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Assessment of alkali activated mortars based on different precursors with regard to their suitability for concrete repair

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HIGHLIGHTS

- Preparation of repair mortars by alkali activation method.
- Three different precursors (fly ash, slag, metakaolin).
- Characterization and assessment of mortars according to EN 1504-3.
- Compressive and flexural strengths meet the standard requirements.

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ABSTRACT

The implementation of repair works on concrete structures is on the increase since many existing concrete buildings have been exposed for long periods of time to different climates, as well as to other severe conditions, and have consequently deteriorated. Repair mortars need to fulfil the requirements of the EN 1504 series before being used in practice. Different mixtures, based on three different precursors (fly ash, ground granulated blast furnace slag, and metakaolin) and processed by alkali activated technology, have been assessed with regard to their suitability for the repair of concrete. Whereas the slag-based repair mortar delaminated from the substrate, and was thus unsuitable for its intended use, the other two mortars which were based on the precursors fly ash and metakaolin exhibited good mechanical properties and good adhesion. The bond strength of the metakaolin and fly ash mortars ranged from 1.8 to 2.3 N/mm^2, and thus met these criteria for both structural and non-structural repair mortars. The capillary absorption of all three mixtures was too high to fulfil the criteria of EN 1504-3 for structural repair products, but the fly ash and metakaolin mixtures still have the potential to be used for non-structural repair works. The problem of efflorescence in all three mixtures was also assessed.

1. Introduction

Despite the recognised exceptional durability of Portland cement concrete, worldwide a very large number of concrete structures have suffered from deterioration [1–4], which has resulted in aesthetic, functional, or structural problems. The reduced service life of concrete is mainly caused by material limitations, inadequate material design and construction practices, severe exposure conditions, and sometimes a lack of structural maintenance. However, environmental factors, such as the corrosion of reinforcing steel due to chloride ingress or carbonation, freeze-thaw, sulphate attack, are a principal source of concrete deterioration [5–6]. Such deterioration processes need to be halted, and meanwhile the damaged structure needs to be repaired so that it can continue to withstand the imposed environmental stresses. Such repair works sometimes consist only of non-structural interventions (mainly preservation of the concrete or its restoration), but frequently, when the degradation is advanced, structural repair and strengthening needs to be undertaken in order to ensure the continued proper service life of the structure. This can involve the removal of damaged parts and their replacement and reinforcement using repair mortars. Requirements for the repair of concrete structures have been established through the series of standards EN 1504 [7], which define the whole procedure of the repair process from assessment of the reasons for damage to the design of repair works and the properties of the repair materials. These standards also define methods for the execution and acceptance of repair works [8]. Many materials for this purpose are already available on the market, but new solutions continue to emerge. The most important parameter in the selection of proper materials is their compatibility with the substrate (established through their

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adhesion strength, capillary water absorption, similar dilatation properties, etc.), their mode of application, and their durability [9–10]. Most nowadays available materials are cement-based (or polymer modified), whereas the new, emerging solutions are based on alkali activation technology [11–14]. Alkali activated materials are inorganic systems, which consist of one or more reactive solid components containing (i) SiO_2 and Al_2O_3 in sufficient amounts, in reactive form (e.g. different types of ash, slag, metakaolin, etc.), and (ii) an alkaline activation solution, which usually consists of (apart from water) alkali hydroxides and silicates, or a combination of these. Mixing the solid and the activator components together first results in the dissolution of the elements in the alkaline activators, and then in hardening due to the formation of an aluminosilicate, whose structure can vary from amorphous to partial crystalline [15]. Alkali activated materials possess many favourable properties, such as rapid setting and hardening, excellent bond strength, good long-term properties and durability [16], a good ability to immobilize toxic metals [17], and improved resistance to the action of fires [18–19] and acids [20]. On the other hand, since alkali activated materials contain much higher soluble alkali metal concentrations than conventional cement, efflorescence could be a significant issue when the products are exposed to humid air or are in contact with water [21–22].

The importance of alkali activated materials in the field of rehabilitation of deteriorated structures has been highlighted by Pacheco-Torgal et al. [23]. Some applications of alkali activated materials as repair mortars have been proposed by Yodsudjai [12], who developed a repair mortar based on fly ash whose properties are similar to those of commercially available repair mortars, but which however do not reach the bond strength and durability of the latter. However, the high early strength development of alkali activated materials can be advantageous in some applications, such as rapid road repairs [24]. Some drawbacks, too, have been reported for alkali activated repair mortars. For instance, Mackechnie and Scott [25] realised that, with lower workability, higher porosity is introduced into the microstructure, thus increasing permeability and compromising durability. Furthermore, influence of the concentration of an alkali activator and its amount on the workability and mechanical properties of alkali activated metakaolin-based repair mortars has been also investigated [26].

