The Effect of Porous Pozzolanic Polydisperse Mineral Components on Properties of Concrete

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Abstract. The role of polydispersity of zeolitic tuff in the realization of its properties as an active mineral addition and optimization of granulometric composition of concrete at the level of the mesostructure have been confirmed. The function of a polydisperse zeolitic tuff and perlite in the creation of water reserve for hydration of cement in conditions of reduced relative humidity and in case of improper curing is substantiated. In dry hardening conditions, concrete containing polydisperse mineral components such as perlite and zeolitic tuff are characterized by a slightly lower percentage of compressive strength reduction in comparison with concrete without additions. Flexural strength of moist cured concrete with polydisperse zeolitic component is 8 and 12% higher than concrete without additives at 28 and 90 days respectively.

Keywords: Zeolitic tuff · Concrete strength · Particle size distribution · Microstructure · Internal curing

1 Introduction

Pozzolanic mineral components of concrete such as fly ash, granulated blast furnace slag, metakaolin, zeolitic tuff (known as mineral additions for Portland cement) have been widely used as a supplementary cementing materials (SCMs) which contribute to the properties of hardened concrete through hydraulic or pozzolanic activity and impart them technical, economical and ecological advantages (Ahmadi and Shekarchi 2010; Bilim 2011; Bostanci et al. 2016; Dvorkin et al. 2012; Zhang et al. 2016). It is well known that mineral components can improve the durability properties, reduce the heat of Portland cement hydration, increase the corrosion resistance and reduce the prime cost of concrete (Najimi et al. 2012; Vejmelková et al. 2015). These pozzolanic mineral components is used in most cases in finely ground state to replace the most energy intensive component such as clinker in Portland cement and latter one in concrete (Sanytsky et al. 2018; Limbachiya et al. 2014). However, the use of fine ground mineral additions in concrete gradually exhausts itself, because their production requires consumption additional energy resources, increases water demand of concrete and as a result the use of higher amount of plasticizer or more effective superplasticizer to obtain

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concrete with appropriate strength and durability properties. New tendencies of concrete technology development are directed to optimize the particle size distribution. In most cases the lack of particles which diameter lays between particle size distribution of Portland cement and fine aggregate is observed in concrete. This volume can be filled in with mineral additions. In this case the optimization of its micro- and macrostructure takes place and influence on properties of concrete. It allows obtaining targeted strength and durability properties of concrete at lower Portland cement content. It meets the strategy of sustainable development in construction industry.

One of the many types of pozzolans which can be used is zeolitic tuff (Kocak et al. 2013; Sobol et al. 2014; Jo et al. 2012; Markiv et al. 2016). This natural pozzolanic mineral component of concrete has unique properties. Although zeolite which is the main rock forming mineral of zeolitic tuff is crystalline, it shows proper pozzolanic activity (Najimi et al. 2012; Markiv et al. 2016). It also has intracrystalline channel porosity. It becomes the basis for studying the possibility of its use for internal curing of concrete. The possibility of zeolitic tuff use for internal curing of concrete is also being investigated by many researchers. Ghourchian et al. (2013) concluded that the performance of porous aggregates in internal curing depends on their crystalline microstructure and they sometimes need pretreatment before use (Yang et al. 2019).

Thus, the aim of this article is to study the influence of particle size distribution (PSD) of zeolitic tuff coming from Sokyrnytsia (Ukraine) on the properties of concrete and its possible use for internal curing.

2 Materials and Methods

2.1 Materials and Mixture Design

Portland cement CEM I 42.5, which conforms the requirements of EN 197 was used in this study. Two types of mineral additives were used for cement substitution: natural zeolitic tuff (clinoptylolite type) derived from Transcarpathian region of Ukraine and expanded perlite with bulk density of 67 kg/m^3. Retaining on sieve 008 for coarse zeolite (ZC) and coarse perlite (PC) was about 12 and 15% respectively.

Three types of concrete mixtures were prepared. Reference mixture (Ref) contained 400 kg/m^3 of Portland cement. For ZC and PC mixtures 10 wt.% of cement was replaced with polydisperse zeolitic tuff and perlite. Amount of expanded perlite was calculated to occupy the same volume in concrete as zeolitic tuff because of its very low bulk density. The content of fine and coarse aggregates for all mixtures was 600 kg/m^3 and 1250 kg/m^3 respectively. All mixtures also contained commercially available polycarboxylate based superplasticizer. The dosage of superplasticizer was 1.0 wt.% of cement. Consistency class of concrete mixtures was S1 (Slump = 20–40 mm). W/c ratio for concretes were 0.38–0.42.

