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Modelling the influence of density, curing time, amounts of lime and sodium chloride on the durability of compacted geopolymers monolithic walls

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HIGHLIGHTS

- A statistic non-linear regression model was developed for predicting loss of mass.
- The influence of dry density, curing time, lime content and NaCl was analysed.
- The four control factors were significant in influencing the response variable.
- Dry density was the dominant factor regarding accumulated loss of mass.
- Dry density was tailed by curing time, NaCl and lime contents, sequentially.

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ABSTRACT

This research investigates the durability (throughout wetting and drying cycles) of compacted fly ash-carbide lime blends to be used as monolithic walls submitted to heavy rainfall, high humidity and hot temperatures (as commonly found in tropical Brazil), considering the effect of four variables: carbide lime contents and sodium chloride contents, curing periods, and dry densities. Its main contribution is a statistic-based non-linear regression model for predicting the influence of such variables in durability (measured in terms of accumulated loss of mass). The four variables were found to be significant in altering the response variable (accumulated loss of mass). Dry unit weight is the main variable, followed by curing time, sodium chloride content, and carbide lime content, respectively. Finally, the R^2 statistic for the fitted non-linear regression model explains 89.1% of the variability in loss of mass.

1. Introduction

The recycling of residues in civil engineering constructions is a growing field, allowing the reduction of use of natural resources and a decrease in the general costs of building industry. In this sense, fly ash derived from the coal combustion in thermal power plants can be seen as an important source of raw material for construction [9,27]. Annually, 750 millions of tons of fly ash are generated in the world, however, only 25% is reused in this global perspective and, in Brazil, this parcel is about 30% [6,12]. Furthermore, another important residue that can be used in the stabilization of the fly ash, as an alkaline activator of the pozzolanic reaction, is the carbide lime generated in the production process of acetylene gas [10,16,26].

Durability stands amongst the mechanical properties of the fly ash stabilized with lime and can be defined as the capacity of the material to retain its integrity when exposed to destructive weathering conditions [13]. Therefore, it is possible to verify the durability through the loss of mass due to wetting and drying cycles ASTM D559 [3] and/or freezing and thawing cycles ASTM D560 [4]. Kampala et al. [19] studied the durability of the calcium carbide and fly ash stabilized silty clay against wetting and drying cycles to ascertain its performance in pavement applications. Neramitkornburi et al. [22] investigated the durability against wetting–drying cycles of waste materials (such as clay and fly ash) for developing a sustainable lightweight cellular cemented construction material. Horpibulsuk et al. [17] explored the durability

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(wetting–drying cycles) of water treatment sludge–fly ash–alkaline activator blends for developing sustainable masonry units.

By using the results of the durability tests, it is possible, for example, to make comparisons amongst the impact of each one of the main moulding variables, such as amounts of cementing agent, varying dry unit weight, curing periods and use of additives. Thus, it allows us to verify the most representative parameter related to the durability and compare the loss of mass results with current normative recommendations. It is advisable that the loss of mass, when soil-cement is utilized in compacted monolithic walls, be placed between 7% and 14% of values of accumulated loss of mass – Brazilian Standard Association NBR 13553 [8].

With respect to the main parameters related to the durability of compacted cemented mixtures, Izemmouren et al. [18] verified that the increase in the lime content from 6% to 8% and 10% has implied in a decrease in the loss of mass for a stabilized volcanic soil in the southeast region of Algeria. Machado et al. [20] stabilized a silty-clay soil with lime, in different compaction energies (standard and modified), concluded that the performance of the mixture, regarding its durability due to wetting and drying cycles, improved for higher compaction energies. Cheema et al. [11] have shown that the curing period is a key parameter regarding durability performance of pond ash-cemented mixtures cured for 7 and 28 days.

Regarding the use of additives, Ramesh et al. [23] have shown that the addition of a small amount of sodium chloride (NaCl) provides an increase in the unconfined compressive strength (UCS) of lime-fly ash blends. Likewise, Saldanha et al. [25] have verified a substantial improvement in the UCS of fly ash-carbide lime blend due to the addition of 1.0% of NaCl. This happens due to the formation of higher quantities of Calcium Silicate Hydrate (C-S-H) and, as well as the establishment of secondary binders [21,14]. Regarding the durability process, the influence of NaCl addition is not known and has not been properly investigated yet.

