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The effect of natural pozzolans on properties of vibropressed interlocking concrete blocks in different curing conditions

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Abstract

Concrete block pavements have become an attractive engineering and economical alternative to both flexible and rigid pavements because of its high strength and durability. The influence of pozzolanic mineral additions – natural zeolite and expanded perlite powder on the properties of concrete interlocking blocks in different curing conditions has been studied. The use of zeolite as a substitute for cement in the production of concrete blocks increased the water demand but decreased the water absorption of the blocks. Obtained results show, that concrete blocks with 10% substitution of cement with zeolitic tuff is characterized by higher strength, lower mass loss and absence of efflorescence.

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1. Introduction

Interlocking concrete blocks (ICB) has been widely used in a number of countries for quite some time as a specialized problem-solving material in areas where traditional asphalt or concrete pavements are less applicable due to many structural, environmental and social constraints (Jamshidi et al., 2019). Their main benefit of ICB over other pavement materials is that individual blocks can later be lifted up and replaced.

Portland cement of type CEM I is usually used for ICB. Blast furnace slag or fly ash are sometimes added (Ganjian et al., 2015; Uygunoğlu et al., 2012). The literature analysis also shows that limited researches is dedicated to cement replacement in paving blocks. Therefore, there is a need in researches of possibility to use active mineral additions in such materials, especially natural pozzolans.

Relatively low cost of zeolitic tuff and its availability in certain regions around the world induces its use in concrete

industry. Zeolitic tuff is crystalline microporous material that contains large quantities of reactive SiO₂ and Al₂O₃ and prove to be great pozzolanic addition in cementitious materials (Tran et al., 2019). Several studies (Nagrockiene et al., 2016) indicates, that 10% substitution of cement with zeolite significantly improves compressive strength and freeze-thaw resistance of concrete.

Previous studies (Markiv et al., 2016; Sobol et al., 2015) have shown that zeolitic tuff contains silicon dioxide, which interacts with Ca(OH)₂, a product of cement hydration, with the formation of calcium hydrosilicates, which improve the microstructure of the cement matrix and increase the durability of building materials and products. In addition, the use of zeolites prevents alkaline and sulfate corrosion.

Perlite is natural volcanic siliceous material that has a relatively high water content. When heated to 900°C, it releases entrapped water and expands to form cellular structure. Grounded expanded perlite is material of good pozzolanic

properties, and can increase strength up to 50%, when used as cement additive (Kotwica et al., 2017). Due to its high porosity, perlite can significantly increase the water demand of the concrete mixture, but at the same time improve mass transport properties of hardened concrete (Karein, 2018).

2. Experimental

Concrete for paving blocks is characterized by lower cement/aggregate ratio in comparison with regular concrete. The high aggregate content in concrete paving blocks results in a zero-slump concrete mix. The machine used in the manufacture of paving blocks should have the capacity to produce paving blocks of a high quality by providing a high level of compaction through the use of hydraulic pressure and high intensity vibration to the moulds in order to remove entrapped air and increase the density (Limbachiya et al., 2016).

As this manufacturing process could not be replicated in the laboratory, the experiment was split into two phases. First phase involved producing of samples from semi-rigid mix in the laboratory. Second phase included prefabrication of concrete blocks from zero slump mixture using industrial high-performance vibrating press.

Commercially available cement CEM I 42.5 R, which meets the requirements of EN 197 was used in this work. Zeolitic tuff (clinoptylolite type) derived from Transcarpathian region of Ukraine and expanded perlite powder with bulk density of 67 kg/m³ were used as mineral additions.

Table 1. Chemical compositions of cement and additives

Material		CEM I 42,5 R	Zeolitic tuff	Perlite
Chemical composition, %	SiO ₂	21.49	75.34	71.78
	Al ₂ O ₃	4.85	8.77	12.77
	Fe ₂ O ₃	3.59	1.30	1.54
	CaO	64.54	4.60	1.31
	MgO	1.44	0.55	0.60
	Na ₂ O	0.41	1.22	3.00
	K ₂ O	1.13	5.41	4.10
	SO ₃	1.60	0.05	0.90
	LOI	0.95	5.76	4.00

Also, commercially available polycarboxylate-based superplasticizer with a specific gravity of 1.05 and solid content of 20% for semi-rigid concrete mixture, and a complex additive with specific gravity of 1.20 for zero-slump concrete mixture were used in this study.

The river sand with fineness modulus of 1.8 was used as a fine aggregate. Fine and coarse granite aggregate of irregular shape was used for the research. Bulk density of coarse and fine aggregate was 1420 and 1440 kg/m³, respectively, voidage was 45% for both aggregates.

