Fig. 1. SEM picture of vermiculite mineral [24] (with permission).

2.1.2.2. Dolomite

Dolomite with chemical formula of $CaMg(CO_3)_2$ is amongst minerals that is widely found in earth's crust. This mineral, with the special weight of $2600\frac{\mathrm{kg}}{\mathrm{m}^3}$ and stiffness of 3.5 to 4.0 Mohs, is considered a relatively hard material. The main elements of dolomite are lime (CaO) and magnesium (Mg); but other elements such as iron oxides, sodium and potassium could be found in its composition (Table 1). Dolomite is used in the glass industry, blast furnace, building materials, tire filler and agriculture (as fertilizer and soil regulator). In recent years, several studies have investigated the usability of dolomite for removing some of the harmful parameters of water and sewage [28]. Also in some studies, effects of dolomite was examined for improving the compressive strength of concrete [29].

2.2. Mixing Steps

The original mixing design of porous concrete was based on the ACI-211/3R standard [30]. Then, the rest of the samples were mixed using a comparative system of different values from 5 to 30% vermiculite and dolomite and their composition with 5-15% of lime sand (with size of 0.5 to 1.2 mm). The size of coarse aggregates was in range of 4.75 to 9.51 mm in all the samples. The cubic samples were 10×10×10 cm (90 samples) to test the permeability and porosity and 15×15×15 cm (90 samples) to test the compressive strength. Also, the amount of coarse aggregates was $1400\frac{\mathrm{kg}}{\mathrm{cm}^3}$. To prevent water adsorption by vermiculite, at first, it was kept in the water for 24 hr to be saturated, and then was placed on a mesh for 48 hours to eliminate its surface water. The mixing ratio for all the samples is given in Table 2.

Table 2. Porous concrete mixing proportions.

Mixture	Water/cement (w/c)	Cement (kg)	Sand	Dolomite	Mixture	Water/cement (w/c)	Cement (kg)	Sand	Vermiculite
C	0.36	330	0	70	C	0.36	330	0	**21**
D5-S0	0.36	340	0	140	V5-S0	0.36	340	0	**42**
D10-S0	0.36	351	0	210	V10-S0	0.36	351	0	**63**
D15-S0	0.36	362	0	280	V15-S0	0.36	362	0	**84**
D20-S0	0.36	370	0	350	V20-S0	0.36	370	0	**105**
D25-S0	0.36	375	0	420	V25-S0	0.36	375	0	**126**
D30-S0	0.36	385	0	490	V30-S0	0.36	385	0	**21**
D5-S5	0.36	351	70	70	V5-S5	0.36	351	70	**42**
D10-S5	0.36	362	70	140	V10-S5	0.36	362	70	**63**
D15-S5	0.36	370	70	210	V15-S5	0.36	370	70	**84**
D5-S10	0.36	362	140	70	V5-S10	0.36	362	140	**42**
D10-S10	0.36	370	140	140	V10-S10	0.36	370	140	**63**
D15-S10	0.36	375	140	210	V15-S10	0.36	375	140	**84**
D5-S15	0.36	370	210	70	V5-S15	0.36	370	210	**42**
D10-S15	0.36	375	210	140	V10-S15	0.36	375	210	**63**
D15-S15	0.36	385	210	210	V15-S15	0.36	385	210	**84**

D= Dolomite, V= Vermiculite, C= Control sample, S=Lime sand.
V*-S* is added vermiculite percent + added lime sand percentage.
D*-S* is added dolomite percent + added lime sand percentage.

2.3. Tests

2.3.1. Porosity and permeability

The permeability is considered as one of the most important abilities of porous concrete. This test was done according to the ACI 522R standard [31], using an apparatus shown in Fig. 2. The permeability of the samples was calculated according to equation (1):

$$K = \frac{al}{At} Ln(\frac{h_1}{h_2}) \tag{1}$$

where, **K** is permeability (cm/min), **a** is internal cross-section of glass container, **l** is sample's length (cm), **A** is the cross-section of the sample (cm^2), $\mathbf{h_1}$ and $\mathbf{h_2}$ are initial and final height of water column, respectively (cm), and **t** is time of water level drop from h_1 to h_2. The gap between internal dimension of the container and samples was 15 mm, which was filled by insulated fibers (Fig. 2).

Fig. 2. Permeability measuring device.

The porosity of porous concrete samples could have a direct link with compressive strength and permeability. This test was done according to the ASTM C1754 standard. Based on this standard, the oven-dried samples were exposed to room temperature for 24 hours. After that, by measuring dry weight ($\mathbf{w_1}$), immersion weight ($\mathbf{w_2}$), sample volume (**V**) and the density of water ($\boldsymbol{\rho_w}$) and using equation (2), the sample porosity (A_t) is calculated as:

$$At = \left(1 - \left(\frac{W2 - W1}{\rho w}\right)\right) \times 100 \qquad (2)$$

2.3.2. Compressive strength

One of the effective factors in selecting the performance of porous concrete is compressive strength. In order to test it, according to the BS 1881 standard, the 15×15×15 cm samples were used. Because of using cement type 5, the samples were tested after being cured for 42 days.

2.4. Urban Runoff Simulation

In this study, in order to examine the ability of proposed porous concrete to manage urban runoff, the performance of all samples for drainage of urban runoff was investigated. Hence, using a drainage apparatus, the needed time for draining storm-urban runoff with various heights of 10, 20, 30, and 40 cm, was examined to get more information on how different amounts of the applied additives influence the ability of porous concrete in drainage of urban runoff in real situations (Fig. 3). It is noteworthy that the stimulated runoff contained total suspended solids (TSS) of 500 ± 75 mg/L and total dissolved solids (TDS) of 3000 ± 350 mg/L.

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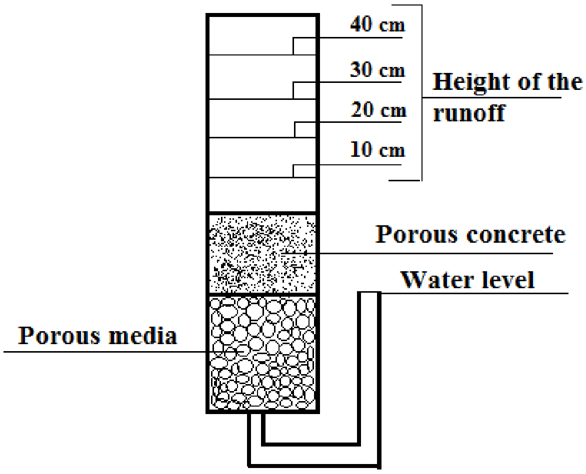


Fig. 3. Measuring device for drainage of runoff from a porous concrete block.

