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Application of waste brick powder in alkali activated aluminosilicates: Functional and environmental aspects

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ABSTRACT

Several alkali activated aluminosilicate (AAA) materials prepared using waste brick powder as precursor are analyzed from both functional and environmental points of view. The functional properties in hardened state are assessed by the measurement of basic physical properties and mechanical parameters. The environmental impacts are examined by determination of energy consumption and carbon dioxide emission related to their production. The obtained results show that functional properties of designed AAAs are comparable with cement-based materials. Their environmental qualities are though substantially higher, which is due to lower demand for common raw materials and lower greenhouse gases emissions and energy consumption. The combined assessment of functional and environmental aspects, which is performed using the energy consumption efficiency index and the carbon dioxide emission efficiency index, reveals that the analyzed AAA mixes can provide up to 45% savings in consumed energy and even 72% in emitted greenhouse gases, as compared with Portland cement paste.

1. Introduction

Since cement manufacturing was recognized as highly energy demanding process with significant negative environmental consequences, the urge to improve environmental sustainability of building materials became an important issue. The production of Portland cement as the most frequently used binder is responsible for almost 5% of world carbon dioxide emissions (IEA, 2008). According to other studies (Allwood et al., 2010), its share can be even higher, 6–8%. Therefore, an extensive research has been aimed at the strategies reducing CO_2 emissions within the past decades. The effort was concentrated mainly on the following areas: substitution of clinker by mineral admixtures, increasing energy efficiency and use of alternative fuels (Summerbell et al., 2016). Besides these main strategies, the use of new binders attracted a considerable attention. Alkali activated materials represented an alternative and less energy demanding solution than ordinary Portland cement based composites (Provis et al., 2015). Alkali activated aluminosilicates (often denoted also as geopolymers) exhibited, according to the previous studies, promising and excellent physical properties, such as durability, acid and sulfate resistance and high temperature resistance, which can be utilized in various applications (Gluknovsky, 1959; (Duxson et al., 2007); (Pan et al., 2018); (Hossain et al., 2018)).

The first experience with alkali activated materials is dated to the ancient times but their first applications in the modern era started in 1940s (Pacheco-Torgal et al., 2008). In 1980s, mixing of alkalis with fine particles of natural minerals became more frequent and new binders called geopolymers were introduced by Davidovits (1998), who invented many different solutions and indicated their consequent possible applications in building industry. Nowadays, geopolymers are subject of intensive investigations by various research groups. A representative state of the art can be found in the extensive report edited by Provis and van Deventer (2014).

From a theoretical point of view, any building material with silica and alumina content can be utilized as alkali activated material. The use of supplementary cementitious materials in building industry represents a promising way to reach sustainable solutions while preserving necessary functional properties. The

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investigations of prospective materials were aimed mainly at metakaolin (Alonso and Palomo, 2001; Bouguermouh et al., 2017), kaolinic clays (Barbosa et al., 2000; Longhi et al., 2016), blast furnace slag (Hwang et al., 2017; Wang et al., 2005), mixtures of slag and various additives, and fly ashes (Samson et al., 2017; Xu et al., 2017) to date. Utilization of industrial by-products or waste products is commonly considered very beneficial for the development of binders with lower environmental impact.

Ceramic waste belongs to materials whose alternative use can reduce the current intensive worldwide landfilling. Despite of the energy demanding requirements connected with crushing raw ceramic waste to sufficient fineness, the utilization of finely ground ceramic waste represents a promising way towards the decrease of both CO_2 emissions and costs, which are associated with extensive applications of ordinary Portland cement (Robayo-Salazar et al., 2017). Compared to Portland cement, ceramic waste does not require any further processing, except for grinding. It can be used in the form of aggregates in cement based composites (Lucas et al., 2016) or as a partial replacement of Portland cement (Puertas et al., 2008; Vejmelkova et al., 2012). Some applications of waste ceramic materials for the preparation of alkali activated aluminosilicates were reported as well (Reig et al., 2013a, 2013b) but they were rare until now.

