

Effect of calcium content on soil stabilisation with alkaline activation

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ABSTRACT

This paper is concerned with the role of calcium content in fly ash used to stabilise soft soils through alkaline activation with sodium-based alkaline activators. A 10 molal sodium hydroxide solution was used to activate fly ash at solution: ash ratios of 2:1 and 4:1, and at a solution: (soil + ash) ratio of 0.40. Fly ash type C, with higher calcium content (FAC), and type F, with lower calcium content (FAF) were used separately, and soil–cement (SC) and soil–lime (SL) mixtures were also tested. Comparing the strength of the FAC and FAF mixtures, the results showed that short-term compressive strength was higher for FAC. However, after longer curing FAF mixtures achieved significantly higher strength levels than SC or SL mixtures. The same relative behaviour was reported when FAF strength results were compared with SC or SL mixtures, i.e., the former achieved lower strength than the latter in the short term, but for longer curing periods FAF strength was significantly higher. XRD (X-ray diffraction), SEM (Scanning Electron Microscopy) and EDS (Energy Dispersive Spectroscopy) analysis showed material modifications that can be related to the strength results. The main conclusion is that low calcium fly ash is a better source for long term soft soil stabilisation with alkaline activation than high calcium fly ash.

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1. Introduction

In general terms, alkaline activation is a reaction between alumina-silicate materials and alkali or alkali earth substances, namely: ROH , $R(OH)_2$, R_2CO_3 , R_2S , Na_2SO_4 , $CaSO_4 \cdot 2H_2O$, $R_2 \cdot (n)SiO_2$, in which R represents an alkaline ion like sodium (Na) or potassium (K), or an alkaline earth ion like Ca. It can be described as a polycondensation process, in which the silica (SiO_2) and alumina (AlO_3) tetrahedrics interconnect and share the oxygen (O) ions. The process starts when the high hydroxyl (OH^-) concentration of the alkaline medium favours the breaking of the covalent bonds $Si-O-Si$, $Al-O-Al$ and $Al-O-Si$ from the vitreous phase of the raw material, transforming the silica and alumina ions in colloids and releasing them into the solution. The extent of dissolution depends upon the quantities and nature of the alumina and silica sources and the pH levels. In general, minerals with a higher extent of dissolution will result in higher compressive strength after the process is complete.

At the same time, the alkaline cations Na^+ , K^+ or Ca^{2+} act like the building blocks of the structure, compensating the excess negative charges associated with the modification in aluminium coordination

during the dissolution phase. Duxson et al. [11] demonstrated that sodium, when used as the alkaline agent, is incorporated into geopolymeric binders only via a charge-balancing role with aluminium. Several authors [8,18,13] report that the polymeric gel, formed immediately after the activator comes in contact with the silica/alumina source, has a Si/Al ratio of around one. Since the silica percentage present in the soil is significantly higher than alumina, this ratio can be explained by the fact that the weaker Al–O bonds are more easily broken than Si–O, which means that at an early stage of the reaction process more aluminium ions will be available. As the reaction evolves, the aluminium source diminishes while silica continues to be dissolved into the matrix, increasing the Si/Al ratio.

The resulting products accumulate for a period of time, forming a high mobility ion “soup”. If calcium is present in the mixture in significant amounts the dissolved Al–Si complex will diffuse from the solid surface and produce a dominant C–S–H gel phase. Otherwise a poly-condensation process occurs in which Si and Al ions precipitate around the nuclei points, sharing all oxygen ions, and form a Si–O–Al and Si–O–Si three-dimensional structure (the formation of Al–O–Al is not favoured). This is a more stable structure than those existing in the original aluminosilicate source (Granizo, 1998). The resulting polymeric Al–O–Si bonds are the main structure of the new material.

To enhance activation results, the source of alumina and silica should firstly be subjected to thermal treatment in order to reduce

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Table 1
Chemical composition of the original soil (wt.%).

Mg	Al	Si	K	Ca	Fe	Others
8.48	15.80	49.12	9.20	6.77	9.42	1.21

Table 2
Soil properties.

Plastic limit	19.7%
Liquid limit	51.9%
Optimum water content	18%
Maximum dry density	20.8 kN/m ³
Fines fraction	52%
UCS (optimum water content)	60–100 kPa

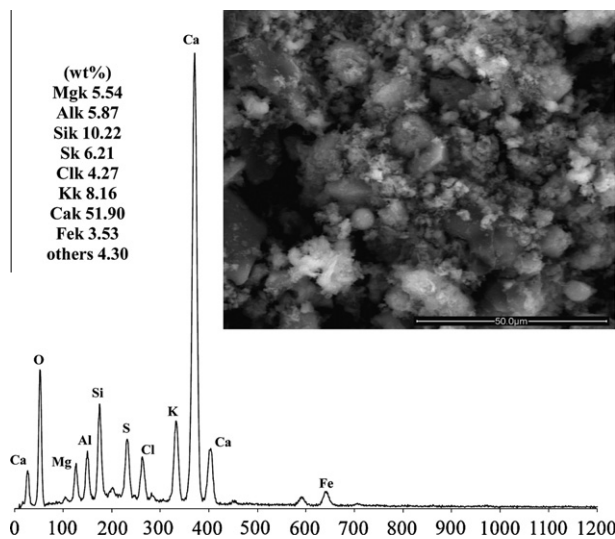


Fig. 1. Micrograph and EDS characterisation of the fly ash type C in general.