3. Results and Discussion

3.1. Performance of Vermiculite and Dolomite on Compressive Strength

3.1.1. Dolomite

In this section, the effect of dolomite, as an additive having the ability of improving the water quality, was discussed to enhance the structural behavior of porous concrete. Based on Fig. 4, it is clear that the compressive strength was continuously increased with addition of dolomite to the porous concrete samples. Moreover, according to Fig. 4, the increase of dolomite percentage has a direct relation with the compressive strength trend. The reason for enhancement of resistance could be filling of the empty voids between the coarse aggregates. Results showed that using 5, 10, 15, 20, 25 and 30% dolomite resulted in increase of the compressive strength from 10.5 MPa in the control sample to 14.05, 14.32, 17.00, 20.79, 24.89 and 24.31 MPa, respectively. This performance enhances using dolomite additive in the porous concrete samples.

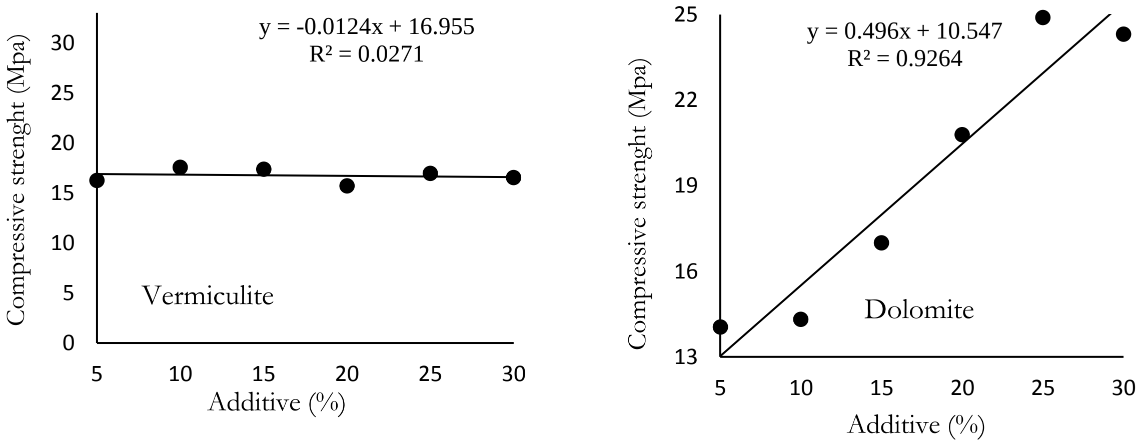


Fig. 4. The scatter diagram between compressive strength and additive percentage.

It was observed that in low additive percent, such as 5%, it is probable that dolomite particles have been captured between the coarse grains, and so they have not been directly exposed to axial loads (Fig. 5). But with the increase of additive value from 15 to 30%, dolomite particles have been completely under the axial loads. In this situation, since dolomite is a hard mineral, the increasing trend of compressive strength was expected. Figure 6 shows where dolomite particles are really located in mixtures with 5, 15 and 30% additive. On the other hand, reports have shown that in the most researches, despite using some expensive additives such as glass, PPS, and steel fibers, the compressive strength of porous concrete was less than 25 MPa and even in many researches, it has been less than 20 MPa [8]. This issue reflects the suitable capability of dolomite as an affordable additive and at the same time appropriate performance in improving the structural behavior of porous concrete. It should be noted that dolomite has also appropriate ability to enhance the quality of wastewater.

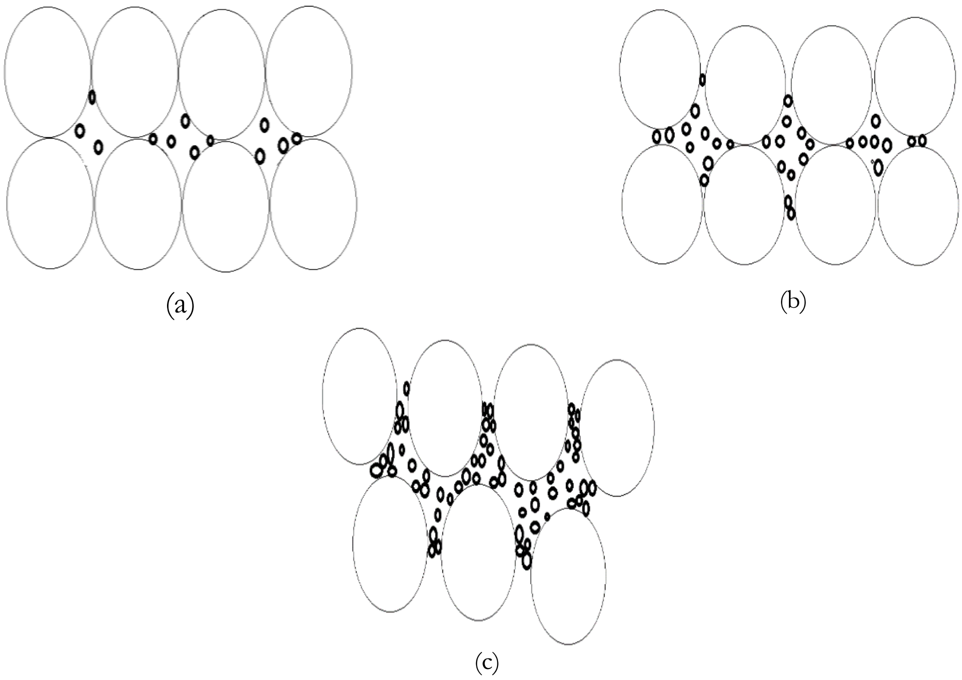


Fig. 5. Schematic diagram of optimum placement of additive particles in porous concrete: a) 5%, b) 15% and c) 30%.

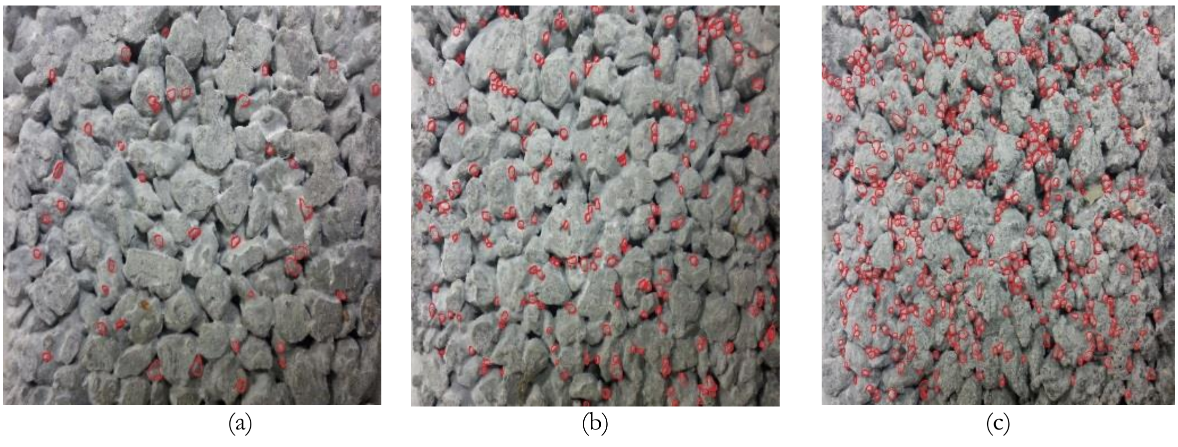


Fig. 6. Optimum placement of dolomite particles in porous concrete: a) 5%, b) 15% and c) 30%.

