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Stabilisation of construction and demolition waste with a high fines content using alkali activated fly ash

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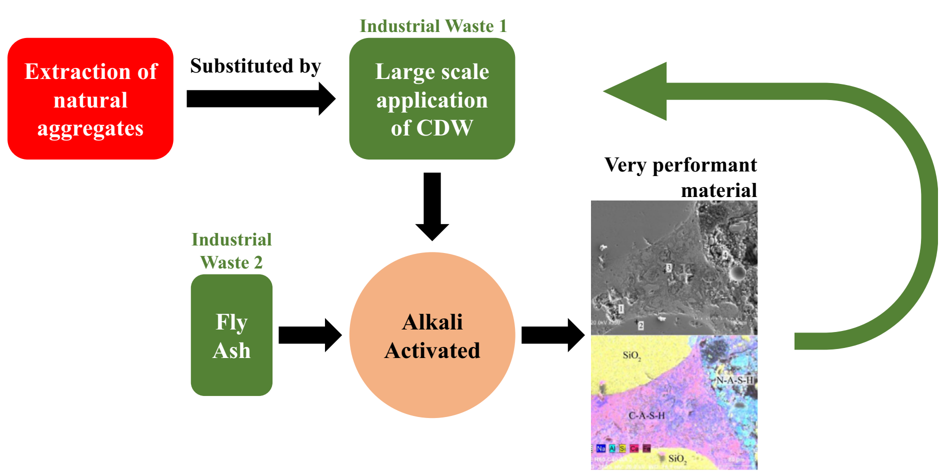
HIGHLIGHTS

- Feasibility of an industrial waste (CDW) for large scale industrial applications.
- Performance similar to natural, high-quality material (soil).
- Possible combination with another industrial waste (fly ash) very advantageous.
- Type of material formed is a combination of N—A—S—H and C—A—S—H gels.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper deals with the stabilisation of the fines portion of Construction and Demolition Waste (CDW) produced by a Portuguese recycling company. The recycled aggregate was analysed with and without the addition of a well-known precursor – fly ash (FA), considering different CDW/FA weight ratios. The resulting mixtures were activated with a solution based on sodium hydroxide and sodium silicate, and their microstructure and mechanical behaviour were extensively characterised, using XRD, FTIR, SEM, BSEM/EDX and uniaxial compression strength (UCS) tests. Results obtained showed that the presence of fly ash improves compression strength and elasticity module, reaching UCS values higher than 8 MPa, after 28 days of curing at ambient temperature and relative humidity. Such values are above any kind of threshold considered for geotechnical works such as road and railway foundations or infrastructure embankments, which are regarded as effective applications for recycled CDW. The products resulting from the alkali activation of the CDW/FA mixtures were characterised as a mixture of the gels N—A—S—H and C—A—S—H, which was attributed to the initial high content of amorphous Si, Al and Ca of these mixtures.

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1. Introduction

Over the last years, the environmental sustainability has been demanding the recycling and reuse of wastes in the most varied sectors of industry, including the construction industry. Until recently, in most European countries, the construction sector was very conservative and reluctant to apply wastes as a substitute, or even as a partial replacement, of traditional materials. However, nowadays, the use of industrial wastes is an imperative need and a compulsory way for a more sustainable world.

According to the Environment Directorate-General of the European Commission, Construction and Demolition waste (CDW) is one of the heaviest and most voluminous waste streams, representing 25%–30% of all waste generated in the European Union (EU). CDW are usually defined as the residues from construction, reconstruction, maintenance and demolition of buildings and other civil infrastructures. These wastes are very heterogeneous and can contain any material that is part of a building or infrastructure, as well as any other materials used during the construction works (e.g. concrete, bricks, gypsum, wood, glass, asphalt, excavated soil and many others).

Due to the large volumes of CDW generated annually, as well as the high potential for reuse and recycling of some of its components, CDW was identified by the European Commission as a priority stream [1]. On the one hand, the reuse of CDW reduces the consumption of natural, non-renewable resources, while, on the other hand, reduces the landfilling of these inert materials coming from the construction industry. Despite these significant advantages of recycling CDW, some member-states of the EU still have low recycling rates, far below the minimum threshold of 70% stipulated by the Waste Framework Directive of the European Parliament, to be achieved in 2020 [2]. This can be partially explained by possible concerns regarding their environmental behaviour. Such concerns are justified and constitute an important section of the national standards designed to establish the conditions necessary for the application of recycled aggregates. Indeed, for any specific application, a set of mandatory requirements are standardised in European and national specifications (e.g. density, sulphates content, chlorides content, organic material content, among others). Apart from the environmental requirements, established in the European Council Decision of 19 December 2002 [3], which regulate the minimum thresholds demanded for each class of landfill, there are several national standards regulating additional physical and mechanical properties required for each type of application. For instance, the Portuguese standard (E 474) sets the minimum requirements for pavement construction applications, regulating the waste in terms of constituents (severe limitation of the floating and unidentified particles), nature and geometry (fines quality, content and maximum dimension), mechanical performance (resistance to fragmentation and wear) and chemical behaviour (soluble sulphates content and classification as inert waste).