2.2 Specimen Preparation, Curing and Testing

First, concrete ingredients in the designed proportions have been mixed with water in laboratory pan mixer for 5 min, to let the porous components absorb the mixing water.

After that superplasticizer and additional water were added to receive the target slump (20–40 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.

Concrete specimens were divided into two parts for curing under dry conditions (RH = 68 ± 3%, t = 20 ± 2 °C) and moist curing (RH = 95 ± 5%, t = 20 ± 2 °C). Concrete specimens were exposed to appropriate curing conditions immediately after casting.

Internal relative humidity (IRH) test was carried out using set-up, shown in Fig. 1. After demoulding a hole was drilled in specimens and digital RH probe was installed in each cube. Probes were sealed with sealant to avoid moisture loss. Similar method was proposed by El-Dieb (2007).

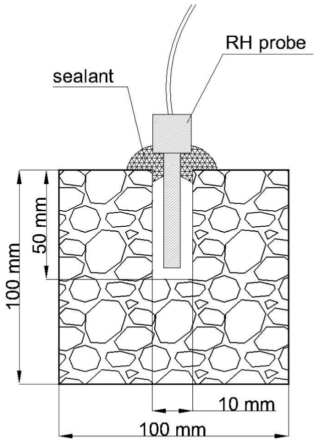


Fig. 1. View of internal relative humidity test

IRH was measured for concrete cured in dry (RH = 68 ± 3%, t = 20 ± 2 °C) and hot (RH = 55 ± 5%, t = 40 ± 2 °C) conditions. Compressive and flexural strengths' tests of concrete were carried out according to EN 12390-3 and EN 12390-5 respectively.

3 Results and Discussion

As it is well-known, high-quality aggregates have low or almost zero content of grains less than 0.16 mm size. Since Portland cement which is produced nowadays is characterized by a significant fineness, there are gaps between the binder and aggregates in the grading curve of concrete ingredients. The diameter of particles of finely dispersed additions ranged from 1 to 60 μm, which corresponds to the PSD of Portland cement. At the same time, diameter of the particles of polydisperse mineral components used in this work are located in the range of 0.4–800 and 6–1250 μ for the polydisperse zeolitic component

(PZC) and polydisperse perlitic component (PPC), respectively. A better continuity of the gradation at the level of concrete mesostructure is provided by introducing a PZC. It is confirmed by the comparison of the distribution curves of the ingredients of studied concrete and the curve of the maximum particle packing density – 0.39 power curve (Fig. 2).

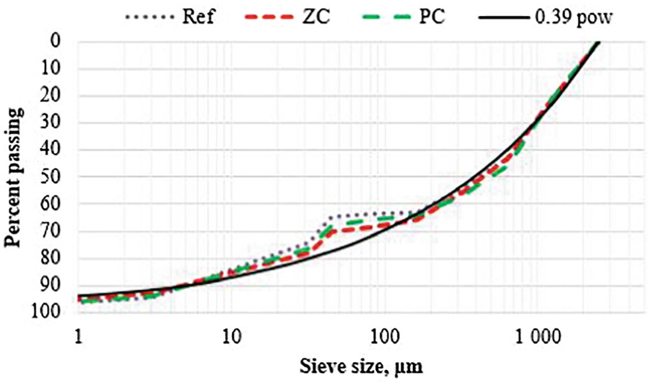


Fig. 2. PSD of concrete ingredients and 0.39 power curve

Generally, incorporation of mineral additions results in decrease of concretes mechanical properties. When additions are used the percentage of concrete strength reduction usually corresponds to the percentage content of additions in concrete. As it can be seen in Table 1, the pattern is retained for concrete with 10% substitution of Portland cement with perlite, it is characterized by 8–10% lower compressive and flexural strength in comparison with Ref concrete. Results of compressive strength test at 28 and 90 days of hardening indicate, that concrete containing zeolitic tuff does not inferior significantly to concrete without additions. At the same time, flexural strength of ZC was 8 and 12% higher than Ref at 28 and 90 days respectively.

