Construction and Building Materials 165 (2018) 914–919

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Study of alkali-activated mortar used as conventional repair in reinforced concrete

Rodrigo H. Geraldo [a], Otacisio G. Teixeira [b], Samile R.C. Matos [b], Francisco G.S. Silva [b], Jardel P. Gonçalves [b], Gladis Camarini [a,c,*]

[a] School of Civil Engineering, Architecture, and Urban Design, University of Campinas (UNICAMP), Rua Saturnino de Brito, 224, Campinas, São Paulo CEP 13083-889, Brazil
[b] Polytechnic School, Bahia Federal University (UFBA), Rua Aristides Novis, 02, Campus da Federação, Salvador, Bahia CEP 40210-630, Brazil
[c] University Center of Minas South – UNIS-MG, Avenida Alzira Barra Gazzola, 650, Bairro Aeroporto, Varginha, Minas Gerais CEP 37031-099, Brazil

HIGHLIGHTS

- Alkali-activated mortar (AAM) was tested as repair in reinforced concrete beams.
- AAM developed a fast strength (30 MPa after 24 h), desirable for repair materials.
- Reinforced concrete beam repaired with AAM achieved higher value than reference.
- There is a great potential to use AAM as repair material to concrete substrates.

ARTICLE INFO

Article history:
Received 11 October 2017
Received in revised form 2 January 2018
Accepted 9 January 2018

Keywords:
Alkali-activated mortar
Repair mortar
Concrete reinforced beams

ABSTRACT

Alkali-activated mortar (AAM) is a growing interest material as an environmentally friendly alternative to the conventional one. In this study, the use of AAM was investigated as repair material to conventional concrete. Reinforced concrete beams of 150 mm wide × 150 mm high × 500 mm long were produced to be repaired by the AAM. The concrete substrates and the AAM mortar were characterized, and the flexural strengths of the reinforced concrete beams with and without the repair were obtained (bending stress curves). The results showed that AAM developed a fast and good strength (30 MPa after 24 h) and had good adherence to the substrate. AAM had good performance and promoted strength increase. This study indicates the possibility of using an AAM as a repair material to conventional concrete substrate.

1. Introduction

Concrete is one of the materials more used in the world, with wide versatile applications [1]. However, there are several factors that can reduce concrete life-cycle, and repair works are usually necessary to ensure its preservation, higher durability, and safety [2,3].

Patch repair consists of removing the deteriorated part of the concrete and reinstate it with a repair mortar [4]. The costs of commercial repair material are expensive and alternatives have been studied, such as the use of the alkali-activated mortar (AAM) as repair material [5].

AAM is an alternative material to civil construction [6]. The AAM is made with alkali-activated binder, a material that can be classified as the third generation cement after gypsum, lime and ordinary Portland cement [7].

Portland cement is the main binder in construction and it is responsible for considerable negative environmental impacts [8]. Alkali-activated binder is an alternative cementing material obtained by the reaction between an alkali source and an aluminosilicate precursor, and it has a great potential to decrease the environmental footprint of the cement industry [9,10].

The most used aluminosilicates as raw material used in alkali-activated binder production are blast furnace slag, metakaolin, and fly ash [7]. Sodium hydroxide (NaOH) is the most used activator due to its availability and low cost [11]. The use of NaOH alone does not promote the gain of mechanical strength and its mixture with sodium silicate is common to produce the alkaline activator

* Corresponding author at: School of Civil Engineering, Architecture, and Urban Design, University of Campinas (UNICAMP), Rua Saturnino de Brito, 224, Campinas, São Paulo CEP 13083-889, Brazil.
E-mail addresses: gcamarini@gmail.com, camarini@fec.unicamp.br (G. Camarini).

https://doi.org/10.1016/j.conbuildmat.2018.01.063
0950-0618/

[12,13]. However, commercial sodium silicate production causes negative environmental impacts [14].

The use of sodium silicate made with a silica source from waste materials can maximize the environmental benefits of alkali-activated binder, and some of them have been proposed [15]. Bernal et al. [16] showed that sodium silicate made from silica fume resulted in materials with compressive strengths similar to those made with commercial sodium silicate and the reaction products are also the same.

An alkali-activated repair material can present environmental and technical advantages. Phoo-Ngernkham et al. [5] studied an alkali-activated repair mortar produced with fly ash, NaOH, and sodium silicate. The interface zone between the repair and the ordinary Portland cement concrete was more homogeneous and denser than the one observed by commercial mortar repairs. Alanazi et al. [8] also observed good bond interface between an AAM and an ordinary Portland cement mortar substrate. The alkali-activated binder used in mortar production was made with NaOH, sodium silicate, and metakaolin.

Zhang et al. [6] found that the AAM exhibited higher degradation in flexural and tensile strengths at high temperatures, but lower degradation in compressive and bond strengths when compared to a commercial mortar. Hu et al. [17] observed a good bond strength and even better abrasion resistance when compared to ordinary Portland cement repair materials.

In this study, NaOH, metakaolin and a sodium silicate solution made from silica fume are used to make an alkali-activated repair mortar cured at room temperature. The main objective of the study was to analyse the performance of an AAM used to repair on reinforced concrete beams subjected to flexural strength.

