Construction and Building Materials 157 (2017) 65–74

Contents lists available at ScienceDirect

Construction and Building Materials

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

Enhancement of strength of coal fly ash–carbide lime blends through chemical and mechanical activation

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HIGHLIGHTS

- Strength increase of fly ash-lime mixes is mainly due to NaCl action as a catalyzer.
- Insertion of NaCl in fly ash-lime blends causes the development of phase thomsonite.
- Increasing specific surficial area of fly ash grains results in strength increase.
- Strength normalisation of distinct fly ash-lime blends into a single framework.
- Unique equation controlling strength of all and any fly ash-lime mixes.

ARTICLE INFO

Article history:
Received 21 May 2017
Received in revised form 14 September 2017
Accepted 15 September 2017

Keywords:
Coal fly ash
Carbide lime
NaCl
Ground fly ash
Compaction
Strength
Normalisation

ABSTRACT

Compacted coal fly ash–carbide lime blends have vast prospects for being used as building materials, such as walls, foundations and floors of habitations, also as base and sub-base of pavements. The residues used on the present research (coal fly ash and carbide lime) offer an advantageous replacement to natural soils or Portland cement due to the pozzolanic reactions arising from SiO_2 and Al_2O_3 (from coal fly ash) and Ca^{++} (from carbide lime), which strengthen and stiffen the blends. Nevertheless, these reactions could be time-consuming at ambient temperatures, demanding lengthy curing periods to reach a minimum unconfined compressive strength – $q_u \geq 1.3$ MPa and 2.1 MPa, to be employed in constructing walls of habitations and base/sub-base of pavements, respectively. Therefore, this investigation aspires to estimate the impact of NaCl and ash grinding on the compressive strength of compacted ash-lime mixtures. Adding 1.0% NaCl or grinding coal fly ash (increasing particles specific surface area in 50%) triplicates strength (regarding analogous specimens deprived of NaCl or grinding). Combining NaCl and ash grinding doubled strength gain on top of the increase of using only one of the techniques. Besides, the strength of the specimens moulded was normalised in order to obtain a single framework quantifying its chemical and mechanical impacts. The established normalisation was efficaciously stretched to other fly ashes treated with carbide lime available from literature, with distinctive curing times and temperatures.

1. Introduction

At present-day, coal fly ash (FA) is the leading industry by-product produced in Brazil. It is estimated that Brazil still has approximately 32 billion tons of coal available for quarrying (Saldanha et al. [1]). Being so, the use of a by-product such as FA as a building material becomes a very appealing engineering solution. Since FA is a known pozzolan, an activator is needed in order to produce a cemented paste. The activator employed on this research is carbide lime another industry by-product originated from the acetylene gas production (Saldanha et al. [1]).

Lime activated pozzolanic reactions are time-consuming, therefore, the supplement of NaCl (sodium chloride) improves strength rate (Saldanha et al. [1]). Alternatively, ash grinding increases surface area per gram, boosting reactions with lime (Consoli et al. [2]).

The construction industry produces a significant effect on the environment. It consumes great amounts of natural resources and, furthermore, yields huge quantities of residues. Therefore, green designs and building materials are desired. The present study focuses in the reduction of consumption of natural resources (raw material, energy, etc.). Bearing in mind the structure for green construction developed by Hill and Bowen [3], two rules support the decrease of natural supplies usage: reduction of the consump-

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https://doi.org/10.1016/j.conbuildmat.2017.09.091
0950-0618/

Nomenclature

ABNT	Brazilian Standard Association	q_u	unconfined compressive strength
ASTM	American Society for Testing and Materials	R^2	coefficient of determination
Bq	Becquerel	Sv	Sievert
L	carbide lime content (expressed in relation to dry mass of fly ash)	γ_d	dry unit weight
L_v	volumetric carbide lime content (expressed as volume of carbide lime over specimen volume)	η	porosity
		x	parameter that might depend on type of fly ash and lime, ash grinding and NaCl incorporation

tion of resources and amplification of the use of residues. The second rule decreases the amount of discarded materials, and therefore extends the lifetime of waste disposal sites, diminishing the demand for natural supplies, and thus supporting the accomplishment of the first rule (Hill and Bowen [3]). According to Pacheco-Torgal and Jalali [4] residues could be reprocessed in order to be used in the construction industry in case of materials stabilised with binders. Turgut [5] and Consoli et al. [6] studied the production of bricks using coal fly ash. Turgut [5] also investigated the use of silica fume in producing bricks.