Table 1. Flexural and compressive strength of concretes, cured in moist conditions

Mixture identification	Flexural strength, MPa		Compressive strength, MPa		
	28 days	90 days	3 days	28 days	90 days
Ref	6.5	7.6	43.8	69.7	73.2
ZC	7.0	8.5	39.7	66.8	70.9
PC	5.4	6.4	37.8	64.0	66.5

Curing conditions are crucial for gaining an appropriate strength and durability of concrete. Internal water reserve plays very important role in providing a more complete hydration of cement matrix. Figure 3 shows changes of relative humidity for concretes with age. Concrete containing PPC showed the highest internal humidity at all ages and both curing conditions, which corresponds to higher amount of absorbed water than PZC. Retained moisture in porous additions can also contribute to pozzolanic reaction, which takes place at later ages of hardening.

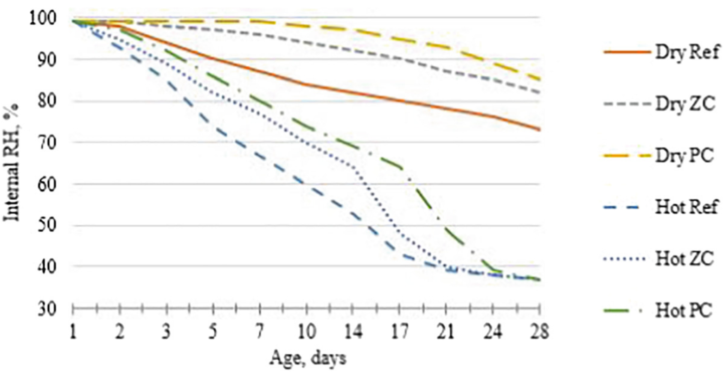


Fig. 3. Internal relative humidity of concretes, cured in dry (RH = 68 ± 3%, t = 20 ± 2 °C) and hot (RH = 55 ± 5%, t = 40 ± 2 °C) conditions

In low RH environment, a self-desiccation process can occur in concrete with low w/c, resulting in incomplete hydration of Portland cement and loss of properties. The influence of porous mineral components on flexural strength tests of concrete, cured in dry conditions, can be seen in Fig. 4. A reduction of flexural strength for Ref concrete at 90 days of hardening corresponds to insufficient moisture content of concrete without additions. The flexural strengths are 32% and 9% higher at 90 days of hardening for ZC and PC concretes respectively in comparison with Ref concrete.

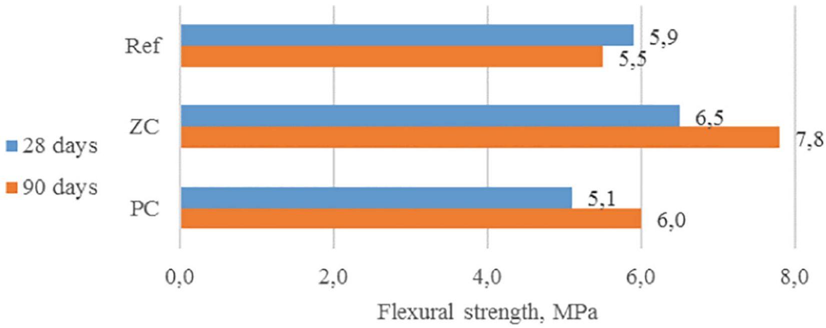


Fig. 4. Flexural strength of concretes, cured in dry conditions

Significantly higher flexural strength of concrete with addition of PZC can be related to both better particle packing and internal curing effect of polydisperse zeolite component as well as its good pozzolanic activity.

Results of compressive strength test are presented in Fig. 5. Ref, ZC and PC concretes are characterized by 6.4, 2.4 and 1% strength reduction in dry curing conditions respectively in comparison with moist cured specimens (Table 1) at 90 days of hardening, which correspond with the tests results of IRH. However, the strength of concrete containing zeolitic component was found to be the highest among concretes under dry curing conditions.