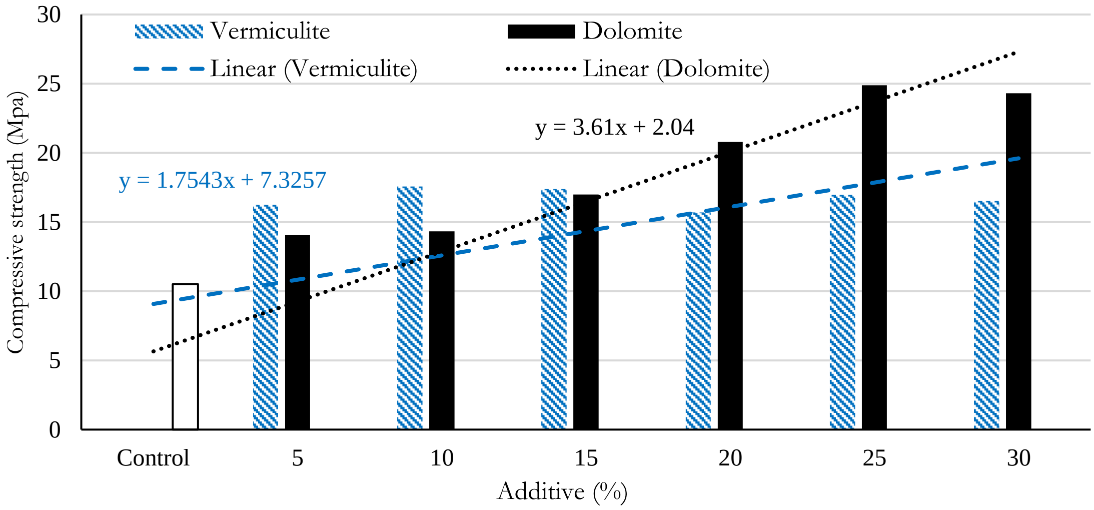


Fig. 7. Variation of compressive strength with vermiculite and dolomite percentage.

3.1.2. Vermiculite

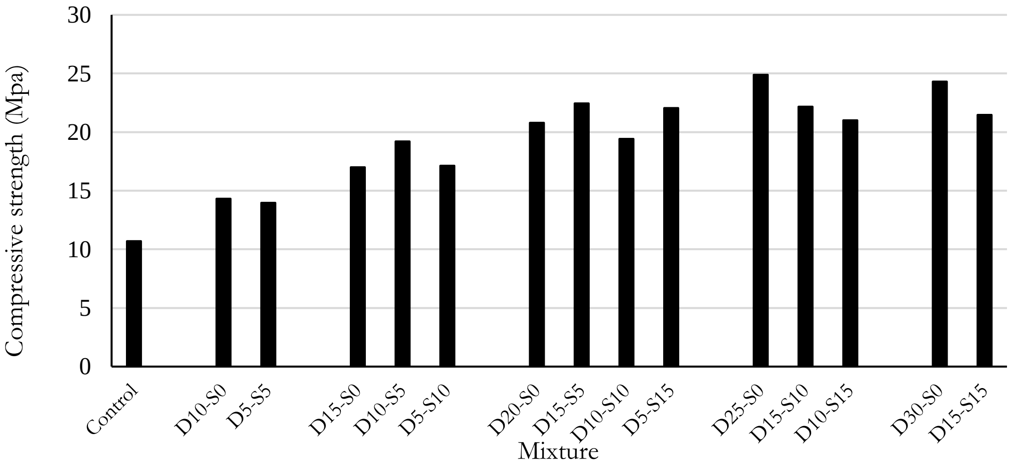
Performance of vermiculite was different from dolomite. According to the Figs. 4 and 7, it was observed that with increase of vermiculite amount, there was no special and meaningful change in the compressive strength. But, in general, it had a positive impact on compressive strength, so that in mixtures containing 5, 10, 15, 20, 25 and 30% vermiculite, the compressive strength increased to 16.26, 17.57, 17.38, 15.70, 16.96 and 16.53 MPa, respectively (an increase of 51, 64, 62, 46, 58 and 54% over control treatment). Results showed that maximum increase of porous concrete strength by vermiculite is 64%. This might be due to the relatively low stiffness of vermiculite as well as the flake-like structure of this mineral (Fig. 1). But the remarkable point in vermiculite results is its more suitable performance than that of dolomite in samples in low additive percent (5, 10, and 15%).

According to Fig. 7, it was observed that compressive strength of 5, 10 and 15% vermiculite mixtures was 15.7, 22.6 and 2% more than dolomite mixtures with similar additive percentages. However, with the increase of additives amount, the variation trend has changed in favor of dolomite; so that in the samples containing 20, 25 and 30% dolomite, the compressive strength was more than vermiculite by 32, 46 and 47%. This could be related to the hardness values of vermiculite and dolomite as well as the mentioned minerals appearance. Vermiculite particles have flake form and are sticky, so that in the mixing process, the vermiculite particles completely stuck to coarse grains and covered their surface more than the dolomite particles (Fig. 8). Thus, in lower additives percentage, because of better coverage in mixtures containing vermiculite, the compressive strength of these samples was more than dolomite. Bahnasawy and El-Refai (1990) reported that dolomite had a positive impact on improving the quality of high strength concrete performance [32].

Fig. 8. Covering of coarse aggregates by vermiculite.

3.2. Effect of Combined Additives and Lime Sand Mixture On Compressive Strength

In this section, effect of lime sand on the resistance of samples containing vermiculite and dolomite is discussed. According to Fig. 9, it was observed that in 3 out of 5 groups, dolomite samples showed higher resistance than the hybrid mixtures (dolomite plus lime sand). In the other two groups, the samples containing a higher percent of dolomite had more suitable performance. In accordance with the mentioned reasons, higher natural resistance of dolomite than lime sand could be the reason why the samples containing dolomite had higher compressive strength than samples combined with lime sand [32, 33].