2. Materials and methods

2.1. Materials

Sodium hydroxide in flakes (NaOH, 94%) was used as alkali source. NaOH solution concentration was 13 M. Metakaolin (MK) and silica fume (SF) were the sources of aluminum and/or silicon. Locally available river quartz sand was the fine aggregate, and water from the municipal supply was used to dissolution/workability. The elementary composition of MK and SF were determined by EDX (spectrometer Shimadzu EDX 720) and the results are presented in Table 1. The results showed that the MK is mainly comprised of SiO_2 and Al_2O_3, and the SF had a high value of LOI (5.50%). The specific gravity of MK is 1906 kg/m^{3}and SF is 2625 kg/m^3.

The reinforced concrete beams produced are composed of Brazilian steel (yield strength 500 MPa (named CA50) and yield strength 600 MPa (named CA60)). The concrete was made with Brazilian Portland cement of high initial strength (CPV-ARI), locally available river quartz sand (same fine aggregate used in AAM), basaltic crushed stones (coarse aggregate) and water from the municipal supply.

CPV-ARI presented surface area of 0.3930 m^2/kg (Blaine method) and specific gravity of 3150 kg/m^3. The SO_3 and free CaO contents are 3.17% and 2.32%, respectively. Aggregates physical properties and sieve analyses are presented in Table 2 and Fig. 1, respectively.

Table 1
Elementary composition of MK and SF (in mass percentage).

Oxides (%)	SiO_2	Al_2O_3	Fe_2O_3	K_2O	TiO_2	MgO	LOI	Others
MK	48.48	35.78	4.93	3.35	2.75	0.56	3.66	0.49
SF	83.41	1.87	3.36	3.67	–	0.61	5.50	1.58

MK = metakaolin; SF = silica fume.

Table 2
Physical properties of the aggregates.

Physical property	Aggregates		Reference
	Fine	Coarse	
Maximum grain size (mm)	1.20	19.00	[18]
Fineness modulus	1.63	6.82	[18]
Specific gravity	2.6	2.8	[19,20]
Material finer than 75-µm (%)	1.28	0.63	[21]

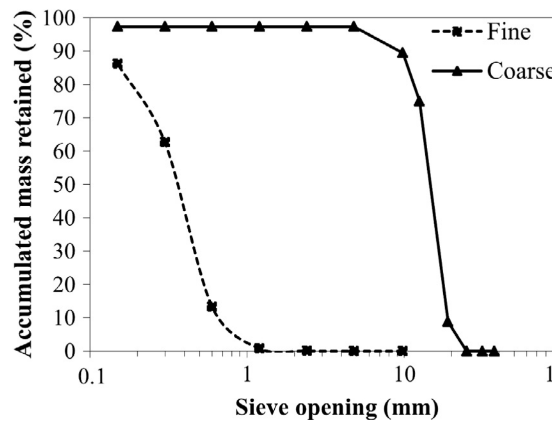

Fig. 1. Aggregates sieve analyses.

2.1.1. Ordinary Portland cement concrete

The concrete used in the beams production had a mix design of 1:2.06:2.54 (cement:fine aggregate:coarse aggregate) in mass. The water to cement ratio was 0.56. The tests in this concrete were in fresh state, slump test [22]; and in hardened state, compressive strength test [23]. Cylinder specimens (100 mm diameter and 200 mm height) were molded and compacted on a vibrating table for 2 min to eliminate the entrapped air. The concrete specimens were cured in air for 28 days at room temperature (average temperature of 25 °C and relative humidity of ~80%).

The concrete slump was 110 mm. The compressive strengths were 18.5 MPa (14 days) and 32.9 MPa (28 days).

2.1.2. Alkali-activated repair mortar

2.1.2.1. Sodium silicate solution. Sodium silicate solution made with SF and NaOH was prepared. To dissolve the silica, a mixture of NaOH, water, and SF was magnetically stirred for 30 min (IKA C-MAG HS7) with heating (90 ± 5 °C). The resultant mixture was stored at ambient temperature for 24 h before using.

2.1.2.2. Alkali-activated repair mortar. Alkali-activated repair mortar (AAM) was prepared by mixing the SF sodium silicate solution with MK for 1 min. Thereafter, the fine aggregate was added with continuous mechanical mixing for more 2 min (Contenco, I-3020). The AAM was made with the molar ratios: $SiO_2/Al_2O_3 = 3.9$; $Na_2O/SiO_2 = 0.2$; $Na_2O/Al_2O_3 = 1.1$; and $H_2O/Na_2O = 9.5$. The MK:sand ratio was 1:2.4.

The AAM had specific gravity of 2210 kg/m^3 and flow of 186 mm, determined by Brazilian Standards [24,25].

The AAM was molded in prismatic molds (40 mm width × 40 mm thickness × 160 mm length). The specimens were cured at room temperature until testing (average temperature of 25 °C and relative humidity of ~80%), and were used to determine the mechanical properties (flexural and compressive strengths) at the ages of 1, 14, and 28 days.

Flexural strength was obtained by the three-point-bending test, and compressive strengths were determined on the far edge of