



Performance of self-compacting concretes with wastes from heavy ceramic industry against corrosion by chlorides



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HIGHLIGHTS

- TGA/DTG of pastes show the pozzolan action of ground clay bricks waste (GCBW).
- XRD tests show more Friedel's salt formation in GCBW paste.
- GCBW concretes present lower chloride thresholds due to their alkalinity decay.
- GCBW concretes present lower porosity, what impacts on compressive strength growth.
- GCBW use enlarges the initiation period of corrosion in environments with chlorides.

ARTICLE INFO

Article history:

Received 13 September 2017

Received in revised form 19 February 2018

Accepted 2 March 2018

Keywords:

Chlorides

Corrosion

Ceramic wastes

Durability

Self-compacting concrete

ABSTRACT

This work analyses the influence of cement replacement by ground clay bricks waste (GCBW) on paste and concrete properties and on reinforcement corrosion triggered by chlorides. TGA/DTG of pastes show the GCBW pozzolanic effect. Porosity decrease in GCBW concretes contributes to their compressive strength increase. XRD tests show more Friedel's salt formation in GCBW paste. GCBW concretes revealed a decrease in chloride threshold due to their alkalinity decay and in chloride transport rate, what is explained by porosity reduction caused by pozzolanic and filler effects and binding ability improvement. Broadly, concretes with 20–30% of cement replacement presented the best performances.

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1. Introduction

The production of cementitious materials involves a significant environmental impact due to the CO₂ emission as well as the extraction of raw materials [1]. The reduction of the clinker consumption has been a way adopted for mitigating the environmental impact of cementitious materials in a significant extent. Thus, works that aim to study the viability of the cement replacement by industrial wastes play an important role in this scenario.

The waste from the heavy ceramic industry, especially from bricks and tiles, is subjected, during the manufacturing process, to a burning procedure that can provide pozzolanic characteristics to this waste [2] in a similar way as calcined clay produced for being used in cement plants. When this kind of waste is milled,

the filler effect added to a possible pozzolanic action makes its use viable as a partial replacement of cement, especially when the aim is to produce self-compacting concretes. This kind of use represents a suitable environmental destination for heavy ceramic industry waste, what prevents it from being dump at places that can cause damage to the environment and also reduces the clinker content in cementitious materials, mitigating the environmental impact related to clinker production too.

Regarding the ground clay bricks waste (GCBW), previous studies show that the use of GCBW in cementitious matrices can contribute to increase the compressive strength, as a consequence of the paste densification, as well as to reduce the chloride transport ability of the matrix [2,3]. This behaviour is similar to that observed in calcined clay studies [4,5].

Although some previous works noticed a loss of mechanical performance, when replacing cement by GCBW, in general, it happened under higher ranges of replacements [6,7]. Under this condition, the impact of the reduction of cement consumption on

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Table 1

Results from literature concerning compressive strength and chloride transport in cement-based materials with GCBW.

Cement-based material	Levels of cement replacement by GCBW	Observations about compressive strength	Observations about chloride transport	Reference
Concrete	20–40%	Decreases for replacements over 20%	N. S.	[2]
Mortar	30%	Increases	N. S.	[11]
Mortar	10–30%	Increases only for 10% of replacement	N. S.	[4]
Mortar	10–40%	Decreases for replacements over 30%	N. S.	[3]
Mortar/Concrete	5–15%	Increases	N. S.	[14]
Concrete	20%	Remains at the same level	Reduces chloride penetration rate	[12–13]
Concrete	10–60%	Decreases for replacements over 20%	N. S.	[10]
Mortar	5–20%	Increases until 15% of replacement	Reduces chloride penetration rate	[7]

N.S. – Not studied.

compressive strength prevailed over the contribution of the filler and pozzolanic effects of GCBW on compressive strength. However, this behaviour depends on the fineness of the mineral addition, as well as on the burning temperature of the bricks. When the fineness of the mineral addition increases, the tendency is that there is a gain of compressive strength even for high levels of replacement [8–10], as well as when the burning temperature favours the formation of more amorphous materials [7,11].

Taking the specific topic of durability performance into account, there are not many studies analysing the impact of GCBW (used as cement replacement) on chloride penetration into concrete. They show that the use of GCBW as cement replacement contributes to decrease the rate of chloride transport into cement-based materials [7,12,13].

Table 1 resumes the observations made in previous works that analysed the performance of cement-based materials with GCBW. In general, there is a tendency of good compressive strength performance until 20% of cement replacement by GCBW [2,3,10]. Concerning chloride transport, the few studies carried out show that there is a decrease in the chloride transport rate [7,12,13]. However, these works did not advance on aspects like chloride threshold, chloride transport parameters and did not consider self-compacting concretes [7,12,13].

As a result, concerning the reinforcement corrosion phenomenon, there is still a lack of knowledge, although this is one of the main degradation causes of reinforced concrete structures. This work focuses on this gap of knowledge and analyses the influence of GCBW addition as a partial cement replacement for the production of self-compacting concrete on reinforcement corrosion triggered by the chlorides action.