D*-S* is added dolomite percentage + added lime sand percentage.

Fig. 9. Compressive strength of combined samples of dolomite-lime sand and dolomite alone.

The performance of vermiculite containing lime sand was approximately different from similar samples containing dolomite (Fig. 10). The reason for this can be issues outlined in the previous section. By increasing the additives percent, it was observed that the compressive strength of the samples containing vermiculite combined with lime sand increased significantly, such that in samples containing 25% and 30% additive, the combined samples had compressive strengths of 40% and 29% more than samples without lime sand. Results indicated that vermiculite in its optimal percentage had suitable performance in improving the compressive strength. Therefore, the compressive strength of vermiculite mixtures was recovered using the combination of lime sand and vermiculite. It is noteworthy that the statistical analysis showed that the compressive strength of dolomite mixtures, samples containing only dolomite or the combination of dolomite and sand, vermiculite mixtures, samples containing only vermiculite or the combination of vermiculite and sand, were statistically significant (P≤0.01), and also they had appropriate R2; 0.87 and 0.85, respectively (Table 3).

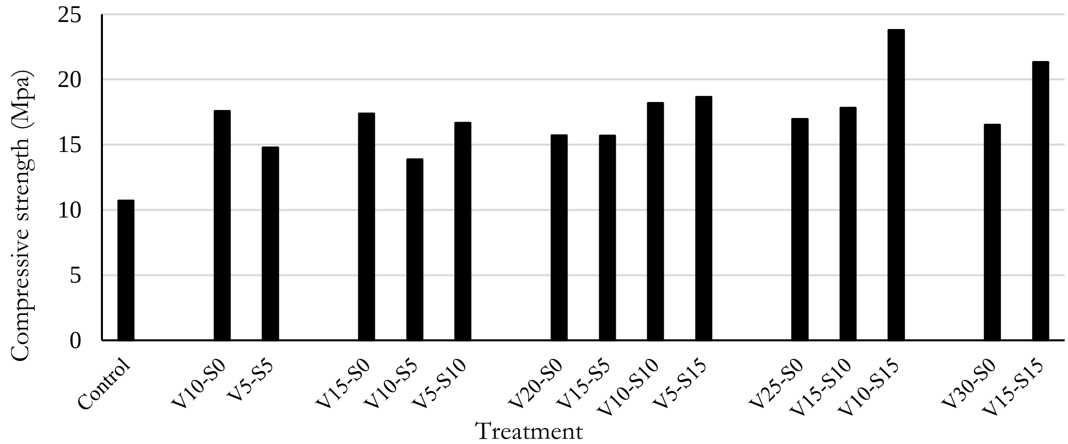


Fig. 10. Compressive strength of combined samples of vermiculite-lime sand and vermiculite alone.

Table 3. Statistical analysis of the compressive strength in different treatments of porous concrete.

			DF	Sum of squares	Mean square	F value	Pr>F	Coefficient of variation	R^2
The compressive strength	Dolomite	Treatment	15	747.47	49.83	14.27**	<.0001	9.79	0.87
		Block	2	2.08	1.04	0.30**	0.74		
		Error	30	104.75	3.49	-	-		
		Total	47	854.31	-	-	-		
	Vermiculite	Treatment	15	371.77	24.78	34.28**	<.0001	4.99	0.85
		Block	2	1.081	0.54	0.75**	0.48		
		Error	30	21.69	0.72	-	-		
		Total	47	394.54	-	-	-		

** Significant at 1% level

3.3. The Effectiveness of Additives on Permeability and Porosity

This investigation showed that increasing the dolomite percentage in the porous concrete samples value, decreased the permeability from 35 cm/min in control sample to 22.7 cm/min in samples containing 30% dolomite. In vermiculite samples, with increase of this additive, the permeability was decreased by a slope nearly three times of dolomite samples (Fig. 11). The permeability was reduced from 30.2 cm/min in V5-S0, which was very close to the permeability of dolomite samples (D5-S0), to less than 2 cm/min in V30-S0. It should be noted that the trend of permeability tests were similar to the porosity tests (Figs. 12 and 13).

It was found that permeability of vermiculite samples was improved by adding lime sand. According to Fig. 14, the permeability of combined samples was better than that of samples containing just vermiculite. Results of porosity tests followed the same trend (Fig. 15). This might be due to better passage of water in samples containing lime sand. On the other hand, results showed that the performance of combined samples containing dolomite and lime sand followed different trend for permeability and porosity. Unlike vermiculite samples, the permeability and porosity of dolomite samples were more than combined samples in many of similar samples (Figs. 16 and 17). This might be due to better capability of dolomite samples for passing water flow. At last, the results of statistical analysis showed that effect of mixtures on three parameters of permeability, compressive strength and porosity is statistically significant (P≤0.01) (Table 4 and 5). It is notable that R^2 of vermiculite mixtures were less that 0.70; 0.56, because, as it mentioned, the permeability results were not in satisfying form, so it was reformed adding sand. In fact, the results of mixtures containing only vermiculite and combination of vermiculite and sand were not in same trend. So, overall results did not culminate in high R^2.

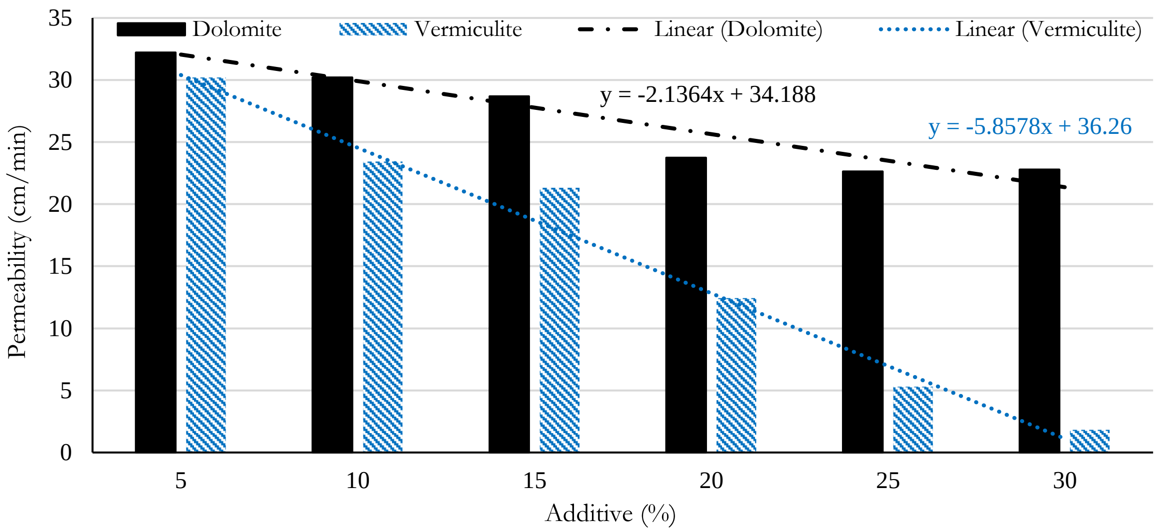


Fig. 11. Permeability of porous concrete samples containing vermiculite or dolomite.

