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Application of Waste Ceramics as Active Pozzolana in Concrete Production

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Abstract. Clay minerals become highly reactive when they are incinerated at temperatures between 600-900°C and then ground to cement fineness. They are mainly formed by siliceous and aluminous compounds. The loss of water due to thermal treatments causes destruction of their crystalline structure, and they are converted into unstable amorphous state. If they are then mixed with calcium hydroxide and water, they undergo pozzolanic reaction and form compounds with enhanced strength and durability. Therefore, they have a potential to be used in mortar and concrete. In this paper, a wide range of parameters of concrete containing waste ceramics as partial replacement of Portland cement is presented, including a comparison with reference concrete without any pozzolana additions.

Keywords: concrete, waste ceramics, mechanical properties, thermal properties

1. Introduction

Supplementary cementing material such as fine-ground ceramics has found the application in concrete production couple of decades ago because of their potential to replace a part of Portland cement in concrete. Fine-ground ceramics belongs to waste materials. Therefore, these materials or their combinations can be considered as environmental friendly cement substitutes.

Waste ceramic materials may become a cheaper but almost equivalent alternative to metakaolin or ground granulated blast furnace slag, fly ash and other materials as supplementary binder in concrete. The ceramic industry often produces calcined clays that result from burning illite-group clays which are commonly used in the production of red-clay ceramic products. A portion of these products (which amounts up to 2% depending on producer and country) is discarded as scrap, thus constitutes industrial waste. The residues of ceramic bricks and floor and roof tiles ground to a suitable fineness can though become active pozzolans [1-3]. So, they have a potential to be used in mortar and concrete.

The measurements of properties of materials containing supplementary cementing materials are similarly as with many other cement based composites mostly concentrated on mechanical properties. This may not always be sufficient because superior mechanical properties are often not accompanied by comparably good resistance against water or salt penetration.

This paper presents an extensive set of parameters of concrete containing different amounts of waste ceramics as active pozzolana replacing a part of Portland cement, including basic material characteristics,

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mechanical characteristics, hygric and thermal properties. The results are also compared with those obtained for reference concrete containing only Portland cement as binder.

2. Materials

The composition of the studied concrete mixes is shown in Table 1. They were prepared with Portland cement CEM I 42.5 R as the main binder. The specific surface area of cement was 341 m^2/kg. A part of cement (10 - 60% by mass) was replaced by fine-ground ceramics, the specific surface area was 336 m^2/kg. The design of the concrete mixes was done according to ČSN EN 206-1. For the sake of comparison, also a reference mix with only Portland cement as the binder was studied. The total mass of binder and the amount of water were the same in all mixtures.

Table. 1: Composition of studies concretes

Component	Amount in kg/m^3				
	BC2 ref	BC2-10	BC2-20	BC2-40	BC2-60
CEM I 42.5R, Mokrá	360	324	288	216	144
Fine-ground ceramics	-	36	72	144	216
Aggregates 0-4 mm	910	910	910	910	910
Aggregates 4-8 mm	225	225	225	225	225
Aggregates 8-16 mm	755	755	755	755	755
plasticizer Mapei Dynamon SX	3.96	3.96	4.29	5.18	6.16
Water	146	146	146	146	146

The measurement of material parameters was done after 28 days of standard curing in a conditioned laboratory at the temperature of 22±1°C and 25-30% relative humidity. The following specimens' sizes were used in the experiments: basic physical properties - 50 x 50 x 50 mm, compressive strength – 150 x 150 x 150 mm, bending strength - 100 x 100 x 400 mm, water vapor transport properties and water transport properties - 100 x 100 x 20 mm, thermal properties - 70 x 70 x 70 mm.

3. Experimental Methods

3.1. Basic Physical Properties

Among the basic properties, the bulk density, matrix density and open porosity were measured using the water vacuum saturation method [4].

3.2. Pore Structure

Characterization of pore structure was performed by mercury intrusion porosimetry. The experiments were carried out using the instruments PASCAL 140 and 440 (Thermo Scientific). The range of applied pressure corresponds to pore radius from 2 nm to 2000 μm. Since the size of the specimens is restricted to the volume of approximately 1 cm^3 and the studied materials contained some aggregates about the same size, the porosimetry measurements were performed on samples without coarse aggregates.

3.3. Mechanical properties

The measurement of compressive strength was done by the hydraulic testing device VEB WPM Leipzig having a stiff loading frame with the capacity of 3000 kN. The tests were performed according to ČSN EN 12390-3 [5] after 28 days of standard curing. The bending strength was determined using the procedure described in ČSN EN 12390-5 [6], after 28 days of standard curing as well.

3.4. Water Vapor Transport Properties

The dry cup method and wet cup methods were employed in the measurements of water vapor transport parameters [4]. The water vapor diffusion coefficient D [m^2/s] and water vapor diffusion resistance factor μ [-] were determined.

3.5. Water Transport Properties

The water absorption coefficient A [kg/m^{2}s$^{1/2}$] and apparent moisture diffusivity κ [m^2 s^{-1}] were measured using a water sorptivity experiment [8].

3.6. Thermal Properties

Thermal conductivity λ [W/mK] and specific heat capacity c [J/kgK] were measured using the commercial device ISOMET 2104 (Applied Precision, Ltd.). The measurement is based on analysis of the temperature response of the analyzed material to heat flow impulses.

