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Performance of Porous Pavement Containing Different Types of Pozzolans

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ABSTRACT

Underlying fabrics can change the appearance, function and quality of the garment, and also add so much longevity of the garment. Nowadays, with the increasing use of various types of fabrics in the garment industry, their resistance to bagging is of great importance with the aim of determining the effectiveness of textiles under various forces. The current paper investigated the effect of underlying on the bagging behavior of denim fabrics. The experiments carried out on four different denim fabrics as the main components including cotton, polyester and lycra, as well as three types of adhesive interlining and three common lining as the underlying components. The adhesive interlining was added to the fabric by using a fusing machine, and the lining was sewn to the fabric. The bagging behavior was assessed by extraction of the residual bagging height using the image processing method and the bagging fatigue percentage by stress-strain diagram. The results showed that with the addition of adhesive interlining and lining to the fabric, the bagging fatigue percentage increased. The lining sewn to the fabric reduced the residual bagging height. Also, the friction between the face fabric and the lining was an important factor that, the bagging fatigue percentage increased with increasing the friction, regardless of the fabric material.

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NOMENCLATURE

A	control	K	Fly Ash
M	Silica Fume	S	Granulated Blast Furnace Slag
Z	Zeolite	C-S-H	Calcium-Silicate-Hydrate

1. INTRODUCTION

Nearly 30 years ago, pervious concrete (PC) pavement was originally used in the USA and England [1]. Based on the studies carried out so far, major parameters affecting on the PC's strength include the porosity, water-to-cement ratio (w/c), paste properties as well as size and content of coarse aggregates [2-4]. For instance, Yang and Jiang [5] concluded that the use of silica fume (SF) and superplasticizer (SP) could enhance the PC's strength substantially.

Kevern [6] reported that the addition of polymer (styrene butadiene rubber) improved the workability, strength, permeability as well as freeze-thaw resistance of the PC.

In 2012, Shirgir et al. [7] experimentally evaluated the effect of aggregates' particle size on permeability and compressive strength of the hardened PC. Based on the results, changes in the size of particles can remarkably affect on the concrete's strength.

In recent experimental studies, the compressive strength of the PC has been evaluated [8]. The strength properties of this type of concrete depend on a number of parameters including porosity, voids volume, etc. [9]. In this respect, some studies have been conducted on the effect of porosity on the strength of cementitious materials [10-12]. In these studies, however, the hydrated cement was utilized as the main material for filling the voids, yet, the porosity exists in the concrete and there lies a direct relation between fraction of porosity and compressive strength of concrete.

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The natural zeolite refers to a mineral material extensively used worldwide [13]. This mineral material is a type of crystallized aluminum silicate with a 3D structure. The crystal of natural zeolite consists of so many canals and voids sized from 3×10^{-4} to 4×10^{-4} mm. The small voids and canals generate a large specific area ranging between 35-45 m^2/g reducing the water absorption by 30%. The natural zeolite takes advantage of the pozzolanic characteristics in addition to its crystallized structure [14].

Application of the FA and GBFS can stabilize characteristics of the ordinary concrete (OC). Reportedly, the strength of concrete against thermal cracks increases due to the low speed of the hydratation process of the FA and GBFS compared to that of the ordinary Portland cement (OPC) [15]. On the other hand, low speed of hydration hindered the increasing trend in concrete strength and thus, presence of FA and GBFS left a negative impact on the speed of growth in strength although, they can improve the strength with respect to curing time [16]. In general, due to the glass texture of these two materials, as the alternative for cement, they can reduce the need for water to attain efficient workability for concrete [15,17,18]. Moreover, they benefited from a proper strength against chloride ions because of their small size by which durability could be improved [19, 20].

Based on the recent studies on the ordinary and self-compacting concretes as well as the researches on mortars and application of various types of pozzolans, it is observed that their partial use as a replacement for cement, can positively effect on the compressive, tensile and flexural strengths as well as water absorption. Consequently, in view of an insufficient number of studies investigating the effect of pozzolans on the PC's characteristics, this study aims to investigate into the characteristics of the concrete specimens in which cement has partially replaced with zeolite, FA, SF, and GBFS.

2. EXPERIMENTAL PROGRAM

In this work, 162 cylindered specimens with the size of 10×20 cm, containing zeolite, SF, FA (Class F - ASTM C618) [21] and GBFS with replacement ratios of 10 and 20% were prepared to conduct the splitting tensile experiments. In addition, the cubic specimens with a size of 10×10×10 cm were constructed to perform the compressive strength (according to ASTM C349 [22]) as well as water absorption tests.

