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Assessment of geopolymers with Construction and Demolition Waste (CDW) aggregates as a building material

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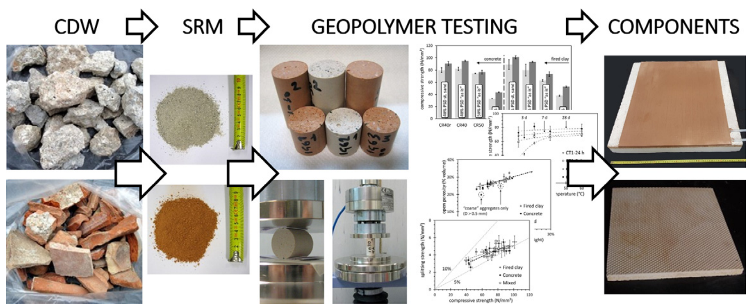
HIGHLIGHTS

- Geopolymer mixtures with CDW aggregates were extensively characterized from a mechanical and physical standpoint.
- Their potential as a building material was explored through the investigation of selected parameters.
- Aspects related to a possible exploitation at industrial level were investigated as well.

GRAPHICAL ABSTRACT



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ABSTRACT

The paper presents the assessment of metakaolin-slag-potassium-silicate geopolymer mixtures containing concrete and fired clay aggregates from Construction and Demolition Waste (CDW). An extensive characterization was carried out from a mechanical and physical standpoint, aimed at exploring their potential as a building material and their suitability for exploitation at industrial level. Based on the obtained experimental results, geopolymers with CDW showed promising properties for use in building elements even with 50% of aggregates and more, although further aspects need dedicated investigations.

1. Introduction

Construction and Demolition Wastes (CDWs) typically comprise inert mineral materials (concrete, bricks, tiles and ceramics, etc.), with smaller amounts of other components (e.g. wood, glass, plasterboard, bituminous mixtures and tar) [1]. CDWs are one of the main sources of waste in Europe, according to official data released by the European Union (EU) [2]. Although estimations may vary, due to illegal dumping and to different waste definitions and reporting mechanisms in force in various Countries [3], CDWs approximately represent one third of the total waste generated by economic activities and households, which in EU-28 are about 2.5–3 billion tonnes per year [2]. Thus, the European CDWs stream is about 0.8–1 billion tonnes per year. As underlined by Peng et al. [4], the recycling of CDWs is of primary importance for several reasons: CDWs are heavy and bulky, thus undesirable for landfill disposal; many of them are potentially very relevant for recovery and

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reuse; their recycling is environmentally significant since it would reduce the consumption of energy and natural resources, the emission of CO_2, and would promote the achievement of recycling goals (70% by weight in the European Union, according to the Waste Framework Directive [5]) and the preservation of valuable space in landfills. Incidentally, it is worth mentioning that a lack of harmonisation still exists in EU, with End-of-Waste (EoW) criteria not fully developed or consistent across different Countries [6].

Currently, two of the main destinations of recycled CDWs are: unbound aggregates for road sub-bases [7] and bound aggregates for concrete mixes [8–10], the latter being a higher added value recycling pathway. According to Nixon [10], just after the Second World War the use as aggregate in fresh concrete of brick debris left by intensive bombardments was documented, and later on concrete rubble coming from demolished fortifications was included as well. Conversely, after that period of intensive rebuilding, there was little research interest until the Seventies, when the increasing availability of CDWs and the expected future scarcity of natural aggregates promoted more systematic investigations on recycled aggregates. Recent studies demonstrated that the production of structural Recycled Aggregates Concrete (RAC) with properties comparable to those of standard concretes is feasible through a careful optimization of CDWs typologies [11,12], grading [13] and mixing approach [14]. This is mainly due to an improved refinement of the Interfacial Transition Zone (ITZ) between old aggregates and the new cementitious matrix [15,16]. Nevertheless, the use of RAC is restrained by several drawbacks. It is worth mentioning, among them, the inferior mechanical properties and the greater drying shrinkage generally exhibited by RACs in comparison to concrete made with virgin aggregates, their lower resistance to carbonation and chloride penetration, and the still low cost of natural aggregates [9–11].

A promising alternative recycling option appears to be offered by Alkali Activated Materials (AAM) and geopolymer binders, incorporating CDWs as either inert aggregates or partially reactive materials. Since AAM/geopolymers were shown to present great flexibility in using numerous types of different industrial wastes and by-products [17,18], the use of CDWs in these binders has been extensively investigated recently, with encouraging results. Concrete and/or fired clay waste aggregates were studied in [19–23]. Concrete, brick, glass and ceramic tile waste in geopolymer binders were investigated also by [24–26], while brick waste aggregates alone were specifically studied in [27] and [28], and ceramic waste aggregates were tested in [29] and [30]. These papers testify both the interest and the potential of AAM/geopolymer binders in the recycling/reuse of CDWs.

