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Cement-free mortars based on aggregates from Construction and Demolition Wastes

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Abstract

This study outlines research activities, carried out in the European RE^4 project, on the development of normal-weight and light-weight mortars consisting of a PFA/GGBS binder combined with aggregates from CDW (e.g. mineral fractions, heterogeneous rigid plastics, mixed wood/plastic). The aim of the study was the assessment of the alkali activated PFA/GGBS binder compatibility with different CDW aggregates thus producing cement-free mortars. Materials (PFA and GGBS, used to replace cement, and CDW used as aggregates) have been fully characterized (e.g. morphological, chemical and physical testing). The design of the PFA/GGBS binder has been at first optimised and, then, combined with different CDW aggregates for mortars production. Technical performance (e.g. consistency, density, flexural strength, compressive strength and thermal conductivity) of the optimised mortars have been finally assessed. The developed formulations, integrating recycled materials used as both binder and aggregate, represent sustainable and cost-efficient solutions and also encourage the use of recycled materials, often disposed since they do no have specific applications, in the building sector.

Keywords: Cement-free binders, Construction and Demolition Wastes aggregates, Green building materials, Circular economy, Materials recycling

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1. Introduction

The construction industry is one of the largest industrial sectors worldwide. This sector is considered the top global consumer of raw materials and energy and the highest contributor to carbon dioxide (CO_2) emissions. This sector is, therefore, constantly required to limit its environmental impacts, to become more sustainable and cost-efficient. In the view of circular economy approach and correct use of resources, a major challenge for this sector is to limit the utilization of non-renewable raw materials, which has become no more sustainable, as well as to prevent wastes disposal. Naturally occurring materials are indeed mined for construction industry with substantial impacts on the environment. Nowadays recycling of industrial by-products and wastes gaining main attention to make building materials environment friendly materials (Baikenkar et al., 2014). Current trends in the construction sector give special attention on the potential of post-consumer materials as binders and aggregates for mortars/concretes. A considerable attention is currently paid to cement-free binders, such as alkali activated materials produced from industrial by-products (Pacheco-Torgal et al. Part 1, 2008; Pacheco-Torgal et al. Part 2, 2008) and recycled aggregates, such as those resulting from construction and demolition activities (Silva et al., 2014; Saiz Martinez et al., 2016).

Research on Alkali Activated Binders (AAB) - produced with industrial by-products e.g. Pulverised Fuel Ash (PFA), from coal-fired power stations, and Ground Granulated Blast-Furnace Slag (GGBS), obtained by quenching molten iron slag - gained considerable attention as sustainable alternative to Ordinary Portland Cement (OPC) for use in mortars/concretes. Alkali activated binders are materials with the potential to provide high-performance alternatives to conventional cements, while contributing to the sustainability and costs reduction of buildings. These binders, compared with conventional cements, have a lower embodied energy and CO_2 footprint and also exhibit good physical, mechanical and durability properties. Alkali activated cements are capable of meeting or exceeding performance requirements specified in construction applications (Provis et al., 2014).

Construction and Demolition Wastes (CDW) management has been identified as a priority target in Europe. CDW represent a significant waste stream in Europe and include concrete, bricks, tiles, gypsum, wood, glass, metals or plastics. An effective way to reduce CDW pressure on the environment is their recycling in the construction sector, thus limiting their disposal and avoiding, at the same time, the consumption of non-renewable resources for building materials development (European Commission website). RE^4, project founded by the European Commission (H2020 Research and Innovation Program) and currently in progress, specifically focus on the integration of CDW in the production cycle of building materials. RE^4 project promotes new technological routes and solutions for the development of eco-compatible and cost-effective pre-fabricated components and elements with high degree of materials recycled from CDW (RE^4 project website).

The aim of this study, carried out in the framework of RE^4 project, was the development of sustainable mortars combining a cement-free binder, from industrial by-products (PFA, GGBS) activated with alkaline solutions, with aggregates recycled from CDW (mineral but also lightweight fractions often disposed since they do not have specific applications). The AAB/CDW compatibility has been assessed and the potential of this recycled materials combination has been investigated targeting the production of mortars.

2. Materials and methods

Conventional mortars consist of a binder, commonly based on cement, incorporating fine aggregates such as natural sand. In this study, mortars have been formulated using recycled materials (alumino-silicate precursors and CDW) in place of conventional binder and aggregates. The binder was produced by alkali activation (with sodium silicate and sodium hydroxide solutions) of industrial by-products: Pulverized Fuel Ash (PFA) and Ground Granulated Blast-Furnace Slag (GGBS or GGBFS) disposed, respectively, from local power stations and steel plants. Both normal-weight and light-weight CDW have been used as aggregates: mineral fractions (MF) and heterogeneous rigid plastic scraps (RP), after mechanical processing, as well as mixed wood/plastic wastes (WP) commonly disposed from CDW recycling plants.

PFA and GGBS powders were tested to assess size distribution, morphology and chemical composition (SiO_2, Al_2O_3, CaO content). In terms of size both powders were in the order of few tens of microns, composition and specific surface area resulted suitable for their use as precursors for alkali activation. CDW fractions have been tested to assess size distribution (EN 933-1), density and water absorption (EN 1097-3, EN 1097-6). MF fraction resulted below 2 mm, RP and WP below 4 mm; density was approximately 2270 kg/m^3 for MF and lower for RP (1140 kg/m^3) and WP (690 kg/m^3). Water absorption of MF resulted comparable to conventional sand, RP showed a hydrophobic behaviour in contrast with WP being highly hydrophilic.

