CEST 2019

16th International Conference on Environmental Science and Technology

Rhodes, Greece, 4 to 7 September 2019

A study of alkali-activated concrete mixes in seawater environments

Mengasini L.[1] , Mavroulidou M.[1,*], Gunn M.J.[1]

[1]London South Bank University, 103 Borough Road, SE1 OAA, London, UK

*corresponding author: e-mail: mavroum@lsbu.ac.uk

Abstract

This paper assesses the performance in seawater environment of concrete mixes based on alkali-activated (AA) cements; these are proposed as an alternative to Ordinary Portland Cement (OPC) to address environmental footprint of cement production and to find new uses for waste materials. The proposed AA cements contained an industrial by-product, ground granulated blast furnace slag (GGBS) and a waste material, paper sludge ash (PSA). Mixes were made with fresh water and seawater respectively and were cured either in freshwater or seawater to simulate future exposure environments. The compressive strength at different curing times and a number of durability-related properties of AA mixes in marine environment were investigated and compared to those of OPC systems. The findings indicated that mixing with seawater rather than freshwater enhanced the performance of the AA mixes in terms of compressive strength and durability (resistance to chloride and sulphate attack). In a seawater environment the AA slag concrete mixes with PSA had the lowest porosity, which can be linked to their good durability performance. The study gives promise for the suitability of the tested alkali-activated concrete mixes in seawater environments.

Keywords: alkali activated cement concrete, seawater environment, durability, green construction materials, solid waste management

1. Introduction

In June 2017 the United Nations (UN) stated that 40% of the world population live within 100 kilometres above the coast level and 10% in the Low Elevation Coastal Zone (LECZ), with an altitude less than 10 metres of sea level (UN, 2017). These coasts will soon be at greater risk because of the predicted global sea level rise due to global warming, expected to be between 0.28 and 0.98 metres by 2100 according to the Intergovernmental Panel on Climate Change 2014 (IPCC) (Field, 2014). This will necessitate the construction of coastal defences to protect the populations in the vicinity of the coasts. Large quantities of concrete will be required with consecutive increases in greenhouse gas emissions, energy and requirements for non-renewable raw materials, hence an increasing need for alternative to Ordinary Portland Cement (OPC) cements. Feasible potential alternatives could be found in alkali-activated cement concretes with the added environmental advantage of incorporating industrial by-products and waste materials.

Concrete coastal structures with OPC, built in severe maritime environments with OPC, have high reported costs of operation, maintenance and repair (Gjørv, 2011). A number of severe problems are encountered during the life-time serviceability of these structures, amongst which concrete deterioration due to sulphate attack and reinforcement steel corrosion due to chloride penetration (Mehta, 2003). These are addressed in the present study for AA cement mixes containing an industrial by-product, ground granulated blast furnace slag (GGBS) and a waste material, paper sludge ash (PSA).

2. Laboratory Experiments

2.1. Mix design

The cement mixes used are shown in Table 1; CEM-I (i.e. regular cement) was used as benchmark. Each mix was mixed and/or cured in three different ways namely: a) FF: mixed and cured in freshwater (conventional current practice); b) FS: mixed with freshwater (F) but cured in seawater (S) (to represent working conditions in seawater environment of freshwater mixed concrete, as per current practice) and c) SS: mixed and cured in seawater (a practice of Romans, who produced very durable cements in seawater environments). For consistent comparisons the same liquid/solid ratio was used for all mixes.

Table 1. Details of mix design (kg/m^3)

Mix ID	CEM-I	GGBS	PSA	Sand	Coarse aggregate	Na_2SiO_3	Added Water	l/s ratio*
GGBS FF	0	415	0	784	1039	112	186.4	0.55
GGBS FS	0	415	0	784	1039	112	186.4	0.55
GGBS SS	0	415	0	784	1039	112	186.4	0.55
GGBS+ PSA FF	0	415	16	784	1039	112	186.4	0.55
GGBS+ PSA FS	0	415	16	784	1039	112	186.4	0.55
GGBS+ PSA SS	0	415	16	784	1039	112	186.4	0.55
CEM-I FF	415	0	0	784	1039	0	230	0.55
CEM-I	415	0	0	784	1039	0	230	0.55

FS								
CEM-I SS	415	0	0	784	1039	0	230	0.55

*****l/s: liquid/solid ratio; it includes water and solids in activator solutions

2.2. Tests performed

The starting point of all concrete testing is the assessment of its compressive strength. In addition to this, to address durability aspects in coastal environment where the transport of deleterious ions occurs through water penetrating the pore structure of concrete, a number of relevant tests were performed, namely: absorption by immersion and by capillary rise, and effective porosity of the specimens using a helium porosimeter apparatus. Resistances to chloride and sulphate attack were also evaluated respectively by the corrosion rate of embedded steel and the expansion of the specimens.