Finally, no studies examining the influence of all these parameters (dry unit weight, curing time, lime content, and sodium chloride) on the durability of fly ash-lime blends have been identified in the literature. This work aims to fulfil this gap: wetting and drying cycles are applied to fly ash-carbide lime blends (considering diverse carbide lime contents, different curing periods and varied dry unit weights, as well as the addition of small amounts of sodium chloride) to assess the loss of mass (durability). In addition, a non-linear statistic was developed to predict the loss of mass of fly ash-carbide lime blends for varying dry unit weight, curing time, and lime and sodium chloride contents.

2. Experimental programme

The experimental programme was carried out in four parts. Initially, the physical properties of all materials involved in the research materials were determined. Following, the minimum amount of carbide lime required for full stabilization, based on the Initial Consumption of Lime (ICL) [24] was determined and a pilot test was conducted to determine the optimum salt content in the mixture. Then, durability (wetting and drying) tests were carried out to establish the influence of the following issues: curing time, amounts of carbide lime, dry unit weights and addition of sodium chloride. Finally, a statistical analysis was carried out for checking the influence of each one these issues on the dependent variable (durability/loss of mass) allowing the formulation of a model for prediction of the loss of mass.

2.1. Materials

The fly ash (FA) used in this research is a residue of the combustion process of mineral coal generated by a thermal power station located nearby Porto Alegre (south of Brazil). It is classified according to ASTM C 618 [5] as type F. Its chemical analysis (X-ray fluorescence) has shown that the fly ash is fundamentally composed by oxides (61% SiO_2 + 24% Al_2O_3 + 5% Fe_2O_3), which are considered essential elements for the occurrence of the pozzolanic reactions. This FA, according to the Unified Soil Classification System (USCS), can be classified as silt with sand (ML). Additionally, its surface area is around 3.2 m^2/g [BET – Brunauer, Emmett and Teller test [2]]. More detailed results concerning the characterization tests of the FA are also presented in Table 1 and Fig. 1.

Carbide lime, a by-product of the manufacture of acetylene gas, obtained from one source, was used throughout this investigation as the activator agent. The chemical analysis showed that the carbide lime is 95% CaO, 2% MgO, 1% $CaCO_3$. The specific gravity of the carbide lime grains is 2.12.

Distilled water was used throughout this study.

The sodium chloride (NaCl) used for this research are provided by industrial companies specialized in the production of these elements in granular form with a purity above 99% (analytical purity).

2.2. Methods

The contents of carbide lime were defined aiming to create a favourable condition for the development of the pozzolanic reactions. Thus, for the determination of a minimum percentage of lime content, ICL method [24] was used. For this research, it was observed that a minimum amount of carbide lime of about 4% was necessary. Hence, based on such result, 5%, 8% and 11% of carbide lime were chosen.

According to Brazilian Standard Association NBR 7182 [7] the results of Proctor compaction tests of coal fly ash containing 8% of carbide lime and no NaCl, for standard (600 kN m/m^3), intermediate (1650 kN m/m^3), and modified (2700 kN m/m^3) compaction efforts, are shown in Fig. 2. Considering the maximum dry unit weight values for each compaction energy, the optimum compaction line can be established (see dotted line at Fig. 2). It is important to point out that changing carbide line contents from 8% to 5% or 11%, and/or inserting up to 1.5% of NaCl barely changes the optimum compaction line. Thus, to comprise all applied compaction energies, the dry unit weights of 12.6 kN/m^3, 11.6 kN/m^3 and 10.6 kN/m^3 and the respective optimum moisture contents of 26.0%, 31.3% and 36.6% were chosen as the moulding points.

Furthermore, in order to find the optimum content of sodium chloride (varying from 0.5% to 1.5%), unconfined compressive tests were carried out in cylindrical specimens (50 mm × 100 mm) moulded with 8% of carbide lime content (the midway amount of lime in the studying range), in the intermediate dry unit weight (11.6 kN/m^3) and cured for 28 days, following ASTM D5102 [1]. Assessments were carried out with the average amount of carbide lime (8%) and with intermediate dry unit weight (11.6 kN/m^3) with the purpose of providing a representative result. Those tests have shown that the highest unconfined compressive strength (UCS) was found for NaCl content of about 1.0% (see Fig. 3). Higher concentrations of NaCl decrease the rate of dissociation of lime,

Table 1
Physical properties of fly ash.

Properties	Fly ash
Plasticity index	Non-plastic
Specific gravity of grains	2.24 g/cm^3
Medium sand (0.2< diameter <0.6 mm)	1.5%
Fine sand (0.06< diameter <0.2 mm)	12.9%
Silt (0.002< diameter <0.06 mm)	82.4%
Clay (diameter <0.002 mm)	3.2%
Mean particle diameter (D_{50})	0.02 mm
Uniformity coefficient (C_u)	4.5