The mixtures of sodium and potassium hydroxide with sodium silicate represent the most frequently used alkaline activators for the preparation of geopolymers (Duxson et al., 2007); Provis and van Deventer, 2014). (Komljenovic et al., 2010) concluded that the most dominant factor during the alkali activation process is the type, ratio, and concentration of the used alkaline activator. The relation between concentration of alkaline activators and final mechanical properties was also reported (Fernandez-Jimenez and Palomo, 2005); (Wang et al., 2005), where higher molar concentrations led to better mechanical properties. (Ken et al., 2015) found, based on the work focused on the combination of alkaline activators, pure water glass or its combination with sodium hydroxide as the most promising way for obtaining the best compressive strength.

Thanks to the minimal requirements of geopolymers on processing and depletion of natural resources, the reduction of human environmental footprint presents an essential factor for their wider application. Surprisingly, opposed to the initial assumptions considering different processing of source materials necessary for the production of geopolymers, contradictory conclusions can be found in literature in that respect. On one hand, Habert et al. (2011) or (Turner and Collins, 2013) rejected geopolymers as an environmental friendly solution due to a significant negative influence of other impact categories, such as abiotic depletion, acidification, eutrophication, and human toxicity, which were increased particularly due to the amount of used alkaline activators. Negative implications of utilization of alkali activated materials were discussed also by Davidovits (2005). On the other hand, several studies (Davidovits, 1998; Komnitsas and Zaharaki, 2007; Van Deventer et al., 2012) posed alkali activated materials as a prospective and favorable solution for a reduction of consumed energy and emitted greenhouse gases (GHGs). Stengel et al. (2009) and Weil et al. (2009) in more specific investigations reported 45% and 70% savings in these two impact categories, respectively. (McLellan et al., 2011) also calculated possible cost savings compared to the application of Portland cement, even though these data can be a subject of further discussion due to the Australia local specifics, such as long transportations distances.

It should be noted that many studies focused on the evaluation of environmental impact of alkali activated aluminosilicates were not accompanied with the assessment of functional properties of studied materials. Conversely, many investigations dealing with the influence of various activators and resulting mechanical properties disregarded any environmental assessment of studied materials. Hence, despite the significant increase of the number of studies focused on the utilization of waste or by-products in alkali activated binders, the developed products mostly require extensive investigations to deliver more representative information on their overall quality. The great potential of alkali activated binders to decrease negative externalities connected with the processing of conventional building materials, together with all demanding requirements and problems associated with their production and applications, presents good opportunities for material engineers to develop novel materials with unusual combinations of functional and environmental properties.

In this paper, several alkali activated aluminosilicates (AAA) are designed, using waste brick powder as precursor and a mix of water glass and sodium hydroxide as alkaline activator. The main goal of this study is to provide a complex assessment of the analyzed materials, taking into account and balancing both functional properties in hardened state and environmental impacts.

2. Materials and samples

2.1. Applied materials

A waste brick powder generated by grinding of thermal insulation bricks was used for the development of the alkali activated binders. The additional advantage of this material, besides being a waste product, laid in its ready-to-use properties, which did not require any thermal treatment or crushing. The collected material was dried at 105 °C for 48 h to remove redundant moisture. Then, the dried brick powder was sieved, in order to separate larger particles or shards and obtain a homogenous material. Only particles smaller than 0.125 mm were alkali activated because of their better reactivity promoting mechanical performance of designed materials in hardened state (He et al., 2013).

For the alkali activation, a mixture of sodium hydroxide pellets (99%, Fichema a.s., Czech Republic) and sodium silicate (water glass) with SiO_2/Na_2O molar ratio of 1.6 (Vodní sklo, a.s., Czech Republic) was used.

2.2. Sample preparation

At the preparation of mixtures of alkali activated materials, sodium hydroxide solid pellets were dissolved in water at first. Then, water glass was added to the solution in the predetermined ratio. The obtained alkali activator was mixed together with the desired amount of waste brick powder. The AAA pastes were prepared at atmospheric pressure by mixing the activator with water and brick powder. Five different AAA mixtures were prepared, denoted as AAP 60, 70, 80, 90 and 100 according to the amount of used water glass. The composition of studied materials is summarized in Table 1.

Samples were cast into 40 mm × 40 mm x 160 mm molds and kept in a climatic chamber at 20 °C and 50% relative humidity for 7 days, taking into account their possible longer plasticity time period (Messina et al., 2018). After demolding, samples were placed again in a climatic chamber at the same conditions for next 21 days. All materials were tested after finishing 28 days curing at described conditions.

3. Assessment methods

3.1. Material characterization

An Analysette 22 Micro Tec plus (Fritsch) laser diffraction device