In order to perform the required tests, the mix designs commonly used in construction projects of Iran were employed although, a few changes in the content of aggregates and cementitious materials were applied. Additionally, the water to cement (W/C) ratios varied from 0.35 to 0.45.

To achieve a proper mix design and concrete specimens with high strength, 12 concrete mixes (Table 1) were considered with different weight and porosity. For each one, three cylindrical specimens with a size of 10×20 cm were prepared and then, the compressive strength test was conducted on them. Finally, the mix design No. 12 with minimum porosity (16%) and maximum compressive strength (13.1 MPa) which is going to be mixed with different pozzolanic materials, was selected as the target mix design to perform the compressive, tensile and water absorption tests.

The letters of A, M, Z, K, and S stand for the control concrete and the specimens containing the SF, zeolite, FA and GBFS, respectively. Furthermore, numbers of 10 and 20 represent the ratios for replacement of cement with the pozzolans.

TABLE 1. Details of the Mix Designs (Kg/m^3)

Mix. ID.	Gravel	Water	Cement	Superplasticizer (Percent of Cement weight)	Porosity(%)	Density (kg/m^3)
1	1480	83	185	3	29	1730
2	1470	95	210	3	27	1743
3	1470	110	245	3.4	25	1778
4	1435	86	205	3	28	1770
5	1505	90	215	3.4	26	1800
6	1610	97	230	3.4	21	1840
7	1500	95	250	3.8	25	1820
8	1590	100	265	3.8	20	1870
9	1680	106	280	3.8	16	1910
10	1500	105	300	4	22	1960
11	1575	110	315	4	18	1985
12	1625	114	325	4	16	1995

2. 1. Material Properties Portland cement type II, produced in Shahrood cement factory, was used which was mixed with the tap water of Garmsar City. In addition, superplasticizers were used to increase flowability and workability of the concrete mixes.

2. 2. Concrete Mix Design The W/C ratio was taken 0.35. In addition, 4% superplasticizer based on carboxylate was used as the high range water reducer (HRWR) aiming to improve the workability of concrete. Meanwhile, the pozzolans were used in concrete mixes as the replacement for cement. The process of concrete mix design was performed in accordance with ASTMC192 [23] in the Concrete Technology Laboratory of the University of Garmsar. Details of concrete mix designs are presented in Table 2.

2. 3. Testing Procedure The concrete specimens were immersed in water according to ISIRI581 [24]. To prepare the concrete mixes, first, the mixes were constructed incorporating the pozzolans and superplasticizer. Then, the 162 mixes were cast such that 3 specimens were built for each test. Each cast was built in three steps and vibrated in each step. After 24 h, the specimens were demolded and immersed in water with a temperature of 25 °C. Thereafter, they were removed from the water at the ages of 7 and 28 days.

3. COMPRESSIVE STRENGTH

After taking concrete specimens out of the water, they were kept out for less than 1 h at the ambient temperature so that their surface moisture gradually dried. Then, the compressive strength test was conducted on the 10×10×10 cm cubic specimens which were loaded by a hydraulic jack with capacity and speed of 2000 kN and 0.25 MPa/s.

To perform the test, the specimens were placed between the two jaws of the testing machine and compressed with a proper rate.

Figures 1 and 2 show the compressive strength diagrams of the specimens containing various pozzolans at the ages of 7 and 28 days. At the age of 7 days, the compressive strength of the PC improved by increasing the replacement ratio of SF, zeolite, FA, and GBFS. In quantitative terms, at 10% and 20% replacement, the compressive strength of the control specimen grew up to 3% and 67%, respectively which is attributed to the completion of hydration process in cement. Among pozzolanic materials, the specimen containing FA had the lowest compressive strength in which inclusion of 10% FA led to a slight decrease at the age of 7 days compared to that of the control concrete. In addition, the highest 7-day strength was obtained in the specimen containing SF whose value is equal to 67% and 51% at the replacement ratios of 10% and 20%, respectively. It is noteworthy that the GBFS and zeolite left similar effects on the PC compared to the SF and FA. In addition, zeolite and FA affect the concrete similarly which means that they both can slightly enhance the strength.

In general, it can be concluded that to overcome the shortcomings of the PC, it is better to include SF and GBFS by which the adherence of mixes increases. Quantitatively, it was observed that the SF and GBFS can improve the compressive strength by 50 to 60%.

Figure 2 illustrates the trend of increase in compressive strength at the age of 28 days. As observed, the level of increase in strength for the specimen containing zeolite is greater than that of the other concrete mixes. Based on the results, the inclusion of the SF increases the strength by 49%.