The aim of the study was to investigate the suitability of selected alkali activated mixtures based on three different precursors for use as concrete repair mortars. For this purpose not only was microstructural analysis of the mixtures performed, but the mixtures were also tested according to the relevant characteristics defined in EN 1504-3 [27].

2. Experimental

2.1. Precursor materials and mortar compositions

The precursors, as well as the basic mortar mixtures, were provided through the work of the RILEM DTA committee RILEM TC 247-DTA: Durability testing of alkali-activated materials. Three different raw materials were used as precursors for the alkali activated mortars: ground granulated blast furnace slag – for the "S mortar" (provided by Ecocem, France), fly ash – for the "FA mortar" (provided by Baumineral, Germany), and metakaolin – for the "MK mortar" (provided by Argeco, France). Among the alkali activators, the water glass used was Crystal 0112, Tennants Distributions (Na_2O: 15.5%, SiO_2: 30.6%) for the S and FA mortar mixtures, and Betol 39T, Woellner (Na_2O: 8.3%, SiO_2: 27.5%) for the MK mortar mixture, whereas the NaOH flakes were supplied by Donau Chemie. CEN Standard sand (with a maximum grain size of 2 mm) was used as the aggregate (http://www.normensand.de/?lang=en&art=9). This is a natural sand, which is siliceous particularly with regard to its finest fractions, the particles are generally isometric and rounded in shape, and have a specific gravity of 2.64 g/ccm.

Table 1
Chemical and physical characteristics of the precursors (b.d.l. = below detection limit).

Precursor	S	FA	MK
Chemical composition (%)			
SiO_2	36.28	51.74	68.82
Al_2O_3	11.30	22.92	24.27
Fe_2O_3	0.35	7.40	2.31
CaO	41.39	6.02	0.47
P_2O_5	b.d.l.	0.68	b.d.l.
MgO	6.38	2.44	0.19
K_2O	0.37	2.21	0.18
Na_2O	0.26	0.79	b.d.l.
TiO_2	0.45	0.91	1.14
Cr_2O_3	b.d.l.	0.02	0.02
MnO	0.32	0.07	0.01
SO_3	1.08	0.49	b.d.l.
LOI	b.d.l.	2.3	1.5
Reactive SiO_2	36.28	38.99	27.88
Physical properties			
BET surface area (m^2/g)	1.1	1.7	16.3

The chemical composition and physical properties of the precursors are presented in Table 1. The chemical composition of the precursors was determined by using a Thermo Scientific ARL PERFORM'X Wavelength Dispersive X-ray Fluorescence Spectrometer (WD XRF). Prior to the measurements, a fused bead was prepared with lithium tetraborate 50%/lithium metaborate 50%, with a mixture of the ash, and flux heated at 1025 °C.

Sulphate content and loss on ignition (LOI) of the materials were determined in accordance with EN-196-2 [28], and the reactive silicon dioxide content according to EN 197-1 [29].

The total specific area (Brunauer–Emmet–Teller (BET) surface area) of the samples was determined by nitrogen adsorption at 77 K over a relative pressure range of 0.05–0.3 using Micromeritics ASAP 2020 equipment. Prior to the performance of these measurements, the samples were heated at 200 °C for 2 h and outgassed to 10^{-3} Torr using Micromeritics Flowprep equipment.

The compositions of the alkali-activated mortars are given in Table 2. The amount of the aggregate was varied until the same flow was reached, i.e. 160 ± 1 mm, which was determined according to EN 1015-3:1999/A2:2006 [30]. Mixing and casting of samples was performed according to EN 196-1 [31], using a vibration table. The liquids and precursors were placed in a bowl, and then immediately mixed at low speed for 30 s; the blend was then further mixed for 30 s, while continually adding sand; the mixer was then switched to high speed and mixing was continued for 30 s; mixing was then paused for 90 s; during the first 30 s of this pause the mortar adhering to the wall and bottom part of the bowl was removed with a scraper and placed in the middle of the bowl; mixing was then continued at high speed for 60 s.

2.2. Test methods

Several properties of the fresh mortar mixtures were investigated. The workability of the fresh mortar mixtures was investigated by means of the flow test according to EN 13395-1 [32], 10 min and 30 min after mixing. The bulk density of the fresh mortar was determined according to EN 1015-6 [33], the air content of the fresh mortar according to EN 1015-7 [34], and the setting time according to EN 480-2 [35].

Compressive and flexural strength as well as the bulk density of the hardened mortars were determined after 7, 28 and 56 days in