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Research paper

Assessment of the suitability of gravel wash mud as raw material for the synthesis of an alkali-activated binder

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ABSTRACT

Gravel wash mud (GWM), a waste product from gravel mining was dried and processed into a fine powder to be activated by different concentrations of sodium hydroxide (NaOH) solutions for the synthesis of an alkali-activated binder. The GWM powders were thermally treated at five different calcination temperatures 550, 650, 750, 850 and 950 °C. The characterisation of the raw material comprises the particle size distribution (PSD) by laser granulometry, the chemical and mineralogical composition by X-ray fluorescence and X-ray diffraction analysis respectively, and simultaneous thermal analysis. The performance of the alkali-activated binders was examined using compression strength tests and the microstructure was observed using scanning electron microscopy (SEM). The GWM was classified as an aluminosilicate raw material with kaolinite and illite as main clay minerals. Furthermore, a mean particle size around 6.50 μm was determined for the uncalcined and calcined GWM powders. The SEM images of the developed binders showed the formation of a compact microstructure, however, relatively low strengths were achieved. This preliminary study highlights an example of an aluminosilicate prime material, which shows very promising chemical and mineralogical characteristics, but its suitability for alkaline activation without further additives was not confirmed as far as performance-based criteria are considered.

1. Introduction

Today's trend of revalorising waste products or industrial by-products to reduce the use of Ordinary Portland Cement (OPC) in building or road constructions has become an ambitious goal and a key objective of current political strategies, industries and research institutions (Friedlingstein et al., 2014; García-Gusano et al., 2015; Liu et al., 2015). Concrete, mainly based on OPC, is stated as the second most used material in the world after water and its production generates up to 5% of the overall annual CO_2 emissions worldwide. One of the main factors responsible for the unfavourable ecological performance of OPC is the high CO_2 emissions linked to the cement production processes like clinker burning including the chemical conversion of limestone ($CaCO_3$) into lime (CaO) and the emissions related to the fossil fuel combustion during cement production (Salas et al., 2016). Nevertheless, the current demand for cementitious binder is reaching record values each year and this trend is likely to increase. However, the incentive of developing sustainable and robust building concepts using alternative construction materials has become increasingly relevant. Therefore, there is a growing challenge in the research communities to develop new, durable and environmental friendly binders as an alternative to OPC binders (Shi et al., 2011).

The concepts of alkali-activated binders or geopolymer cements are intensively investigated and discussed as a very promising alternative to OPC. However, even if the concepts of alkali-activated materials and the geopolymer technology are researched since last mid-century, there are discrepancies and no overall accepted consensus considering the terminology of these materials. Fig. 1 shows a short illustration of the general differences between alkali-activated binders and geopolymers in terms of characteristics of the raw materials, activating solutions and reaction mechanisms.

Glukhovsky (1959) was the pioneer in this field of research as he extensively studied the presence of analcime phases, which are classified as zeolites, in the cements of ancient constructions and later developed binders made from aluminosilicates in reaction with alkaline industrial wastes, which he named “soil silicate concrete” and “soil cements”. The early investigations on alkali-activated binders mainly focused on the activation of blast furnace slag, a by-product of the metallurgical industry. After, the next wave of interest raised after the results of Davidovits (1979, 1994), who developed and patented a novel

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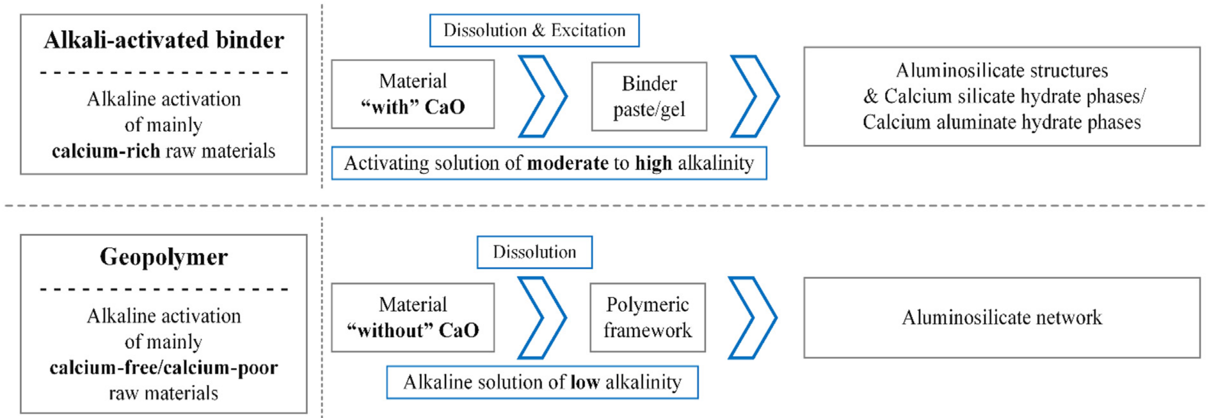

Fig. 1. Overview of the general reaction mechanisms of alkali-activated binder and geopolymer.