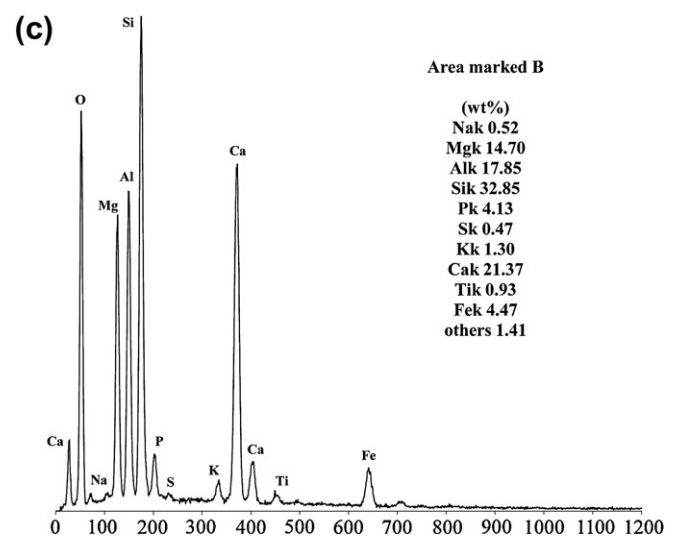
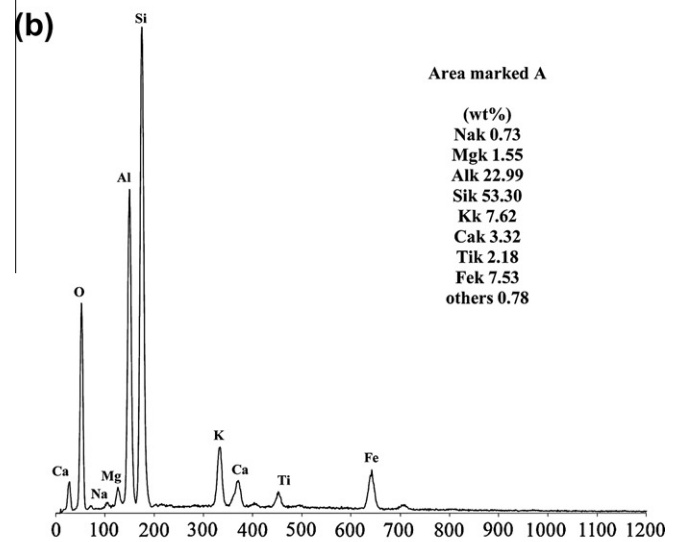
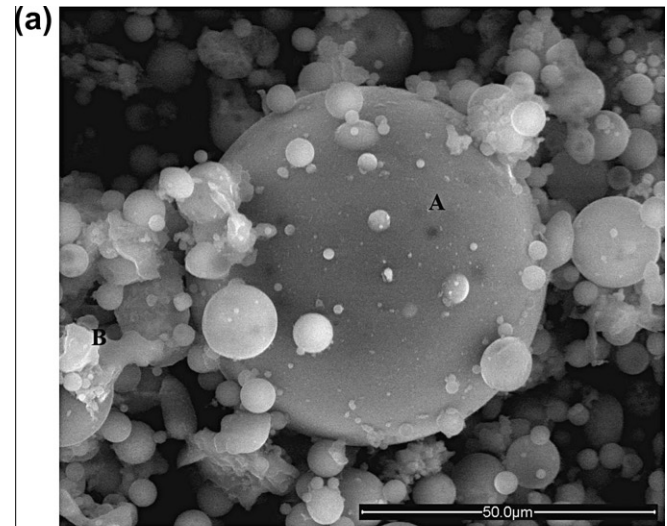


Fig. 2. Micrograph of the fly ash F (a) and EDS characterisation of areas A (b) and B (c).

the amount of crystallisation water and alter the structural order between the aluminium and the oxygen ions. An amorphous chemical structure is created, with a very reactive chemical response. Since fly ash has already undergone thermal treatment, together with the fact that it is an abundant waste material with few applications, makes it an ideal source of silica and alumina for alkaline activation. However, the calcium percentage in the fly ash is an important and sometimes neglected consideration. Fly ash is obtained from the combustion of coal, consisting of the inorganic matter that did not burn during the process. If a sub-bituminous coal is used the resulting ash will be classified as type C due to its higher amounts of calcium [2]. This type of ash has self-cementing properties, which means that in theory water is the only additive needed to hydrate this material and form cementitious products similar to those obtained from Portland cement. If a bituminous coal is used the resulting by-product is classified as class F fly ash (calcium usually not higher than 5%), with no self-cementing properties [12]. It is clear that the calcium percentage has a major impact on the properties of fly ash as a construction material, even when no alkaline agent is used to enhance its behaviour. Antiohos and Tsimas [1] added quicklime to cement and fly ash mixtures and concluded that it increased both the early and long-term strengths. Temuujin et al. [19] studied the effect of calcium compounds on the mechanical properties of fly ash based geopolymers and concluded it had a positive effect when the samples were cured at ambient temperature, but reduced their mechanical strength when they were cured at

elevated temperatures. According to Fernandez-Jimenez et al. [13], aluminosilicate gels formed after short reaction times are not homogeneous, since some ash particles react earlier than

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