4. Experimental Results and Discussion

4.1. Basic Physical Properties

In Table 2 the basic physical properties of studied composites measured by the water vacuum saturation method are shown. The bulk densities of materials with lower amount of fine-ground ceramics (BC2-10, BC2-20) and reference material (BC2-ref) differed only up to about 1%. Materials with higher amount of ground ceramics achieved about 2% lower bulk density than reference material BC2-ref. The values of matrix density were within about 3% for all materials. The highest matrix density achieved BC2-60 with 60% of fine-ground ceramics, the lowest BC2-ref without pozzolana admixtures. The highest porosity had material BC2-60 with the highest amount of supplementary cementing materials, the lowest porosity achieved the reference material BC2-ref.

Table. 2: Basic physical properties of studies concretes

Material	Bulk Density	Matrix Density	Open Porosity
	[kg/m^3]	[kg/m^3]	[%]
BC2-ref	2234	2571	13.1
BC2-10	2263	2614	13.4
BC2-20	2258	2613	13.6
BC2-40	2182	2581	15.5
BC2-60	2194	2630	16.6

4.2. Pore Structure

The pore size distribution of all materials is presented in Figure 1 in form of cumulative curve. The total pore volume was increasing with increasing fine-ground ceramics content; the mean pore radius increased slightly as well.

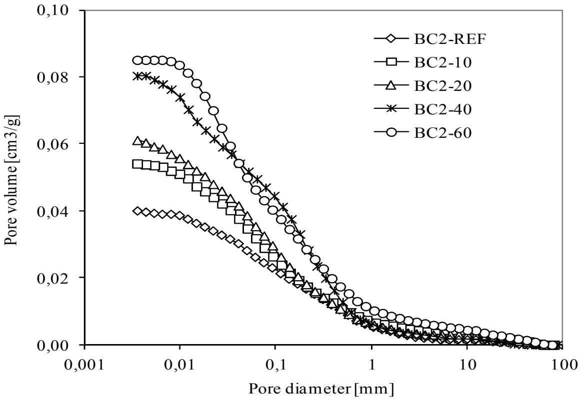

Fig. 1: Pore size distribution of studied concretes

4.3. Mechanical Properties

The mechanical properties of five studied concretes are shown in Table 3. The replacement of Portland cement by find-ground ceramics of up to 20% led to only about 10% decrease in compressive strength and

3% decrease in bending strength, which was still acceptable. For the replacement level higher than 20% of mass of cement the compressive strength was affected in much higher extent than bending strength. For BC2-60 the compressive strength was more than two times lower as compared with the reference concrete mixture BC2-ref but the bending strength was only about 20% lower.

Table. 3: Mechanical properties of studied concretes

Material	Compressive Strength	Bending Strength
	[MPa]	[MPa]
BC2-ref	56.87	6.4
BC2-10	55.89	6.4
BC2-20	49.58	6.2
BC2-40	37.45	5.9
BC2-60	22.23	5.3

4.4. Water Vapor Transport Properties

The results of measurements of water vapor transport properties of the analyzed materials are presented in Table 4. Comparing the data measured for all studied materials in both cases (dry cup, wet cup), we can see that the lowest μ value achieved material BC2-60 with 60% of fine-ground ceramics which was in a good qualitative agreement with the porosity data in Table 4. The highest water vapor diffusion resistance factor in both cases had BC2-ref without pozzolana admixtures which exhibited the lowest porosity.

Table. 4: Water vapor transport properties of studied concretes

Material	5/50%		97/50%	
	D	μ	D	μ
	[m^2/s]	[-]	[m^2/s]	[-]
BC2-ref	2.67E-07	86.44	5.54E-07	41.53
BC2-10	2.77E-07	84.31	5.83E-07	39.45
BC2-20	2.92E-07	78.89	6.09E-07	37.75
BC2-40	3.18E-07	72.41	7.44E-07	31.23
BC2-60	3.59E-07	64.06	1.02E-06	22.53

4.5. Water Transport Properties

The results of water sorptivity measurements are presented in Table 5. They were in a good qualitative agreement with the open porosity data (Table 2). The liquid water transport parameters increased with the increasing amount of fine-ground ceramics in the mix. The lowest water absorption coefficient had the reference material BC2-ref, about two times lower than BC2-60 with the highest amount of fine-ground ceramics. The comparison of apparent moisture diffusivities was similar to water absorption coefficients, as the differences in porosity were lower than those in water absorption coefficient.

Table. 5: Water transport properties fo studied concretes

Materials	A	κ
	[kg /$m^2s^{1/2]}$	[m^2 /s]
BC2-ref	0.0066	2.66E-09
BC2-10	0.0068	2.56E-09
BC2-20	0.0079	3.85E-09
BC2-40	0.0107	5.50E-09
BC2-60	0.0135	8.16E-09

4.6. Thermal Properties

Thermal properties of studied concretes are shown in Table 6. We can see that the values of thermal conductivity of studied concretes in dry state were in a qualitative agreement with open porosity results (Table 2). The thermal conductivity decreased with the increasing amount of Portland-cement replacement by fine-ground ceramics.

Table. 6: Composition of studies concretes

Material	λ	c
	[W/mK]	[J/kgK]
BC2-ref	1.893	721
BC2-10	1.773	730
BC2-20	1.700	726
BC2-40	1.643	765
BC2-60	1.710	781

The values of specific heat capacity slightly increased with the increasing amount of fine-ground ceramics; the maximum difference was about 8%, as compared with the reference HPC.

5. Conclusions

The experimental results presented in this paper showed that waste ceramic ground to an appropriate fineness can be considered a prospective pozzolana material suitable for the replacement of a part of Portland cement in concrete industry. This solution may have significant environmental and economical consequences. Waste ceramic as recycled material used in concrete production presents no further CO_2 burden to the environment, and its price is much lower as compared to Portland cement.

6. Acknowledgements

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