Three types of concrete mixtures with different additions were prepared. Mixture proportions and fresh concrete properties are listed in Table 2. Amount of expanded perlite was calculated to occupy the same volume in concrete as zeolite because of its very low bulk density.

In the first phase, concrete ingredients in the designed proportions have been mixed with water in laboratory pan mixer. After that superplasticizer and additional water were added to receive the target slump (30-40 mm) for all mixtures. Then, prepared fresh concrete were casted into 100×100×100 mm cube and 100×100×400 mm prism moulds and compacted by means of laboratory vibrating table.

Table 2. Mixture proportions and fresh concrete properties

Concrete mixture	Cement (kg/m ³)	Zeolite (kg/m ³)	Zeolite (wt.%)	Perlite (kg/m ³)	Perlite (vol.%)	Sand 0-2 (kg/m ³)	Coarse aggregate 2-10 (kg/m ³)	Superplasticizer (% of cement)	Slump (cm)	Concrete mix density (kg/m ³)
C	400	0	-	0	-	600	1250	1.0	4	2430
Z	360	40	10	-	-	600	1250	1.0	3	2376
P	360	-	-	6.2	10	600	1250	1.0	4	2390

Production of ICB was performed on Mustafa Yontar KPM 1036 machine (Figure 1). Table 3 shows the mixture proportions of ICB concrete.



Fig. 1. View of ICB production equipment

Type B blocks were compacted in one layer, schematic view of ICB are presented in Fig.2.

Table 3. Mixture proportions of ICB concrete

Mixture	Cement (kg/m ³)	Zeolite (kg/m ³)	Sand (kg/m ³)	Fine agg. FM = 2,5 (kg/m ³)	Coarse agg. 5-10 (kg/m ³)	Complex additive (cem. wt.%)	w/c
Cntr	380	0	500	775	850	0.65	0.34
Zeol	342	38	500	775	850	0.65	0.35

Concrete specimens were divided into two parts for curing at dry conditions (RH=55±5%, t=20±3°C) and normal curing

(RH=95±5%, t=20±3°C). Concrete specimens were exposed to appropriate curing conditions immediately after casting.

Compressive and flexural strengths' tests of concretes were carried out according to EN 12390-3 and EN 12390-5, respectively.

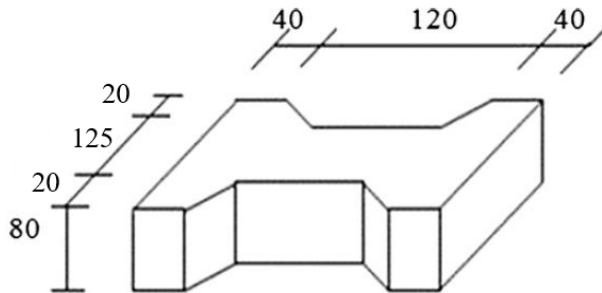


Fig. 2. Schematic view of ICB

The mass loss of ICB specimens was measured in laboratory conditions at several time intervals after production. ICB water absorption were determined by the weight measurements of saturated specimens in air and dry weight (oven drying at 105 °C to constant weight).

Efflorescence observation test of ICB was performed on specimens partially immersed in water and subjected to constant airflow for 3 days.

3. Results and discussion

According to the test results (Table 3), concrete samples with zeolite are characterized by a slightly lower flexural strength in early stages of hardening (3 days) in dry conditions, but after 28 days Z concrete shows by an average of 7% higher flexural strengths comparing to C. Similar increase can be observed for compressive strength. So, the compressive strength of dry cured tested samples with 10% zeolite exceeds the strength of specimens without additive by 5% after 28 days of hardening.

Table 4. Strength test results of concrete samples

Mixture	Compressive strength of the samples, MPa, at age, days		Flexural strength, MPa, at age, days	
	3	28	3	28
Wet curing				
C	35.3	59.1	6.0	7.0
Z	33.0	60.9	5.3	7.4
P	35.1	53.5	5.8	6.5
Dry curing				
Control	34.8	56.7	5.8	6.8
Z	32.6	60.1	4.9	7.3
P	34.7	52.6	5.4	6.3

Compressive strength results indicate, that substitution of cement with perlite powder have no significant influence on concrete's mechanical properties in normal and dry curing conditions. However, P concrete samples at 28 days show lower flexural and compressive strength than the control samples both in normal and dry curing conditions.

Vibropressed ICB are usually produced at low water-to-cement ratios (w/c=0.28 – 0.36). Obtained results show, that partial substitution of cement with zeolitic tuff can allow to maintain appropriate mechanical properties of ICB.