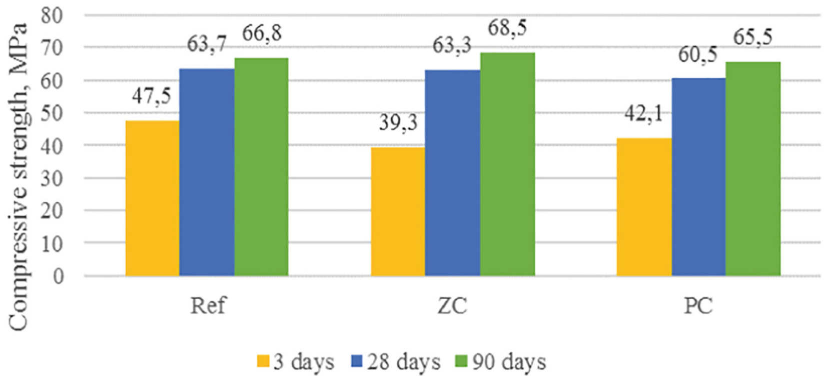
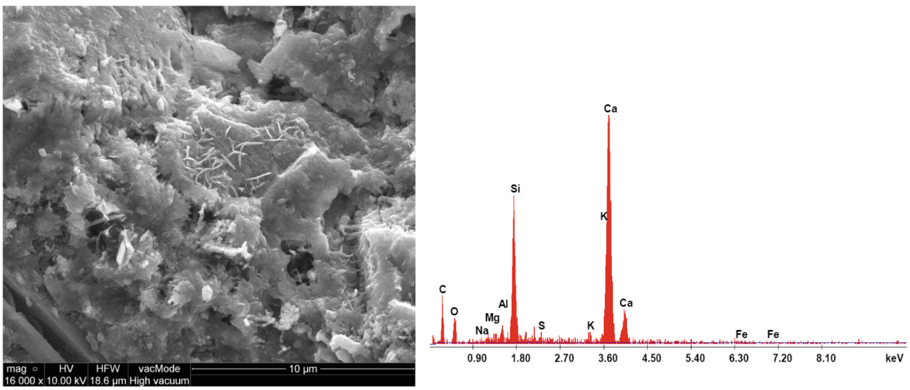


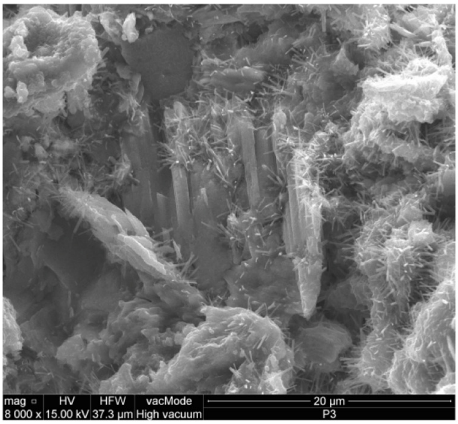
Fig. 5. Compressive strength of concretes, cured in dry conditions

Observation under scanning electron microscope (Fig. 6a) shows, that microstructure of concrete incorporating natural zeolitic tuff has different habitus of crystals of hydraton products. There are no large structural elements of Portlandite $Ca(OH)_2$ inherent to concrete without additions (Fig. 7).



a b

Fig. 6. SEM image (a) and EDX point analysis (b) of concrete containing zeolitic tuff after 28 days of hardening



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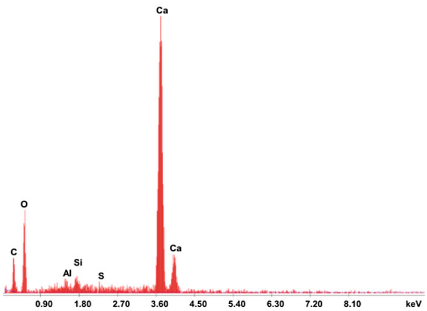

b

Fig. 7. SEM image (a) and EDX point analysis (b) of Ref concrete after 28 days of hardening

Results of EDX point analysis (Fig. 6b) indicates the presence of low-alkali fiber-like crystals of calcium hydrosilicates CSH(I). They reinforce the contact zones in hardening concrete and provide colmatation of pores, therefore improving concrete's flexural strength.

4 Conclusions

In the present study, the expediency and effectiveness of use of a polydisperse zeolitic component in concrete are proved. The following conclusions can be drawn:

1. The addition of PZC provides better particle packing of concrete ingredients at the mesostructure level and improves strength characteristics of hardened concrete.
2. The presence of low-alkali fiber-like crystals of calcium hydrosilicates CSH(I) in ZC concrete reinforces its contact zones and improve flexural strength.
3. Porous polydisperse components provides internal curing effect by creating additional water reserve for hydration of cement in conditions of reduced relative humidity.

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