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Mechanical and Thermal Properties of HSC with Fine Natural Pozzolana as SCM

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Abstract. The article describes the influence of fine natural pozzolana as supplementary cementitious material on the properties of high strength concrete. Natural pozzolana (NP) is a porous material which results in higher porosities and thus lower compressive strength when used in high replacement levels. But if only a small part of cement (up to 10% of weight) is substituted by NP it has positive consequences. The open porosity is on the contrary lowered, resulting in better strength in compression. Thermal characteristics are as usually enhanced with the growth in the content of pores which is in disagreement of mechanical properties and durability of concrete.

Introduction

High strength concrete (HSC) belongs nowadays among the main concerns for many researchers and its development is rapidly growing. The design of such a material cannot be done without the use of suitable additives and admixtures [1]. Natural pozzolana presents good prospects in HSC as a partial substitution of cement when it is used along with some other more reactive additive. NP - namely natural zeolite is a mineral of volcanic origin with white or grey colour [2]. Its inner structure is very porous, which results in lower bulk density of the eventual product [2, 3]. This property is related to high surface area of NP and so NP shows good pozzolanic activity [4]. The supplies of NP are very rich in some countries such as China, Iran, Japan, USA or Cuba [5]. The nearest resource of NP to Czech Republic was found in Slovakia [2].

In this study the focus is aimed at measuring the basic physical parameters of five mixtures of HSC with the addition of natural pozzolana (including the reference mixtures) and assessing the connection of this measured data with values gained from the test of mechanical properties. Basic physical parameters include bulk density, matrix density and open porosity, mechanical parameters are represented by strength in compression after 28 days of curing. The picture of the material parameters is completed with thermal properties described by the means of thermal conductivity and specific heat capacity.

Materials

The composition of studied mixtures can be seen in Table 1. The used NP - natural zeolite comes from Slovakia and is of clinoptilolite type, i.e. the clinoptilolite presents highest part of contained minerals. Table 2 provides its chemical composition. Cement CEM I 52,5 R was selected as the main binder constituent, which was then replaced partly by silica fume with the constant amount of 140 kg/m3 (except the reference mixture BZ3 - ref0) and partly by NP of 10, 30 and 50% of weight of cement for BZ3-10, BZ3-30, BZ3-50 respectively. Water to binder ratio was kept constant at 0.21. Silica aggregates in four fractions along with silica flour was used to gain the sufficient grain size distribution.

Table 1. Material composition.

Component	BZ3 - ref0 [kg/m^3]	BZ3- ref [kg/m^3]	BZ3 – 10 [kg/m^3]	BZ3 – 30 [kg/m^3]	BZ3 – 50 [kg/m^3]
Silica aggregates 0.1-0.6 mm	415	415	415	415	415
Silica aggregates 0.3-0.8 mm	265	265	265	265	265
Silica aggregates 0.6-1.2 mm	207	207	207	207	207
Silica aggregates 1-4 mm	150	150	150	150	150
Silica Flour	140	140	140	140	140
Silica Fume	0	140	140	140	140
Superplasticizer	28.3	28.3	28.3	28.3	28.3
CEM I 52.5 R	618	618	556	433	309
Natural pozzolana	0	0	62	185	309
Water	160	160	160	160	160

Table 2 Chemical composition of natural pozzolana.

Component	Amount [%]
SiO_2	68.15
Al_2O_3	12.3
Fe_2O_3	1.3
CaO	2.63
MgO	0.9
K_2O	2.8
Na_2O	0.75
TiO_2	0.2
Loss on ignition	10.86

Testing Methods

Basic physical parameters. Water vacuum saturation method was used for determination of the fundamental physical material characteristics. These characteristics include bulk density [kg/m^3], matrix density [kg/m^3] and open porosity [Vol.-%] [6].

Mechanical properties. To characterize the mechanical properties of the materials for the purpose of this article the compressive strength test after 28 days of curing was selected. The testing method was performed according to ČSN EN 12390-3 [7] with the use of loading device EU 40.

Thermal properties. Thermal properties were measured in dry state using the commercial device ISOMET 2104 (Applied Precision, Ltd.) [8].The method is based on evaluating heat flow impulses emitted by the device and reflected back by the studied material. The output are the measured values of thermal conductivity [W/m K] and specific heat capacity [J/kg K].

Results of the Experiment

Basic physical parameters. Results of water vacuum saturation method are given in Table 3. Bulk density of the reference mixture BZ3 - ref0 is slightly lower than reference mixture marked as BZ3 - ref. This is because of the fact, that BZ3 - ref0 doesn´t contain any supplementary cementitious material, whilst in the mixture BZ3 – ref there is part of cement replaced by silica fume, which is very finely ground and so fills even small pores and voids better. This fact is clearly visible by the decrease of open porosity by 5%. With the addition of natural zeolite bulk density continues to grow when only 10% of cement is replaced (because of the filler effect), but then it decreases as the part of cement replaced by NP increases. This corresponds to open porosity which shows exactly the opposite trend. Natural zeolite is a porous material which leads to significant rise in open porosity when used in higher amounts. This fact than has negative effects on mechanical properties and durability of the material. Matrix density is lower in all cases compared to the reference mixture without any additives (BZ3 - ref0), which is caused by lower specific gravity of the additives compared to cement.

Table 3. Basic physical properties.

Material	**Bulk density** [kg/m^3]	**Matrix density** [kg/m^3]	**Open porosity** [kg/m^3]
BZ3- REF 0	2141	2513	14.8
BZ3 - REF	2160	2395	9.8
BZ3 - 10	2187	2402	9.0
BZ3 - 30	2089	2300	9.2
BZ3 - 50	2034	2333	13.1

Mechanical properties. Figure 1 presents the results of compressive strength test after 28 days. All the mixtures reached values higher than 60 MPa and so can be classified as high strength concrete. There is significant difference between the reference mixture (BZ3 - ref0) and the reference mixture with silica fume (BZ3 - ref). This approves the need of proper additives to gain high strength. Addition of natural zeolite also shows improvement in strength, but only when used in lower replacement level (BZ3 - 10). With higher amounts there is the negative influence of high porosity of the material.