Table 5 reports the compressive strength of ICB in different curing conditions. As it can be seen, compressive strength of concrete without the addition of zeolite in the early stages of hardening is slightly higher than that of concrete containing zeolite, regardless of curing conditions. However, at the age of 28 days, the strength of ICB containing zeolite exceeds the strength of the blocks based on Cntr mixtures by 28 and 19%, for dry and normal curing conditions respectively. The difference between the results can be interpreted in several ways. Firstly, zeolitic tuff is reported to show high pozzolanic activity, which can enhance the mechanical properties of concrete. Secondly, concrete with porous mineral additive, such as zeolitic tuff, tends to have higher w/c ratio, which can result in better ICB mixture compaction. At last, higher water content in mix provides better resistance to drying.

Table 5. Compressive strength of ICB in different curing conditions

Mixture	Curing conditions	Compressive strength, MPa, at age, days		
		3	7	28
Cntr	Normal	24.9	29.6	35.2
Zeol	Normal	21.1	29.8	41.9
Cntr	Dry	27.9	29.1	31.6
Zeol	Dry	27.1	31.7	40.4

The measurement of the water absorption of ICB, cured in different conditions (Fig. 3) indicates that all block mixtures reported satisfactory results (namely less than 6%). It should be noted, that Zeol ICB mixtures showed almost twice lower absorption rates in comparison to Cntr, which is assumed to be due to the greater refinement of the microstructure.

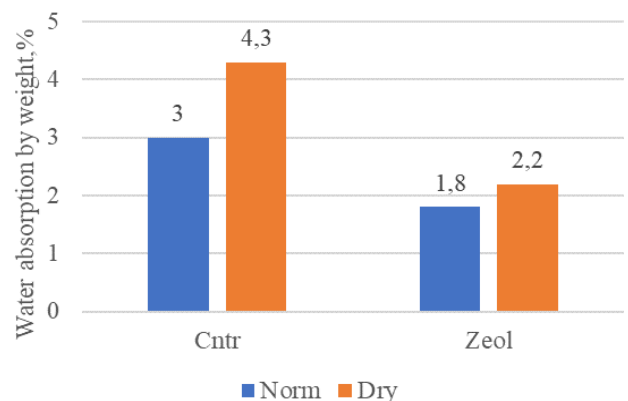


Fig. 3. Water absorption of ICB, cured in different conditions

Generally, high mass loss for both concretes were observed at early stages of hardening (Fig. 4). However, concrete with zeolitic tuff was found to have slightly lower mass loss comparing to the control mixture. It could be attributed to higher compaction and, as a result – higher density of ICB.

Concrete contains a variety of soluble mineral salts, both from the cement and from admixtures. When moisture or water vapor migrates through ICB, it can bring soluble salts (including carbonates, chlorides and sulfates) to the surface of the concrete.

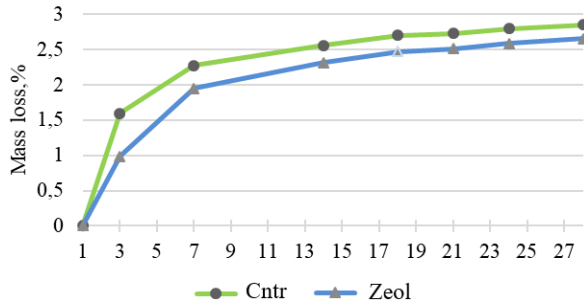


Fig. 4. . Mass loss of ICB

This white plaque on the surface of the concrete is known as efflorescence. Observation test showed no clear sign of this phenomena on Zeol ICB samples (Fig. 4).



Fig. 4. . Efflorescence observation test of Zeol ICB

4. Summary and conclusion

From the study, the following conclusions can be drawn:

1. A 10% substitution of cement with zeolitic tuff does not cause a significant reduction in strength compared to the concrete, which does not contain additions.
2. Results indicate that cement concrete in dry conditions is characterized by unsatisfactory development of strength compared to concrete under normal curing conditions, but

addition of zeolitic tuff can increase both flexural and compressive strength of concrete at late stages of hardening.

3. The concrete paving blocks tests showed the effectiveness of the developed concrete composition for ICB, which are characterized by increased strength, lower water absorption and absence of efflorescence.

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天然火山灰对不同养护条件下振动互锁混凝土砌块性能的影响

關鍵詞

混凝土联锁块
沸石
珍珠岩
具体实力
固化条件

摘要

由于具有高强度和耐用性，混凝土砌块路面已经成为一种有吸引力的工程，并且对于柔性和刚性路面都是经济的替代方案。研究了火山矿添加剂 - 天然沸石和膨胀珍珠岩对不同养护条件下混凝土联锁块性能的影响。在混凝土砌块的生产中使用沸石作为水泥的替代物增加了用水需求但降低了砌块的吸水性。获得的结果表明，具有10%水泥替代沸石凝灰岩的混凝土砌块的特征在于更高的强度，更低的质量损失和没有风化。