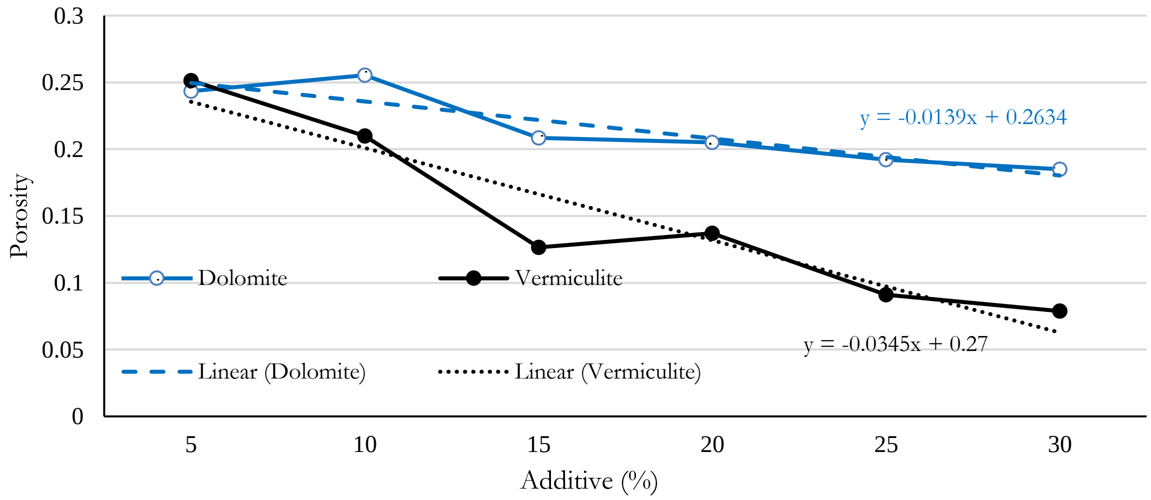


Fig. 12. Porosity of porous concrete samples containing dolomite or vermiculite.

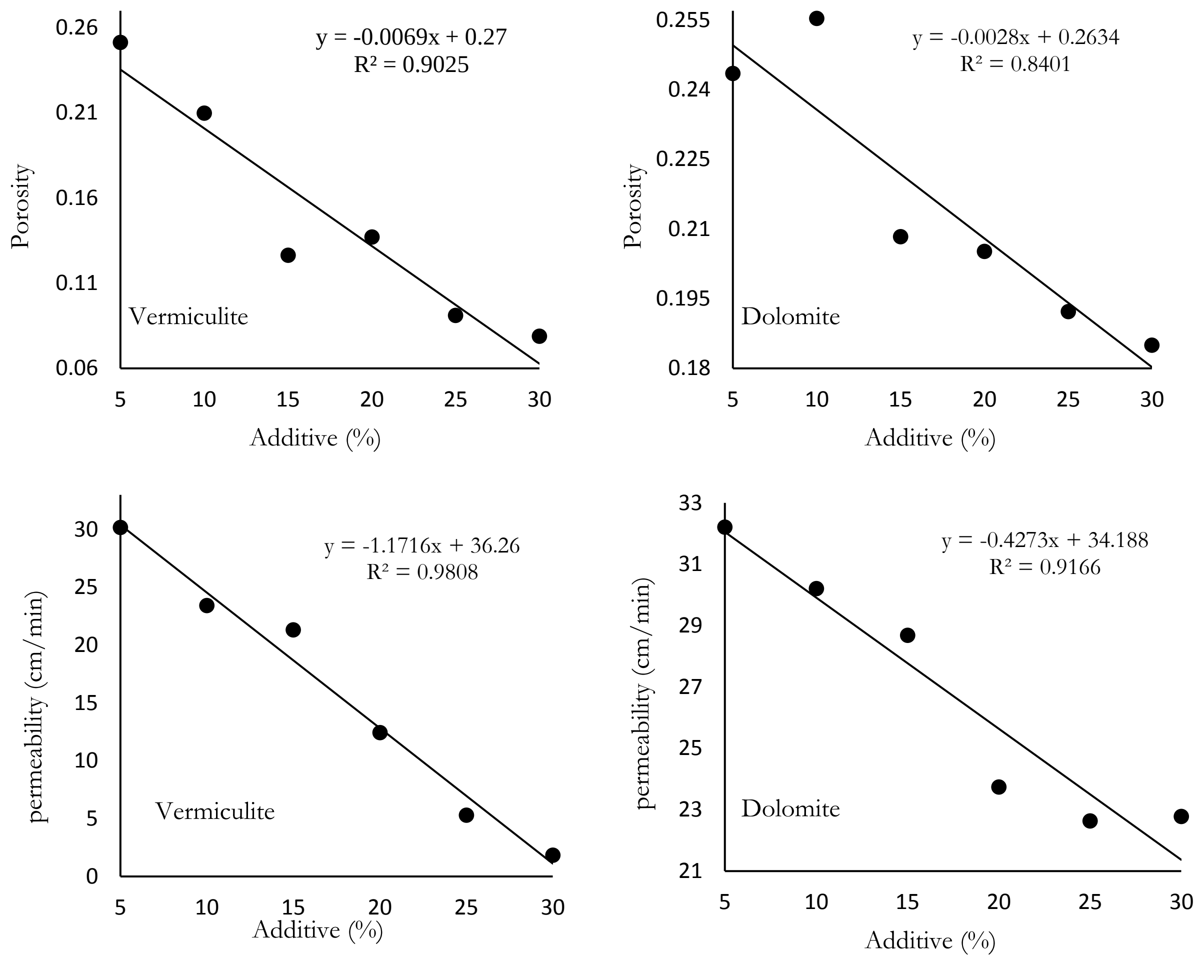
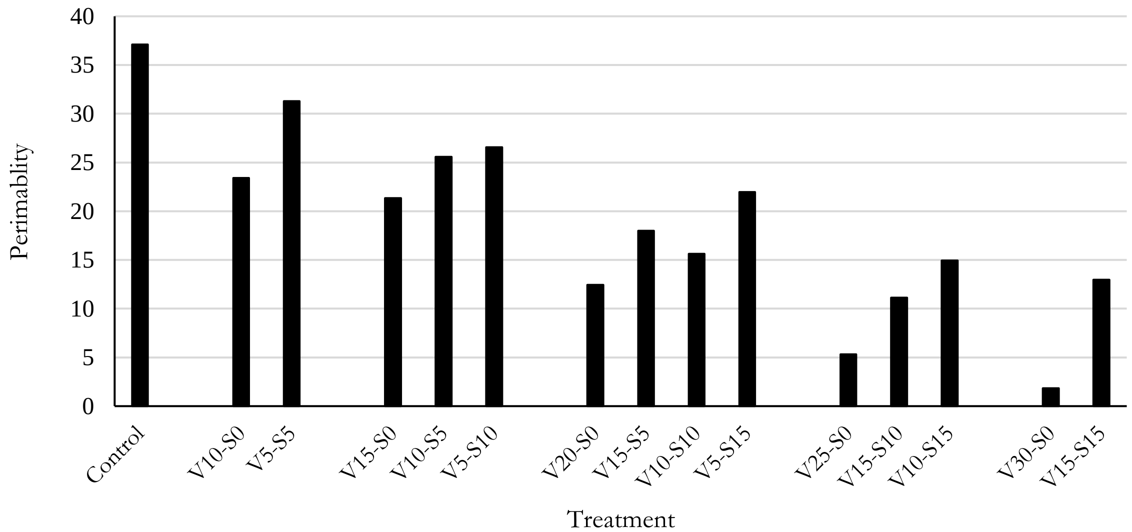
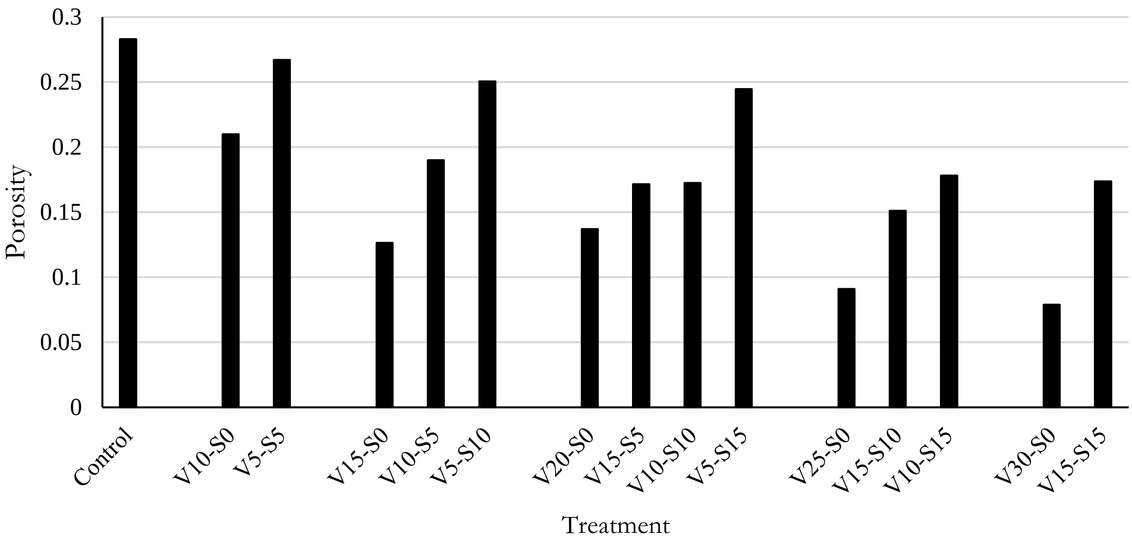