Numerous studies have been carried out on the use of recycled aggregates from CDW in base and subbase layers of roadways [4–11], in masonry construction products [12] and in concrete production [13–18] showing the high potential of these materials. Other studies tackled the use of CDW fine fractions as an alternative pipe backfilling material [19] and also as a filling material for geosynthetic reinforced structures [20,21]. Albeit these positive results, the fine grain portion of the CDW, due to the high fine content and scattering of its constituents (soil, glass, concrete, mortars, clay masonry units, among others), is frequently considered inappropriate for the above-mentioned applications. The present work is thus oriented towards the development of an outlet for the fine fraction of CDW, based on its stabilisation through alkali activation, either alone or mixed with fly ash.

The inclusion of this recycled material in alkali activated mixtures constitutes a recent research approach. However, some studies have been produced in the last few years, either related with the use of the CDW as a precursor or related with its use as a filler and/or courser aggregate in mortar and concrete. Regarding the use of CDW in a precursor role, Lampris et al. [22] showed that the fines (mostly silt) resulting from the washing of the CDW have the capacity to be activated, producing maximum compressive strengths of 18 MPa and 22 MPa (when mixed with 20% FA), after only 7 days curing at 25 °C. Such results were possible due to the extensive work developed to optimise the mixtures, in terms of solids/liquids ratio, soluble Si concentration, NaOH concentration and curing conditions. For comparison purposes and considering only the results that were obtained with parameters similar to those used in the present paper, a clear similarity can be observed, i.e. compression strength results between 8 and 12 MPa.

Reig et al. [23] have also shown the precursor potential of a ceramic CDW, reaching compressive strengths of up to 41 MPa and 29 MPa, with mortars prepared from red clay bricks and porcelain stoneware, respectively. Such significant differences relatively to the values obtained in the present research can be attributed to different curing conditions (7 days at 60 °C) and to the presence of a granular phase formed by siliceous sand with a maximum particle size of 2 mm.

Komnitsas et al. [24] studied the potential, for geopolymer synthesis, of concrete, red clay bricks and ceramic tiles. The CDW was submitted to previous pulverisation, and the alkaline activated pastes were cured for 7 days at 60, 80 or 90 °C. The tile-based mixtures reached a maximum of 58 MPa, while the brick-based and concrete-based mixtures showed considerably lower strength values of 35 MPa and 13 MPa, respectively, thus concluding that the CDW originated from concrete showed a lower precursor potential than the ceramic residues. However, it should be noted that such compressive strength values were only possible using curing temperatures of 80 °C or 90 °C, and after extensive pulverisation of the initial wastes. Pathak et al. [25] confirmed this trend through calorimetric analysis, obtaining higher reaction rates from brick dust than concrete power.

Robayo et al. [26] evaluated the mechanical and microstructural properties of red clay brick waste (RCBW) activated with sodium hydroxide (SH) and sodium silicate (SS), either single or in combination with up to 20% of Portland cement. The addition of SS to the original SH activator represented a strength increase of 626% (from 7.49 MPa to 54.38 MPa) for the RCBW precursor, cured at 25 °C for 28 days. The addition of 20% cement to the SH + SS activator yielded a further strength increase, to 102.6 MPa. The addition of only 10% cement to the original SH activator produced a compression strength of 41.1 MPa, for the same curing conditions. The authors concluded that a Ca source represents a major contribution towards the performance of the final material.

Vásquez et al. [27], using an activator composed of sodium hydroxide and sodium silicate, and curing for 28 days at room temperature, obtained compressive strengths of about 25 MPa, with a 100% CDW geopolymer; 33 MPa, with a hybrid geopolymer (70% CDW + 30% Portland Cement); and 46 MPa, with a binary geopolymer (90% CDW + 10% metakaolin). The higher strength values of the hybrid and binary systems, when compared with the results obtained in the present study, are not surprising, given the addition of cement and metakaolin. Regarding the value obtained for the 100% CDW mixture, also higher than the values achieved in this study, it is probable that such difference is due to the quality and origin of each CDW (which, in the reported study, was 100% demolished concrete).

Research targeting the use of CDW as an aggregate in a geopolymeric matrix is even scarcer. Mohammadinia et al. [28] mixed