binder (Davidovits and Sawyer, 1985; Heitsmann et al., 1987) which he named "geopolymer cement". The first geopolymer binder was a slag-based geopolymer cement, which consisted of metakaolin, blast furnace slag and alkali silicate. The main driver for the development of this technology is the lower environmental impact compared to OPC technology. Several authors have evaluated the CO_2 emissions related to the production of these binders and have stated significant reductions of up to 80% lower CO_2 emissions compared to cement production (Davidovits et al., 1990; Provis and Van Deventer, 2009). Further benefits over conventional concrete is the rapid strength gain while reaching the maximal strength at early hours and the development of a durable and compact microstructure (Davidovits, 1994). Moreover, higher thermal resistance, higher resistance to chemical attack, low permeability and better passivation of the steel reinforcement have been identified (Pacheco-Torgal et al., 2012; Aguirre-Guerrero et al., 2017). Finally, the production of alkali-activated binders or geopolymer cements provides a sustainable and viable alternative use for "waste" materials, which have to be very uneconomically disposed in landfills.

Subsequent studies have been carried out based on these original material concepts and various authors have contributed by their research to the understanding of the chemical mechanism and the development of alkaline binders (Glukhovsky et al., 1980; Shi et al., 1991; Roy et al., 1992; Wang et al., 1994; Wang and Scrivener, 1995; Wang et al., 1995; Phair and Van Deventer, 2001; Escalante-García et al., 2003; Yunsheng et al., 2010; Le Saoût et al., 2011; Provis, 2014, 2017; Provis et al., 2015; Myers et al., 2017; Wianglor et al., 2017).

However, the application of these binders in construction elements has already become challenging as the price of these commercially available raw materials has risen over the last decades due to the high demand and the limited raw material availability, which is highly dependent on the primary industrial processes. Therefore, there is a trend to investigate on alternative prime materials to be revalorised for development of alkali-activated binders.

Sun et al. (2013) investigated on the synthesis of geopolymers out of waste ceramics, which were activated by alkali hydroxides and/or sodium/potassium silicate solutions. The maximum compressive strength for the synthesized geopolymer pastes measured after 28 days was 71.1 MPa and favourable thermodynamically stable properties in terms of compressive strength evolution after thermal exposures were observed. Pacheco-Torgal et al. (2007) investigated on an alternative to OPC using tungsten mine waste mud as prime material. The mineralogical analysis indicated the presence of muscovite and quartz minerals. After activation with a mix of sodium hydroxide and sodium silicate, different fine aggregates were added and the new binders showed very high strength at early ages. The compressive strengths for the different mixtures measured after 28 days ranged from about 60 to 75 MPa. Poowancum et al. (2015) developed a geopolymer binder using water-treatment-sludge and rice husk ash as raw material. The alkaline activator used was a mixture of sodium hydroxide and sodium silicate and the resulting maximal strengths were around 16 MPa for a rice husk content of 30%. Chen et al. (2009) studied the practicability of calcined sludge from a drainage basin of a water reservoir as a precursor for alkaline activation into an inorganic polymer. The raw material consisted of a sludge containing fractions of silts and smectite clays with high content of aluminosilicates (around 85%) and some impurities. The maximum compressive strength measured after 28 days was 56.2 MPa using the raw material calcined at 850 °C.

Ferone et al. (2013) examined the potential of two clay sediments from different reservoirs, Occhito and Sabetta, as raw material for the production of geopolymer binder. These sediments were subjected to different calcination treatments and the binder was synthesized by mixing the calcined aluminosilicates with 5 M NaOH solutions. After undergoing different curing conditions, the mechanical performance of the samples was examined. In general, a rapid strength development was observed and the maximal achieved compressive strength was around 10 MPa for the samples made of Sabetta sediments. Finally, the authors stated that the calcination temperature applied to the sediments plays a major role in the effectiveness of the geopolymerisation.

Molino et al. (2014) performed a similar series of experiments on calcined sediments from Occhito reservoir to synthesise binders using various concentrations of three different alkaline solutions, namely sodium hydroxide solution, sodium aluminate solution and potassium aluminate solution. The authors recommended for impure precursors with low content of alumina to use alumina-containing activating solutions as the samples activated with the sodium aluminate solution showed the best mechanical performance and achieved compression strengths up to 7 MPa.

Recently, Messina et al. (2017) conducted investigations on the production of precast building elements by the synthesis of geopolymer binders based on water potabilization sludge and clayey sediments, both considered as waste products from reservoir management. After calcination, different proportions of the raw materials were activated using a mixture of sodium silicate solution and a 14 M sodium hydroxide solution. The highest mechanical performance of the binders is stated around 23 MPa in compression strength and around 2 MPa in tensile splitting strength.

In general, further research on potential alternative raw materials could approve their adequacy for OPC replacement as a high compressive strength and low cost alkali-activated binder (Balek and Murat, 1996; Buchwald et al., 2009a,b; Yunsheng et al., 2010; Bignozzi et al., 2013; Gartner and Hirao, 2015).

In this work, the suitability of a waste material, gravel wash mud (GWM), as raw material for the development of novel binders is examined by conducting different material characterisation techniques and experimental tests. The main focus relies on finding the best parameters for the calcination of the GWM powders. An optimal