3. Results

All mixes showed good compressive strengths, adequate for structural concrete (Table 1). The lower strengths of GGBS+PSA FF were due to some partial damage of the poorly hardened samples upon demoulding and storing in the curing water tank one day after casting. Interestingly however, the same mix cured in seawater (whether mixed with fresh water, i.e. GGBS+PSA FS or seawater, i.e. GGBS+PSA SS) did not present any such problems. The strength of the AA mixes improved in all instances when these were cured in seawater (whether mixed with seawater or not), whereas strength of CEM-I was little affected (the small decrease is unlikely to be significant).

Although higher water uptakes by immersion and by capillary rise were recorded in AA concretes compared to CEM-I (Table 1), which could be attributed to pore size, the steel corrosion and sulphate resistance performance of the AA was superior to that of CEM-I mixes which showed a lower resistance to chlorides and sulphates with visible cracks forming. AA mixes with GGBS+PSA showed a somewhat improved resistance to sulphates compared to AA mixes with GGBS only, with length changes which remained approximately stable over a period of 90 days. AA mixes with seawater did not show expansion during sulphate exposure and slightly reduced the expansion of CEM-I mixes due to accelerated chemical reactions thus less deleterious for the hardened concrete in the long-term. Further tests (not shown here for brevity) showed (a) considerable compressive strength gains at the end of the sulphate exposure for the AA systems as opposed to CEM-I mixes; (b) that AA mixes with PSA had the best corrosion resistance performance in freshwater; in seawater this reduced slightly compared to AA mixes with GGBS only. However, all AA systems exposed in seawater had mass losses less than 2%, while all CEM-I mixes were badly damaged and measurements were not possible (i.e. steel bar had completely disintegrated) in most cases or otherwise mass losses of approximately 10% were recorded.

Table 2. Summary results: strength,absorption, porosity

	Compressive Strength (MPa)		Absorption (%) I: by immersion C: capillary		porosity (%)	
MIX ID	28 days	56 days	28 days	56 days	28 days	56 days
GGBS FF	52.8	58.9	3.9(I) 4.1(C)	3.7(I) 3.3(C)	15.3	15.4
GGBS FS	53.6	62.9	4.5(I) 4.2(C)	4.7(I) 3.4(C)	14.8	13.1
GGBS SS	56.0	65.9	5.8(I) 5.7(C)	5.1(I) 4.8(C)	15.8	14.8
GGBS+ PSA FF	46	52	4.3(I) 2.9(C)	3.8(I) 3.4(C)	13.7	13.3
GGBS+ PSA FS	53.2	56.9	4.2(I) 3.8(C)	3.9(I) 3.2(C)	14.2	13.1
GGBS+ PSA SS	55.4	58.5	5.5(I) 5.2(C)	5.5(I) 5.6(C)	11.6	11.7
CEM-I FF	55.4	62.5	2.4(I) 0.9(C)	2.1(I) 1.9(C)	11.8	_
CEM-I FS	57.3	61.8	2.5(I) 1.3(C)	2.3(I) 1.8(C)	15.0	_
CEM-I SS	58.2	61.4	-	-	15.7	_

4. Conclusions

All AA mixes showed good compressive strengths, adequate for structural concrete. AA mixes without PSA were stronger compared to mixes where PSA was added due to slower hardening of the latter mixes. This requires further study: recent results (not shown here) indicated that a longer constant moisture content curing before immersion in freshwater gives improved the strength strength of the mixes with PSA. AA mixes were more durable in marine environments based on sulphate and chloride attack tests. The addition of PSA further enhanced the durability performance of AA mixes compared to CEM-I mixes. This gives promise for a more cost-effective and environmentally friendly alternative to regular cement for increased resilience and sustainability.

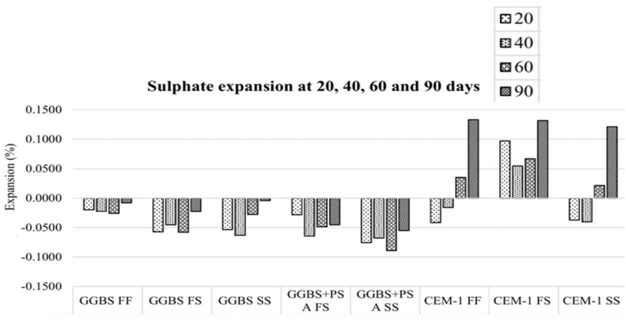

Figure 1. Expansion upon immersion in sulphate solution

References

United Nations (UN) (2017). Factsheet: People and Oceans. In: The Ocean Conference. [online] Available at: http://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf.

Field, C. (2014). Global and sectoral aspects. Cambridge Univ. Press, New York.

Gjørv, O. (2011). Durability of Concrete Structures. Arabian Journal for Science and Engineering, **36**(2), 151-172.

Mehta, P. (2003). Concrete in the Marine Environment. 1st ed. Elsevier Science Publisher Ltd.