Fig. 13. The scatter diagram between permeability and porosity with additive percentage.



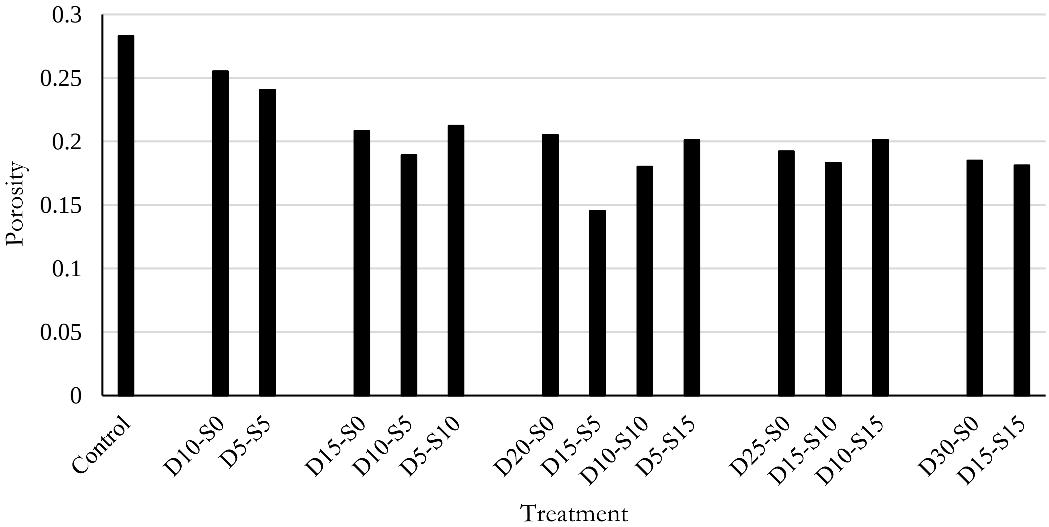
V*-S* is added vermiculite percentage + added Lime sand percentage.

Fig. 14. Permeability of combined samples of vermiculite-lime sand and vermiculite alone.



