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Pre-packed alkali activated cement-free mortars for repair of existing masonry buildings and concrete structures

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HIGHLIGHTS

- Sustainable alkali-activated slag-based mortars were studied.
- The influence of powder activator-dosage was investigated.
- Rheological, physical and mechanical properties are affected by activator dosage.
- Compressive strength is "tailored" by changing the activator/precursor ratio.

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ABSTRACT

This paper is aimed to study a ground granulated blast furnace slag activated with alkali powder to manufacture Portland-free mortars for conservation, restoration and retrofitting of existing masonry buildings and concrete structures. Activator/precursor represents the key parameter – not only for elasto-mechanical performances – influencing the rheological properties and the shrinkage: the higher the activator dosage, the higher the consistency class and shrinkage. Moreover, elastic modulus of slag-based mortars is lower than that of OPC-mortars at the same strength class. AAMs seem to be more promising for a sustainable future in construction since the GER and GWP are reduced by about 80% compared with traditional Portland cement mortars with the same compressive strength.

1. Introduction

One of most important challenge of twentieth century is to achieve a sustainable development model, especially in the building industry. The main challenge is to support the growth of the population, and the subsequent industrialization and urbanization, protecting the environment and reducing the energy consumption and natural resources [1]. Today, Portland cement is the most widely used construction material in the world. The consumption of this material is increasing dramatically in developing countries and expected that, by 2020, the global demand would increase by approximately 400% by 2050 [2]. Production of Portland cement is energy-intensive (requiring kiln temperatures of 1450–1550 °C), consumes 1,5 tons of raw materials each ton of Portland clinker [3,4] and is responsible for global warming, accounting for 7% of worldwide CO_2 emissions.

Sustainability in construction industry can be achieved through several options: a) use alternative fuels and/or alternative raw materials to reduce CO_2 emissions [5,6], b) replace Portland clinker to the greatest extent with low-carbon supplementary cementitious materials (SCM) in concrete production [7,8], c) develop alternative Portland-free low-carbon binders [9], d) reduce natural resources consumption increasing waste utilization in concrete manufacturing [10–13].

Reduction of energy consumption and pollutants emissions is achievable with the use of belite Portland cements, blustfurnace or pozzolanic cements [14], calcium-sulphoaluminate cements, CSA-based ternary binders [15], alkali-activated binders [16] and geopolymers [17]. Finally, depletion of natural resources can be avoided using in concrete production recycled aggregates from demolition of existing structures or industrial processes, replacing natural aggregates [18–20].

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Among those above mentioned, alkali activated binders replacing Portland cement could represent in the next future a very promising solution to make the construction world more environmentally friendly. The first use of the alkali activation of aluminosilicate precursors in order to obtain an ordinary Portland cement alternative material is a patent of Kuhl in 1908. But it is only thanks to the studies of Glukhovsky in the 1950s that scientist and researchers began to talk about alkaline cements. Relevant changes took place in the 1970s with the findings of Davidovits [21] who coined the term "geopolymer" in 1979 having patented several aluminosilicate formulations. In 2009 Provis and van Deventer [22] summarized the state of art describing the process of transition from natural or synthetic powders to geopolymer-alumina-silicates. Alkaline cements are cementitious materials formed as the result of an alkaline attack on the amorphous or vitreous aluminosilicates. When mixed with alkaline activators, these materials set and harden, yielding a material with good binding properties. Different alumino-silicate materials can be activated by alkali, but ground granulated blustfurnace slag presents a lot of positive issues. In fact, the worldwide production of iron slag has been estimated around 300–360 million tons in 2015 [2]. Moreover, in recent years, due to the growth in the world iron production, the amount of slag has increased considerably. However, the vast majority of this slag is still disposed in landfills. For this reason, a slag-based activated binder represents an attractive alternative to disposal. However, a preliminary grinding of slag is needed to use the waste as precursor in Alkali Activated Mortars (AAMs) and concrete. The energy required to grind granulated blast furnace slag is only approximately 10% of the total energy required for Portland cement production [14]. Hence, alkali-activated binder based on ground granulated blast furnace slag (GGBFS) represents an eco-friendly alternative to Portland cement due to its lower raw materials consumption and CO_2 emissions [23].