Consoli et al. [6] found out that the porosity/lime index is a feasible parameter for the assessment of unconfined compression strength (q_u) of fly ash–carbide lime blends. Investigations conducted by Saldanha and Consoli [7] concluded that the q_u of compacted coal fly ash–carbide lime specimens subjected to accelerated curing (at temperatures of 40 °C and 60 °C) on a short time period (up to 7 days) are very similar to the q_u attained with specimens cured up to 360 days at ambient temperature (23 °C). The relations obtained in the study were used for the development of accelerated mix design of lime stabilized coal fly ash. Saldanha et al. [1] have tested the influence of addition of distinct salts (NaCl and $KMnO_4$) in ash-lime blends. Results have shown that small amounts of such salts allowed an acceleration of q_u increase of coal fly ash–carbide lime mixtures. Amongst the analysed salts, NaCl provided the best results.

Hence, present research has the objective of investigating the separate and combined effects of FA grinding and the addition of small amounts of NaCl to FA-lime blends in reaching the minimum compressive strength – $q_u \geq 1.3$ MPa and 2.1 MPa to be employed in constructing walls, foundations and floors of habitations (Hall and Djerbib [8]) and base/sub-base of pavements (ABNT [9] and NCHRP [10]), respectively. The study has considered different dry unit weights of the blends and distinct amounts of carbide lime.

Additional topic to be evoked is the prospect of taking advantage of normalising the strength responses, exploiting the porosity/lime index. Furthermore, it was feasible to generalize such normalisation (achieved for a specific FA) to other fly ashes treated with carbide lime taken from literature, contemplating distinct curing periods and curing temperatures.

2. Experimental program

The experimental program began by establishing the physico-chemical properties of the not ground and ground coal fly ash, as well as of the carbide lime. Following, specimens were moulded in order to evaluate the effect of dry unit weight, amount of lime, NaCl incorporation and ash grinding on strength. Finally, unconfined compression tests were carried out.

2.1. Materials

Type "F" fly ash from coal combustion provided by a local power plant in southern Brazil was employed in current investigation. X-ray diffractometry of studied coal fly ash is presented in Fig. 1. A large amount of amorphous phase, quartz, hematite and mullite were found. As a result of X-ray Fluorescence Spectrometry (XRF) it was possible to identify the main components of the FA, among which stand out SiO_2 (64.8%), Al_2O_3 (20.4%), Fe_2O_3 (4.8%), CaO (3.1%), K_2O (2.1%), SO_3 (0.4%), MgO (0.3%), P_2O_5 (0.1%), and Na_2O (0.1%). Also, on the FA composition were found trace amounts of MnO, Cr_2O_3 and CuO. According to ABNT [11] and US Code [12] the studied coal fly ash is a non-dangerous but also non-inert material (might solubilize some components in concentrations superior that of the potable water). Fundamental description of natural and ground coal fly ash are presented on Table 1. Both natural and 2 h ground coal fly ashes are classified as silt (ML).

The carbide lime employed as the chemical activator material on this research was provided by a local acetylene gas production industry. Stoichiometrically, it has 81.0% of $Ca(OH)_2$ and 9.40% of $CaCO_3$. Lime grains' specific gravity was found to be 21.2 kN/m^3.

Distilled water and granular NaCl (when appropriate) were employed for moulding the specimens.

2.2. Methods

Natural and 2 h ground (on a ceramic ball mill) coal fly ash were employed in present research with the purpose of examining the effect of increasing specific surface area of the FA grains on the strength of ash-lime blends. The following proportions were used: dry unit weights (γ_d) ranged from 11.0 to 13.0 kN/m^3; carbide lime (L) amounts ranged from 5.0% to 15.0% of the mass of FA; moisture content was maintained constant at 18.0%; NaCl quantities used ranged from zero to 1.0% of the mass of FA combined with carbide lime. Curing period was fixed at 7 days.

2.3. Specimens moulding and curing

In order to carry out strength tests, cylinder-shaped specimens were prepared with 50 mm diameter and 100 mm height. The moulding procedure was carried out as follows: FA (natural or ground), carbide lime, NaCl (when appropriate) and water were weighted; subsequently FA and carbide lime were blended until a uniform consistency was achieved. At this stage, NaCl was added (when appropriate) on water and mixed together for approximately 10 min until complete dissolution. Following, the water-NaCl mix was added to the mixture, and the blending procedure was sustained until a uniform paste was produced. Specimens were compacted in three layers until attaining the intended γ_d. The mixing and compaction procedures were completed in less than 20 min. After the moulding procedure, every specimen was assessed (measured and weight). For every dosage three specimens were moulded. Specimens were cured in a moist controlled chamber (95% relative humidity) at 23 °C ± 2 °C for 7 days.