(a) (b)

Fig. 1. PFA/GGBS mix used to replace conventional cement (a) and corresponding alkali activated binder used for mortars (b)

(a) (b)

Fig. 2. Rigid plastic (a) and mixed wood/plastic scraps (b) used to replace conventional aggregates of mortars

The method applied to develop AAB-CDW mortars consisted in the following steps:

- optimization of the AAB (replacement of cement with a PFA/GGBS mix, combination of the mix with the alkaline solution);
- development of AAB-CDW mortars (combination of the AAB with 100% standard sand, 100% MF and replacement of such fraction with RP up to 30% and WP up to 15%);
- testing of AAB-CDW mortars in terms of consistency (EN 1015-3), density (EN 1015-6, EN 1015-10), flexural and compressive strength (EN 196-1, EN 1015-11) and thermal performance assessment (EN ISO 10456).

3. Results

3.1 Binder (AAB) tests

Table 1 gives an overview of the results achieved for the binders developed by alkaline activation of industrial by-products (PFA/GGBS mix).

Table 1. Performance of AAB from industrial by-products

Binder ID	Consistency	Density (fresh binder)	Density (14 dd)	Flexural strength (14 dd)	Compressive strength (14 dd)
		kg/m^3	kg/m^3	MPa	MPa
Binder 1	Rapid setting	1912	1793	0.6	30.8
Binder 2	Fluid	1881	1727	0.6	31.2
Binder 3	Very fluid	1794	1604	-	21.6

Binders are cement-free (sustainable building materials) and have been prepared using conventional procedures and equipment; moreover, the curing occurred in standard lab conditions as for cementitious binders. Binder 3 was considered suitable for the incorporation of CDW aggregates and, therefore, for mortars production.

3.2 Mortars (AAB/CDW aggregates) tests

Table 2 and Table 3 give an overview of the results achieved for mortars based on the binder previously optimized and, respectively, mineral aggregates (standard sand/SS and MF from CDW) and lightweight aggregates (RP and WP from CDW).

Table 2. Performance of normal-weight AAB/CDW aggregate mortars.

Mortar ID	Consistency	Density (fresh mortar)	Density (14 dd)	Flexural strength (14 dd)	Compressive strength (14 dd)	Thermal conductivity (14 dd)
		kg/m^3	kg/m^3	MPa	MPa	W/mK
Mortar 1 (100% SS)	24.5	2368	2225	0.8	33.3	> 1
Mortar 2 (100% MF)	17.0	2227	2113	0.8	24.1	> 1
Mortar 3 (100% MF)	22.0	2316	2031	0.8	17.0	> 1

Table 3. Performance of light-weight AAB/CDW aggregate mortars

Mortar ID	Consistency	Density (fresh mortar)	Density (14 dd)	Flexural strength (14 dd)	Compressive strength (14 dd)	Thermal conductivity (14 dd)
		kg/m^3	kg/m^3	MPa	MPa	W/mK
Mortar 1 (30% RP)	10.0	1814	1651	0.4	10.9	0.80-1.00
Mortar 2 (30% RP)	14.0	1905	1750	0.5	10.0	0.80-1.00
Mortar 3 (15%WP)	13.0	1585	1297	0.3	1.7	0.57
Mortar 4 (10% WP)	14.0	1638	1457	0.5	3.9	0.57-0.80

Mortars are cement-free and incorporate recycled aggregates (sustainable building materials). The mortars have been prepared using conventional procedures and equipment and cured in normal lab conditions as for cementitious mortars. Mortars based on MF, if compared with RP or WP based mortars, resulted in higher consistency, density and mechanical resistance (up to 24 MPa versus 11 MPa or 4 MPa). On the other side, the reduced density when using RP and WP aggregates improves the thermal conductivity (0.57-1.00 W/mK versus > 1 W/mK). Overall, MF based mortars have the potential to be used when higher mechanical performance are required (e.g. masonry applications), while mortars based on RP or WP might be proposed when mechanical performance are less important (e.g. plasters) and improved thermal properties are mainly required.

(a) (b)

Fig. 3. Mortars based on AAB and CDW aggregates on fresh state (a) and after flexural tests (b)

4. Conclusion

This study deals with the development of sustainable mortars formulations combining Alkali Activated Binder (AAB) and aggregates from Construction and Demolition Wastes (CDW). The compatibility of the AAB with CDW aggregates (mineral fractions, lightweight scraps e.g. heterogeneous plastic and mixed wood/plastic commonly disposed) has been assessed as well as the suitability of such recycled materials combination for the production of mortars. The proposed solutions, based on recycled binders and aggregates in place of natural resources, can be considered sustainable in terms of used materials and costs. Moreover, the developed solutions have technical advantages such as manufacturing procedures and curing conditions similar to standard mortars. Concerning the cement-free mortars performance, depending on the used CDW aggregate, suitable mechanical properties can be achieved (compressive strength up to 24 MPa using 100% mineral fractions) or improved thermal performance (thermal conductivity 0.80-1.0 W/mK using 30% of rigid plastic and 0.57-0.80 W/mK using 10% of wood/plastic).

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