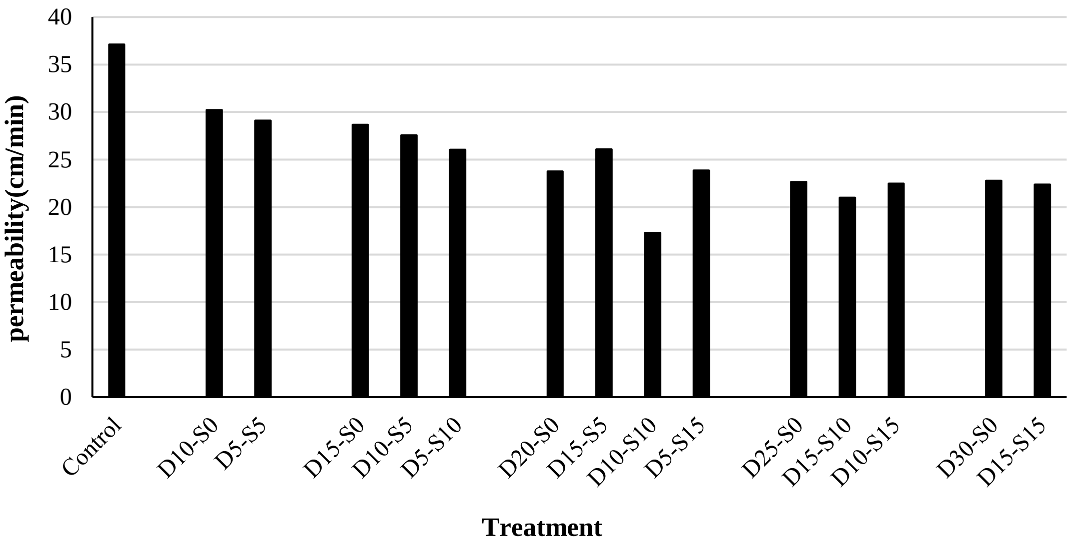
V*-S* is added vermiculite percentage + added Lime sand percentage.

Fig. 15. Porosity of combined samples of vermiculite-lime sand and vermiculite alone.



D*-S* is added dolomite percentage + added lime sand percentage.

Fig. 16. Porosity of combined samples of dolomite-lime sand and dolomite alone.



D*-S* is added dolomite percentage + added lime sand percentage.

Fig. 17. Permeability of combined samples of dolomite-lime sand and dolomite alone.

Table 4. Statistical analysis of the permeability in different treatments of porous concrete.

			DF	Sum of squares	Mean square	F value	Pr>F	Coefficient of variation	R^2
The permeability	Dolomite	Treatment	15	594.62	39.64	6.40**	<.0001	8.84	0.76
		Block	2	14.02	7.01	1.13**	0.33		
		Error	30	185.7	6.19	-	-		
		Total	47	794.3	-	-	-		
	Vermiculite	Treatment	15	2459.98	163.99	2.51**	0.01	40.50	0.56
		Block	2	45.88	22.94	0.35**	0.70		
		Error	30	1958.9	65.29	-	-		
		Total	47	4464.8	-	-	-		

** Significant at 1% level

Table 5. Statistical analysis of the porosity in different treatments of porous concrete.

			DF	Sum of squares	Mean square	F value	Pr>F	Coefficient of variation	R^2
Porosity	Dolomite	Treatment	15	2187.8	145.85	18203.5**	0.001	4.59	0.99
		Block	2	0.02	0.01	1.47**	0.24		
		Error	30	0.24	0.008	-	-		
		Total	47	2188.07	-	-	-		
	Vermiculite	Treatment	15	2192.9	146.1	16419.7**	0.001	4.90	0.99
		Block	2	0.017	0.008	0.98**	0.38		
		Error	30	0.26	0.008	-	-		
		Total	47	2193.2	-	-	-		

** Significant at 1% level

3.4. Performance of Porous Concrete Samples in Drainage of Various Runoff Depths

The ability of water disposition is considered as one of the most important principles in drainage systems. For this, the ability of porous concrete was examined to drain the synthetic urban runoff. Results showed that all dolomite and dolomite-lime sand samples had good capability to drain runoff, such that, on the average, these samples have disposed the runoff with height of 10, 20, 30 and 40 cm in just 12, 27, 43 and 60 seconds, respectively. Even in the case of the most impermeable samples, the highest runoff depth (40 cm) was drained only in less than 70 sec. In Fig. 18, the minimum, average and maximum required time are presented for drainage of stimulated runoff.

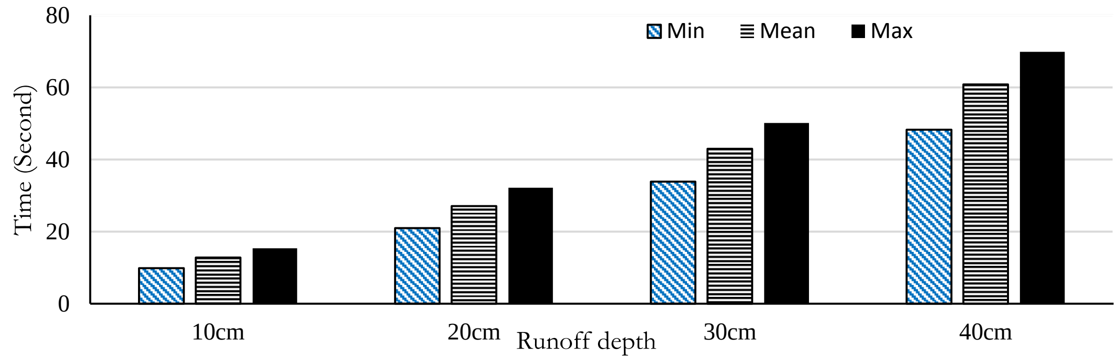


Fig. 18. Minimum, average and maximum times for drainage of urban runoff by porous concrete blocks.

But the performance of vermiculite samples was uncertain. The ability of draining runoff in samples with 5, 10, 15 and 20% of vermiculite was good and the required time for disposing the highest runoff depth (40 cm), even in V20-S0, was less than 2 minutes. But in samples containing 25% and 30% vermiculite, the drainage time was increased dramatically; such that to drain 40 cm of the runoff, these samples were drained after 245 and 878 sec, respectively. The performance of vermiculite samples was modified by lime sand, so that the trend of increasing runoff disposal time against its height was greatly reduced from 236 to 30 sec, on the average (Fig. 20). Therefore, the disposal time of 25% and 30% was improved by 68% and 87% and the required time was decreased from 245 and 878 sec to 76 and 113, respectively (Fig. 19).

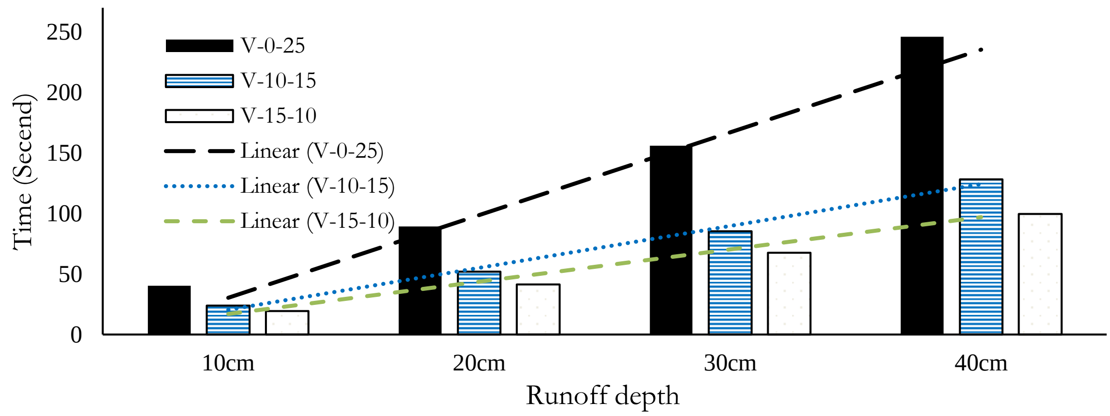


Fig. 19. Performance of vermiculite and modified vermiculite samples to drain urban runoff blocks.