Within this context, a research was developed in the framework of the H2020 European project "InnoWEE – Innovative prefabricated components including different waste construction materials reducing building energy and minimising environmental impacts", focused on the development of architectural components (i.e. prefabricated panels for insulation, ventilated façades and radiant heating/cooling) made with geopolymer mixtures embedding CDWs. The present work presents the assessment of metakaolin-slag-potassium-silicate mixtures containing concrete and fired clay aggregates derived from CDWs. The extensive mechanical and physical characterization herein reported aimed at exploring their potential as a building material and their suitability for exploitation at industrial level. It is worth noting that the term "geopolymer" was used instead of the more general "AAM", according to Provis et al. [31], due to the primary role of the aluminosilicate and highly coordinated binding phase.

Several parameters were selected for the study, among the numerous variables that may affect the behaviour and the performance of mixtures. The test program was focused not only on mechanical performance and physical properties, but also on aspects that may influence the exploitation in industrial processes. The experimentation was obviously not exhaustive, because the subject is very wide and there are challenging aspects [32,33] (e.g. drying shrinkage, efflorescence, freeze-thaw in presence of salts, lacking of effective superplasticizing agents, etc.), whose investigation is currently at a preliminary stage. Nonetheless, the aspects presented in the following sections were assumed to be of primary importance at the first stage of the assessment process.

2. Experimental program

The experimentation involved the thorough testing of 41 geopolymer mixtures with CDW aggregates, whose detailed features are provided apart as supplementary data, for the sake of brevity. The mechanical performance of each mixture was evaluated in compression, at 7 days and 28 days of age, and in splitting at 28 days (some of them also at 7 days), except those aimed at investigating the effects of curing temperatures, which were tested only in compression but at the additional ages of 24 h and 3 days (two of them also at 3 and 6 months). Bulk and material density, open porosity and water absorption of each mixture were also measured after at least one month of curing.

In order to optimize time and material consumption, 3 repetitions for each test were envisaged, for overall 300 compression tests, 168 splitting tests and 123 measures of bulk density, material density, open porosity and water absorption. The test matrix is shown in Table 1, where mixtures are grouped by scope. It is to be noted that the original labelling of mixtures was herein revised to improve clarity, thus the present labels might not match those apparent in photos. Groups are sorted in logical order, but they do not reflect the chronological sequence of testing. Details about materials, sample preparation and test methods are reported in the following sections, along with specifications of the investigated parameters. It is to be noted that, for the sake of clarity, aggregate contents are expressed throughout the paper as a percentage of the overall dry weight of the mixture, differently from the common practice of concrete and mortars, where aggregates are usually indicated by the ratio with the binder.

2.1. Materials and specimen preparation

2.1.1. Binder

The geopolymer binder was prepared by mixing commercial metakaolin (MK: Argical MK 36), with median particle size 8.6 μm, and commercial furnace slag (SL: Minerali Ind. LV 425), with median particle size 9 μm, as reported in their datasheet. The quantitative chemical analysis of the reagents by Energy Dispersive X-ray Spectrometry (EDS), carried out with a FEI Quanta 200F FEG-ESEM equipped with an EDAX Genesis EDS system, is reported in Table 2. Two types of potassium-silicate activator with a modulus SiO_2/K_2O of either 1.26 (dens. 48.3%, type A) or 1.88 (dens. 44.1%, type B) were prepared by mixing LUDOX® TM-50 colloidal silica and KOH pellets (both from Sigma-Aldrich) with distilled water at least 24 h prior to use. Based on the chemical composition of the reagents, the generic SiO_2/Al_2O_3 molar ratios of the activator and the solid precursors were comprised between 4.4 and 4.8, while $K_2O/SiO_2 \sim 0.35$ and $K_2O/Al_2O_3 \sim 0.84$.

2.1.2. Aggregates

Aggregates used in geopolymer mixtures were obtained from the in-house grinding of concrete and fired clay scraps, both coming from two different sources. In the first phases (mixtures belonging to Group 1 – blend of aggregate types, and Group 2 – curing temperature), wastes with known origin were used, labelled CR0 and FC0. Then, they were replaced by wastes (CR1 and FC1)