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Development of alkali-activated concrete for structures — Mechanical properties and durability☆

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Summary Alkali-activated concretes for structures have been developed for last 10 years, especially for the production of precast elements. These concretes were designed as self-compacting with the water to binder ratio 0.5. Later they were modified using PNS-plasticizer. In this way concretes with the water to binder ratios 0.45 and 0.40 and with convenient workability were prepared with 28-days strength up to 90 MPa. These concretes also show improved frost-resistance.

Non-destructive tests for compressive strength were performed as well as and new correlation relationships were found. Finally, both fracture properties and fatigue tests were performed.

All of these tests are important for a practical application of alkali-activated concretes for structures.
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Introduction

Alkali activated concrete (AAC) is an often investigated class of cement free concrete — an alternative to portland cement-based concrete. Much experience and research investigations (Shi et al., 2006; Provis and van Deventer, 2014) show very good properties for AAC but some experimental experience show worse properties, especially from the point of view of durability. For example, very good freezing and thawing resistance is mentioned in many references (Shi et al., 2006; Provis and van Deventer, 2014) but inverse results also exist (Bilek and Rovnanik, 2006; Bilek and Szklorzova, 2009). They can be explained — similarly as in the case of ordinary portland cement based concretes — by the not optimum proportioning of concrete (Bilek et al., 2015). This is one of the reasons for a careful observation for not only 28-days parameters (which can be really excellent), but also for an investigation of long-term properties; that is, durability investigation. In terms of 28 days properties, it is important to reach optimum properties from the point of view of strengths, minimum volume changes, minimum microcracking, good fatigue behaviour and similar

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Table 1 Chemical compositions of GBFS.

	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	K_2O (%)	Na_2O (%)	TiO_2 (%)	SO_3 (%)	Sp. surf. (m^2/kg)
GBFS	41.5	37.7	6.5	0.4	10.1	0.4	0.6	—	0.8	380

properties. For a long-term investigation, non-destructive tests are very convenient which allow for an evaluation of a state of construction in service.

Experimental procedure

Materials

Ground granulated blast furnace slag with specific surface 380 m^2/kg is commercially delivered by Kotouc Stramberk company and it is commonly used as an admixture in concrete production. It meets the requirements of EN 15167-1; for chemical composition see Table 1. In addition to the amorphous phase this slag also contains small amount of akermanite $Ca_2Mg(Si_2O_7)$ and orthorombic form of dicalciumsilicate Ca_2SiO_4.

Mix of sodium water—glass with silicate modulus $M_s = 2.0$ and a 50% solution of KOH were used as activators.

Commercial sand 0/4 mm and crushed aggregates 4/8 and 8/16 mm were used as well. Concretes were mixed in a laboratory mixer; the volume of batches was 30 L — see Table 2 for the composition of mixtures. Workability was measured using reverse Abrams cone — Table 2. After mixing the concrete was placed into steel moulds. After demoulding at the age of 22 h specimens were wrapped in PE-foil to avoid water exchange with the environment. Wrapped specimens were stored in laboratory conditions ($t \approx 20\,^{\circ}$C, r.h. ≈ 60%) up to the time of testing.

Specimens

Prisms 40 mm × 40 mm × 160 mm were made for the measurement of flexural and compressive strengths of mortars from compatibility tests.

Cubes 150 mm were used for compressive strengths measurement at the age of 24 h, 2, 3, 7, 28 and 90 days. Additionally NDT with different types of rebound hammers were also performed (Vrba, 2013). Schmidt hammer *N* is widely used in NDT of concrete structures.

Prisms 80 mm × 80 mm × 480 mm were made for the testing of fracture and fatigue properties and for testing of frost resistance. A notch to one-third of high of specimens (ca. 28 mm depth) was cut into the beams 220 mm from the one end of the beam at the age of 28 days. Fracture tests in accordance to Karihaloo and Nallathambi model (Karihaloo and Nallathambi, 1989) were performed on the notched beam (span 400 mm). The fracture toughness K_{IC} is main result of these tests. The modulus of elasticity in three points bending on notched beam *E* as well as the modulus of rupture f_r (which is calculated as the flexural strength on the notched beam) are the partial results of these tests. After the fracture test a part of the broken beam, whose length is approximately 260 mm, was used for the test of flexural strength f_b (span 220 mm). Other beams 80 mm × 80 mm × 480 mm were exposed to 125 freezing and thawing cycles (FT-cycles) in accordance to Czech norm CSN 73 1322. One cycle represents 4 h in the freezer in temperature −20 °C and 2 h in water +20 °C. After the cycles, values of flexural strength, modulus of rupture and modulus of elasticity were measured and compared with values at the age of 28 days. Activity indexes I_K, I_b, I_r and I_E were calculated as a ratio value of *values comparative beams/values of frosted beams*.

Fatigue properties were tested using the three point bend test of prisms with the central notch, the ratio depth of notch/depth of prism $a/W = 0.10$. Wöhler curves were obtained from tests carried out in a computer controlled servo hydraulic testing machine, for more details, see Seitl et al. (2014) and Seitl et al. (2016).

Experimental results and discussion

Points of saturation for different plasticizers and alkali activated mortars

For the choice of an optimum plasticizer and its optimum dosage the compatibility of plasticizer and alkali activated

Table 2 Composition and workability of AAC with content of activator and different water to slag ratio.

	10%-0.50	10%-0.45	10%-0.40	8%-0.45	6%-0.45
GBFS 380 m^2/kg (kg)	450	450	450	450	450
Na—water glass $M_s = 2.0$ (kg)	57	57	57	45	34
50% KOH (kg)	42	42	42	34	26
Water (kg)	170	143	125	153	163
PNS plasticizer (kg)	0	5	10	10	10
0/4 sand (kg)	840	855	880	855	865
4/8 crushed aggregates (kg)	380	385	400	385	400
8/16 crushed aggregates (kg)	390	400	415	400	410
Cone flow (mm)	590	680	580	600	500

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