In a similar manner, replacement of cement with 10 and 20% FA, enhances the strength up to 31 and 16%, respectively. Hence, it is recommended to prevent using the FA in the PC due to the behavioral differences in comparison with conventional concrete.

TABLE 2. Mix details (Kg/m^3)

Mix. ID.	Gravel	Water	Cement	Pozzolan	Superplasticizer (Percent of Cement weight)
A	1625	114	325	-	4
M10	1625	114	292.5	32.5	4
M20	1625	114	260	65	4
Z10	1625	114	292.5	32.5	4
Z20	1625	114	260	65	4
K10	1625	114	292.5	32.5	4
K20	1625	114	260	65	4
S10	1625	114	292.5	32.5	4
S20	1625	114	260	65	4

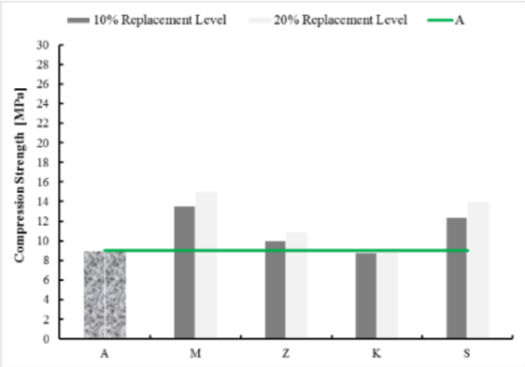

Figure 1. 7-day compressive strength of the specimen containing different types of pozzolans

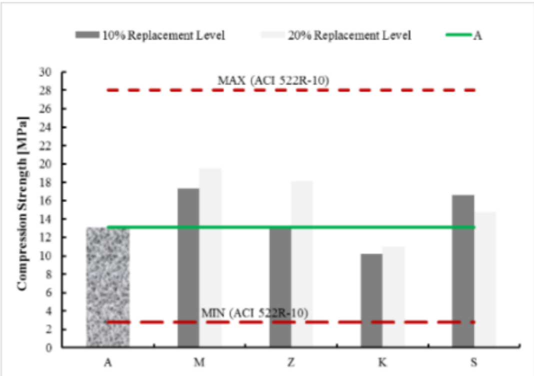

Figure 2. 28-day compressive strength of the specimen containing different types of pozzolans

As a result, it is concluded that replacement of cement with the SF, zeolite, and FA improves the 7- and 28-day compressive strength of the PC. Moreover, it is observed as the specimens become aged, zeolite manages to more effectively affect them which is caused by convenience in the release of C-S-H (i.e. Calcium-Silicate-Hydrate) [25] gel compared to the other pozzolanic materials.

According to ACI 522R-10 [26], the 28-day strength of the PC should range between 2.8 to 28 MPa. Hence, it can be said that all results are in a standard range as their values range between 10.2 to 19.1 MPa. Moreover, according to the same standard, porosity percentage of concrete is supposed to range between 15 to 35% and in this respect, in the 12 mix designs used herein, the porosity varies between 16 to 19% to meet the standard.

4. TENSILE STRENGTH

According to ASTM C496 [27], the Brazilian splitting test, as an indirect test method, was employed to assess the tensile strength. In this test, a concrete cylinder was placed horizontally and loaded in tension along the length of the cylinder by the same jack as well as the same capacity and speed of loading adopted for compression tests.

Figures 3 and 4 demonstrate the tensile strength diagrams of the specimens containing the pozzolans with different replacement ratios at the ages of 7 and 28 days. As can be seen, At the age of 7 days, the SF has improved the tensile strength up to 270% compared to the control specimen. Comparatively, the SF has left greater effects on the tensile strength at the age of 7 days compared to the other pozzolans. It should be mentioned that the same observation was made in the case of compressive strength. Additionally, the use of zeolite and GBFS has led to a remarkable enhancement in tensile strength. According to the results, 10% of the FA has not significantly affected on the 7-day strength, while at 20% replacement, the strength has improved by 50%. It is recommended to use all pozzolans except for the FA (as the pozzolanic characteristic of fly ash cannot be activated) to improve the tensile strength of the PC.