2. Experimental work

2.1. Materials

The cement used in this work was a Brazilian Portland cement of high early strength (ASTM type V). Their physical and chemical characteristics are presented in Table 2. The fine aggregate used was a quartz sand with 1.75 fineness module and 2620 kg/m³ specific density. The coarse aggregate was a granitic crushed rock with 9.5 maximum diameter and 2690 kg/m³ specific density.

The waste used in this work was ground clay bricks waste (GCBW), which was firstly picked as broken bricks in a heavy ceramic industry placed in João Pessoa city, in the northeast of Brazil. As this waste was picked in the industry in small pieces, it was milled in a balls mill until reaching the specific surface of 5100 cm²/g. The operating temperature of the ovens in which the bricks were burnt ranged between 850 and 950 °C. Table 2 shows the physical and chemical characteristics of this waste. The pozzolanic activity index of GCBW was 86% according to Brazilian standard 5752 [15].

SEM images of GCBW particles are presented in Fig. 1. The samples were gold metalized under 10A current during 3 min in a SC – 701 Quick Coater equipment. SEM images were obtained in a VEGA3 TESCAN equipment under SE image detection method. SEM images show that GCBW grains are not spherical particles, as can be seen in Fig. 1, but they have good shape. By SEM images, it was possible to evaluate the shape index (ratio between the largest and smallest perpendicular dimensions) of about 100 particles and the average value was 1.63 ± 0.59, which is not ideal considering the reference of spherical particles but represent a good value for this property (not so far from 1) and certainly helped in obtaining self-compactness in studied concretes.

Table 2

Chemical composition and physical properties of cement and GCBW.

Analysed characteristics	Cement	GCBW	
Chemical composition (%) XRF	Na ₂ O	–	0.4
	MgO	0.4	1.1
	Al ₂ O ₃	2.6	16.2
	SiO ₂	10.9	51.9
	Fe ₂ O ₃	5.0	16.4
	P ₂ O ₅	–	0.2
	SO ₃	4.1	1.2
	K ₂ O	0.6	4.8
	CaO	73.3	3.5
	SrO	0.1	0.1
	ZrO ₂	–	0.1
	TiO ₂	0.4	2.0
	V ₂ O ₅	0.1	0
	BaO	–	0.2
	MnO	0.1	0.3
Cr ₂ O ₃	–	0.1	
Loss on ignition (%)	2.4	1.5	
Blaine specific surface (cm ² /g)	4020	5100	
Specific weight (g/cm ³)	3.15	2.62	

Three mixtures of self-compacting concrete and a reference conventional concrete were used. The absence of enough fine particles in REF concrete composition hindered reaching a self-compactness condition without segregation. Thus, REF concrete was a conventional concrete. All the self-compacting concrete mixtures used GCBW and the method used for designing these concrete mixtures was the one proposed by Gomes and Barros [16]. Self-compactness tests were based on Brazilian standard 15823-1 [17], which considers flowability, plastic viscosity and passing ability of the mixture. Table 3 shows the characteristics of concrete mixtures used in the present work.

All the studied concretes presented similar binder contents. Mortar and paste contents were the same for all mixtures as well. Considering the Brazilian standards 15823-1/2/3 recommendations [17–19], the diameter obtained in slump-flow test shall be between 550 and 850 mm and this diameter shall not be reduced more than 50 mm in J-ring test. There is no recommendation about the flow time. These recommendations were all attended by GCBW concretes. Concrete with 30% of GCBW content presented higher flowability and passing ability. However, it was the mixture SCC40 that presented better cohesion and was less prone to segregation.

2.2. Experimental tests

2.2.1. Thermogravimetric and X-ray diffraction (XRD) tests

Thermogravimetric and XRD tests were performed in cement pastes, which had the objective of making it easier to analyse the pozzolanic effect and Friedel's salt formation, as discussed in the following paragraphs. The levels of cement replacement, although not following exactly the same levels of cement replacement adopted in concrete mixtures, covered a wide range of replacements, which allowed the study of the influence of this variable.

Thermogravimetric tests were carried out aiming to help on identifying pozzolanic activity of GCBW by analysing the calcium hydroxide consumption. Three pastes with 0%, 10% and 30% of GCBW and water to cement ratio of 0.5 were produced with this purpose. The cement and water content were the same for all the pastes. These pastes were manually mixed in a porcelain mortar, casted in small plastic cylindrical moulds and removed from them in the following day. After that, these pastes remained submerged in water and in a sealed flask until being tested to avoid previous carbonation of the samples. TGA/DTG tests were carried out at 90 days. They used an inert atmosphere of nitrogen. The temperature increase rate was 5 °C/min and the band of temperature variation was 25–800 °C.

XRD tests were carried out aiming to analyse the binding ability of the matrices by Friedel's salt formation. Two pastes with 0% and 30% of GCBW were produced for these tests, which respected the same mixing, casting and curing procedures

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