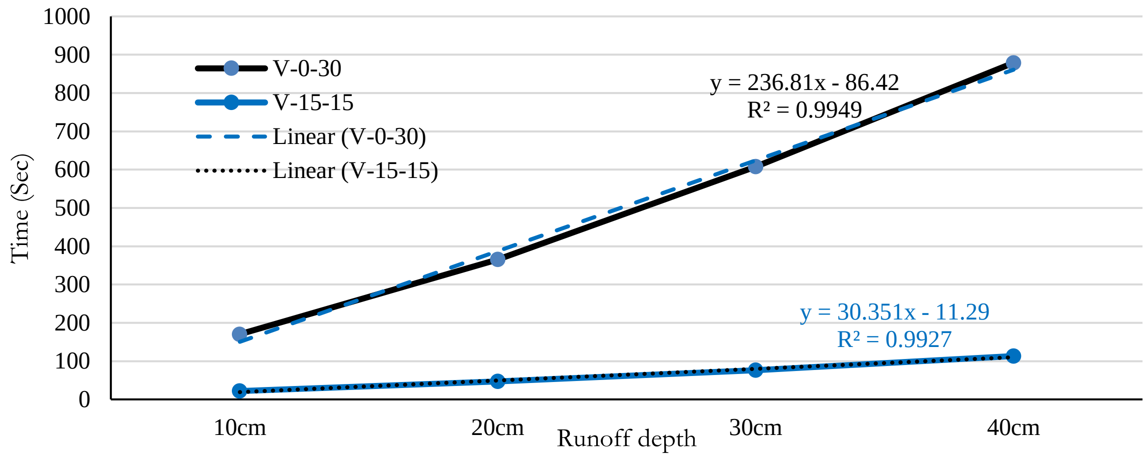


Fig. 20. Performance of vermiculite (V-0-30) and modified vermiculite samples to drain urban runoff.

3.5. Performance of Additives in Specific Weight of Porous Concrete Samples

The weight of dolomite and vermiculite samples and their combinations with lime sand is shown in Fig. 21. Results showed that vermiculite has a positive impact on special weight of the porous concrete samples. Samples containing vermiculite have average specific weight of 1682 kg/m^3, about 100 kg/m^3 lighter that dolomite samples, with average specific weight of 1783 kg/m^3. These results could be considered for places which need to reduce the pavement weight.

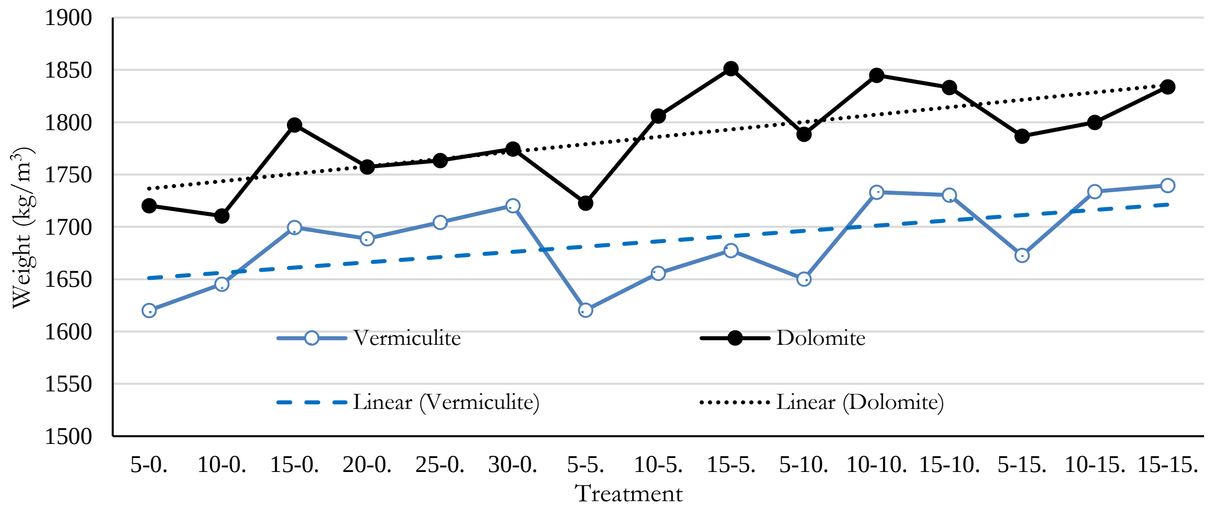


Fig. 21. Specific weight of porous concrete samples containing dolomite and vermiculite.

4. Conclusions

Porous concrete, known as a new eco-friendly material, has been used in different studies to manage urban runoff in the last decades. It is not only able to drain storm runoffs, but also can improve the runoff quality. This ability can be enhanced by adding some mineral additives like vermiculite and dolomite. Of course, the mechanical effects of these additives on porous concrete should be investigated. In the current study, application of dolomite- a mineral with high compressive strength-, vermiculite- a lightweight mineral-, and combination of both additives with ordinary lime sand was investigated. Results showed that adding 5, 10, 15, 20, 25 and 30% dolomite and vermiculite enhanced the compressive strength from 10.5 MPa in control sample to 14, 14.3, 17, 20.7, 24.8, and 24.31 MPa and 16.26, 17.57, 17.3, 15.7, 17 and 16.5 MPa, respectively. Adding fine aggregates culminated in reduction of the permeability of samples containing vermiculite from 34 cm/min in control sample to 30.2, 23.4, 21.3, 12.4, 5.3, and 1.8 cm/min, respectively. However, they were improved using combined vermiculite with lime sand such that the permeability of worst case improved from 1.8 to 12.96 cm/min. On the other hand, results indicated that all samples containing dolomite, dolomite-lime sand, and vermiculite-lime sand had acceptable performance in draining various stimulated urban runoff depths such that samples containing dolomite and vermiculite samples, on the average, disposed the runoff height of 10, 20, 30 and 40 cm in just 12.8, 27.07, 42.9 and 60.8 sec and 17.07, 36.63, 59.4 and 87.5 sec, respectively.

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