According to the results at the age of 28 days, although the of the FA improved the tensile strength, this incorporation couldn't provide an appropriate margin of safety for an efficient improvement in tensile strength of

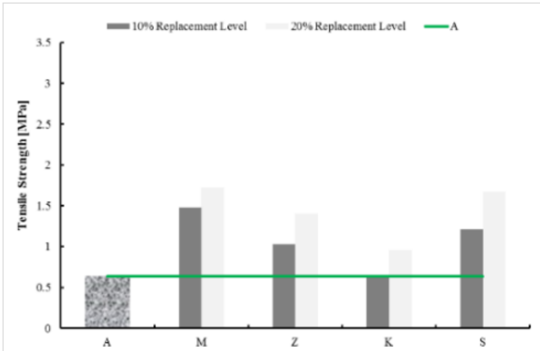

Figure 3. 7-day tensile strength of the specimen containing different types of pozzolans

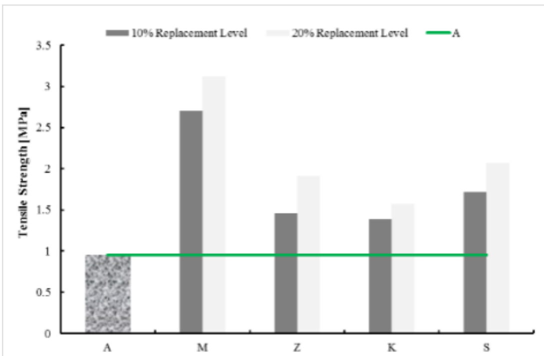

Figure 4. 28-day tensile strength of the specimen containing different types of pozzolans

the PC. The trend of variations in tensile strength caused by use of the other pozzolans at the age of 28 days, was similar to that of the age of 7 days, whereas the specimens containing the SF, experienced an increase up to 330% in their 28-day tensile strength. Generally, to enhance the tensile strength of the PC, the ratio of 20% for replacement, is recommended.

5. WATER ABSORPTION TEST

Water absorption test was conducted on the cubic specimens sized 10×10×10 cm at the ages of 7 and 28 days as per ASTM C642 [28].

Absorptions of 5% and beyond, 3–5% and 0–3% were categorized as poor, average and good limits with respect to CEB-FIP [29], respectively. As shown in Figure 5, the specimens containing the zeolite, FA and GBFS had the water absorption of less than 5% which can be classified as good and average quality in this condition. However, the concrete mixes containing the SF and control specimen both had water absorption greater than 5% indicating their poor quality. Thus, it is not recommended to utilize the SF at the age of 7 days, as it does not improve the water absorption.

The results of water absorption test for 28-day concrete are demonstrated in Figure 6. As can be seen, absorption of the specimens containing zeolite, FA and GBFS is less than 5% which can be classified as good and average concrete quality, similar to the results of concrete specimens at the age of 7 days. However, the specimen containing the SF and the control concrete is not in good condition in terms of water absorption.

According to the results, the water absorptions were diminished as the age of concrete specimens passed, which can be due to the tendency of cement paste for absorbing water and curing process at the early ages. Reduction of water absorption for the specimen containing zeolite at the age of 28 days was greater than that of other mixes. Based on this finding, the use of zeolite in the PC is justifiable at the older ages.

One of the significant results that can be derived from the water absorption test, is concerning the concrete durability in different environmental conditions. The less the water absorption is, the less harmful materials can penetrate into the concrete. Besides, according to Figure 5, at the age of 7 days, adding zeolite, fly ash and granulated blast furnace slag improves the durability of the PC and only the specimens containing the SF did not encounter enhancement in their durability because C-S-H gel was not released. Approximately, the same trend is observed in the specimens aged 28-day (Figure 6). Accordingly, the water absorption of the 28-day specimens containing zeolite decreased by 5 times compared to that of the 7-day specimen and subsequently, they became more durable. Besides, the durability improved in the other specimens (except the specimens containing the SF) following the inclusion of the pozzolans to the concrete.

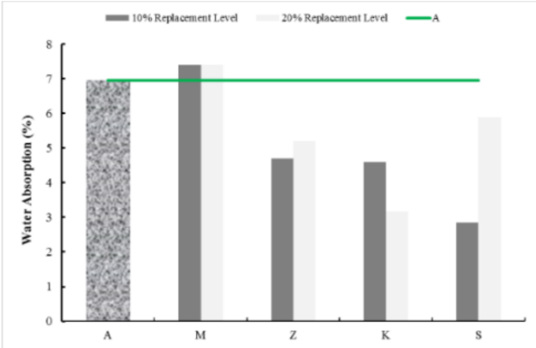

Figure 5. Water absorptions of the specimens containing different types of pozzolans at the age of 7 days