The purpose of the present study is the production of mortars based on ground granulated blast furnace slag activated by a mixture of sodium metasilicate pentahydrate, potassium hydroxide and sodium carbonate in powder form for multipurpose application, from plasters and renders to repair mortars for retrofitting and seismic upgrade of reinforced concrete elements.

2. Materials and methods

2.1. Materials

Ground granulated blast furnace slag with 28-day pozzolanic activity index equal to 0.76 (according to UNI EN 15167-1 and EN 196-5) as precursor and sodium metasilicate pentahydrate: potassium hydroxide: sodium carbonate = 7: 3: 1 in powder form as activator were used to produce different mortars with the dosage of activator between 2% and 32% vs binder mass. The maximum activator/precursor ratio was limited to ensure both environmental and economic sustainability. The physical properties, laser granulometry and XRD analysis of GGBFS are reported in Table 1 and Figs. 1 and 2.

The water was adjusted in order to attain the same workability at the end of the mixing procedure, equal to 160 mm ± 10 mm by means of a flow table. Furthermore, sand/binder ratio was fixed equal to 3 (maximum diameter of natural siliceous aggregates equal to 2.5 mm).

Table 1
Physical properties of GGBFS.

	D_{50} [µm]	Specific surface [cm^2/g]	Specific mass [g/cm^3]
GGBFS	12,42	3440	3,13

2.2. Tests on mortars

Workability was measured by means of flow table according to UNI EN 1015-3. The pot-life of the mixture, corresponding the time during which workability by flow table is higher than 140 mm, was also detected. In addition, specific mass on fresh mortars according to EN 1015-6 standard was evaluated. Moreover, pH of the solution obtained mixing the activator with the same amount of water required to produce the mortar was measured. Specimens 40 × 4 0 × 160 mm^3 were produced, cured for 24 h in mold and stored in a climatic chamber at 20 °C and R.H. 60%. Specific mass, compressive and flexural strength at 1, 7 and 28 days of mortars were also determined (EN 1015-11). Drying shrinkage was measured over time on prismatic specimens stored 24 h after the mixing in a climatic chamber at a controlled temperature and humidity (T = 20 °C, R.H. = 60%) according to EN 12617-4. In addition, optical microscopy observations were performed on AA slag- and OPC-based specimens in order to evaluate the micro-cracking formation in binder paste. Finally, elastic modulus (in accordance with method B, EN 12390-13) on 28-day cured cylindrical specimens was measured.

3. Results and discussions

3.1. Fresh mixture

Compositions and fresh properties of mortars are shown in Table 2. The amount of water to achieve 160 mm spreading depends on the percentage of activator. The water/precursor decreases if the dosage of alkaline activator is at least 4% (Figs. 3 and 4). In other words, activator reduces the amount of water to obtain the target initial workability. In particular, the water reduction with respect the slag reference mortars without activator is equal to 15% and 25% when the activator dosage is 16% and 32%, respectively. This behavior is in accordance with Kashani et al. [24] that explain the plasticizing and deflocculating effects of sodium silicate on alkali activated slag-based paste with the increasing of the magnitude of repulsive double layer electric forces, causing the reduction in the yield stress at early ages.

Pot-life of reference mortar (6 h) is dramatically shortened to 30 and 60 min from casting when the activator is added (Fig. 5). The reduction of setting times is in agreement with Huanhai et al. [25] and Chang [26] that show as increasing the percentage of activator increases the released heat and shortens the peak time. In fact, a higher concentration of activator helps the resolution of calcium ions from the slag grains and consequently increases the reaction rate.

Moreover, no influence is observed in the fresh state on specific mass values similar to those of traditional Portland cement mortars at the same strength class. The difference between fresh and hardened specific mass decreases as the activator/precursor increases (Fig. 6). This behavior could be ascribed to the higher amount of water that can evaporate in reference mixture without activator and in mortars manufactured with 2 and 4% of the alkaline powder.

3.2. Hardened mixtures

Compressive and flexural strength tests were carried out on prismatic specimens according to EN 1015-11. Table 3 and Fig. 7 show compressive and flexural strength at 1, 7, and 28 days. After 24 h mortars activated with a dosage lower than 8% were not