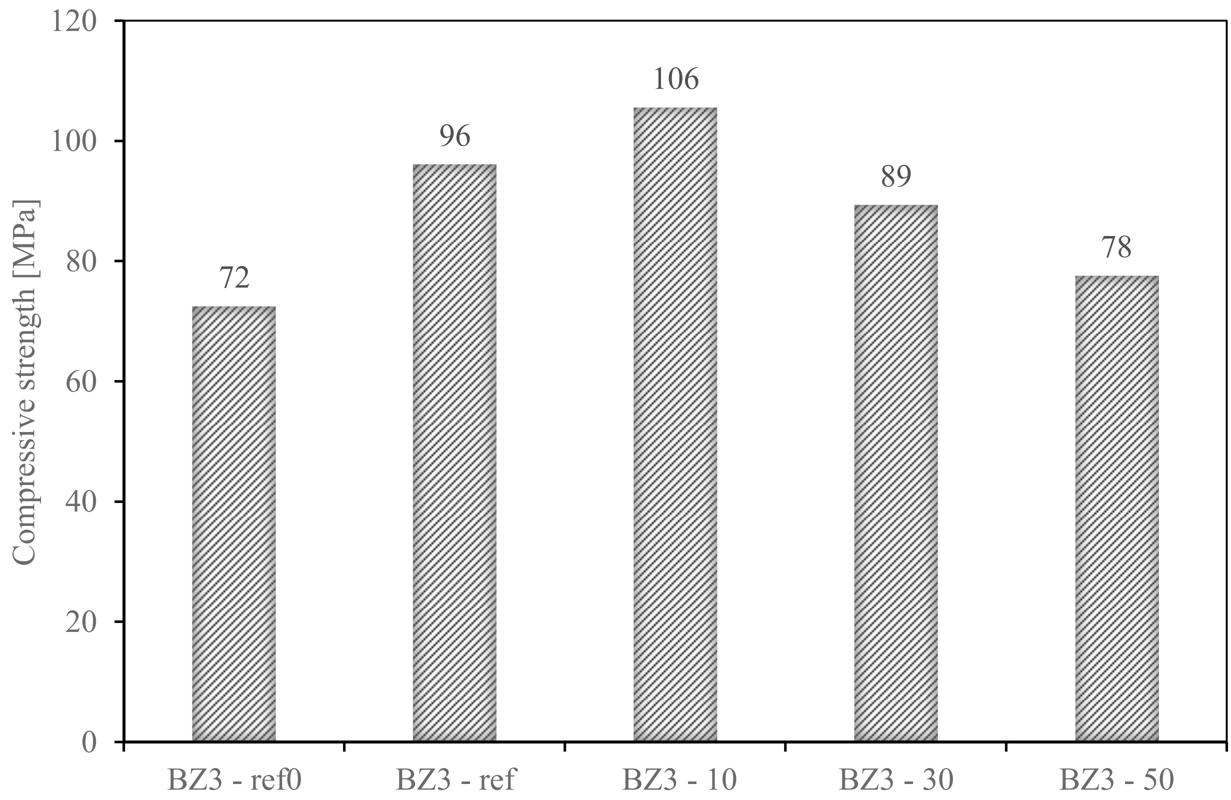

Fig. 1 Compressive strength after 28 days [MPa].

Thermal properties. In Table 4 there are thermal properties in dry state of the studied materials summarized. Thermal conductivity is strongly related to open porosity of the material: the higher the open porosity, the lower the thermal conductivity. Exception is the reference mixture BZ3 - ref0 where the porosity is quite high (compared to other studied materials), but it doesn´t have so considerable effect on thermal conductivity. The inner structure of NP improves the thermal properties of the materials. As far as specific heat capacity is concerned, there is no clear trend visible. BZ3-ref shows the highest value which is by 12% above the reference mixture BZ3-ref0. With the addition of natural zeolite specific heat capacity demonstrates similar values as BZ3-ref0. The difference is within 4%.

Table 4. Thermal properties in dry state.

Material	**Thermal conductivity** [$Wm^{-1}K^{-1}$]	**Specific heat capacity** [$Jkg^{-1}K^{-1}$]
BZ3-ref0	1.958	703.04
BZ3-ref	2.019	798.97
BZ3-10	1.739	710.98
BZ3-30	1.676	684.47
BZ3-50	1.541	714.85

Summary

The study was focused on the effects of natural zeolite as a supplementary cementitious material on the properties of high strength concrete. Studied properties were basic physical characteristics, mechanical characteristics represented by strength in compression after 28 days and thermal properties.

From the obtained data some basic facts can be concluded:

- Open porosity of concrete can be significantly reduced by sufficient additives – addition of silica fume decreased the volume of pores by 5%, while bulk density increased only slightly.
- The effect of NP on open porosity and bulk density of studied mixtures can be described by two trends – with low amount of NP open porosity is decreased and bulk density slightly increased; with higher replacement the tendencies of both parameters are opposite.
- With higher amount of NZ in the mixture its porous nature reflected in high open porosity of the end product negatively affect the mechanical properties but thermal characteristics are improved.
- On the other hand NP shows good pozzolanic activity and its surface area is high which can be of importance in the enhancement of strength caused by filler effect, but only in low replacement levels (up to 10%).
- From the above mentioned facts the optimal percentage of cement substitution by NP in this study is 10% by weight.

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