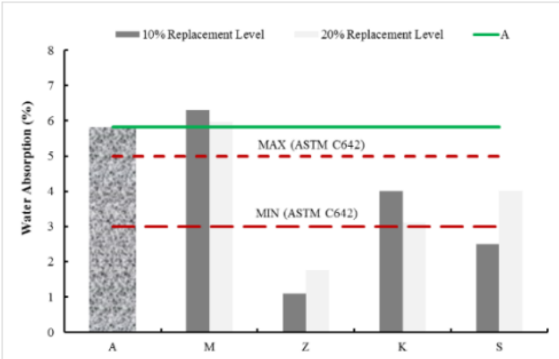

Figure 6. Water absorptions of the specimens containing different types of pozzolans at the age of 28 days

6. CONCLUSION

In this paper, the behavior of the pervious concrete (PC) incorporating different replacement ratios of zeolite, silica fume (SF), fly ash (FA) and granulated blast-furnace slag (GBFS) was evaluated by means of compressive and tensile strength as well as water absorption tests. The following conclusions are drawn:

- Based on the results of compressive strength tests at the ages of 7 and 28 days, it was concluded that application of 10% fly ash at the age of 7 days, reduced the strength by approximately 2% compared to the control specimen. In addition, the specimens containing zeolite and FA, experienced an increase in their strength at the age of 28 days although, its level was insignificant. However, the compressive strength of the specimens in which 10 and 20% of cement was replaced with the SF, enhanced by 67 and 51%, respectively.
- With respect to the results of compressive strength test, the specimens containing 20% zeolite, exhibited an

improvement in their strength at the age of 28 days compared to that of 7 days.

- The results of tensile strength tests indicated that inclusion of the SF at the ages of 7 and 28 days, can improve the strength by 2.7 and 3.3, respectively. The other pozzolans have greatly increased the strength among which, the GBFS led to the most desirable outcomes.
- Based on the comparison of the rate of increase in tensile strength of specimens at the age of 28 days to that of 7 days, the strength of specimens containing the SF has improved by 83%. Moreover, the use of 10% FA could not substantially enhance the tensile strength. However, the strength grows by 65% compared to the age of 7 days when the replacement ratio of the FA raised by 20%.
- According to the results derived from the water absorption test at the ages of 7 and 28 days, use of the SF is not recommended to improve the water absorption characteristics of the PC due to its high water absorbability. Whereas, the water absorption of the other pozzolans is less than 5% rated as fair and good. Besides, water absorption of the specimen containing zeolite is reduced by 77% in comparison with the age of 7 days and this rate in the other specimens is limited to 20% at most.
- In a general conclusion, the specimens containing the GBFS and zeolite managed to exhibit the best performance. However, the other specimens in which the SF and FA are used, some of the behavioral parameters improved, nevertheless, they cannot leave satisfactory effects based on the results obtained from compressive and tensile strength as well as water absorption tests.

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چکیده

در این مقاله به بررسی عملکرد بتن متخلخل روسازی حاوی انواع پوزولان ها در سنین ۷ و ۲۸ روزه پرداخته شد. بدین منظور تعدادی نمونه ی استوانه ای به ابعاد ۱۰*۲۰ سانتی‌متر و مکعبی ۱۰*۱۰ سانتی‌متر جهت انجام آزمایشات مقاومت فشاری و کششی و همچنین آزمایش جذب آب ساخته شد. پوزولان های بکار رفته شامل میکروسیلیس، زئولیت، خاکستر بادی و سرباره‌ی کوره‌ی آهن‌گدازی بوده که بعنوان جایگزین بخشی از سیمان در مقادیر ۱۰ و ۲۰ درصد بکار رفتند. لازم به ذکر است شن ریزدانه ی بکار رفته در این مقاله از معدن هامش‌بر استان سمنان بعنوان مصالح بومی بکار گرفته شد. نتایج حاکی از آن است که استفاده از میکروسیلیس و سرباره کوره آهن گدازی در بتن متخلخل بیشترین تأثیر را در بهبود مقاومت فشاری و کششی داشته بطوری که بطور میانگین مقاومت فشاری را ٦۰ درصد و مقاومت کششی را تا حدود ۳ برابر نسبت به نمونه شاهد بهبود می بخشد. همچنین در آزمایش جذب آب بتن متخلخل، بجز نمونه حاوی میکروسیلیس که نتنها مقدار را کاهش نداده بلکه افزایش هم داد، اما در سایر پوزولان‌ها مقدار جذب آب نمونه ها کاهش پیدا کرده بطوری که طبق آیین‌نامه CEB-FIP در رده متوسط و خوب قرار گرفتند.

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