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Alternative cements based on alkali-activated red clay brick waste

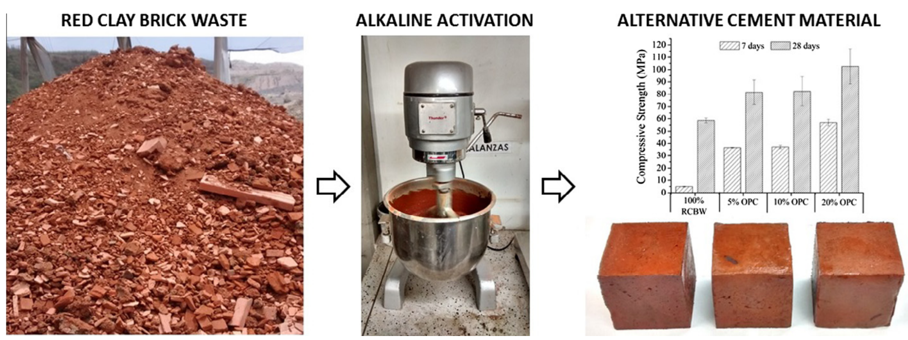
Rafael A. Robayo, Alexandra Mulford, Jorge Munera, Ruby Mejía de Gutiérrez *

Composites Materials Group (CENM), School of Materials Engineering, Calle 13 # 100-00, Edif. 349, 2° piso, Universidad del Valle, Cali, Colombia

HIGHLIGHTS

- The alkaline activation of red clay brick waste (RCBW) was investigated.
- The effect of the addition (⩽20%) of Portland Cement (OPC) was studied.
- The addition of Na_2SiO_3 and OPC contributed in the better mechanical behaviour.
- Compressive strength of up to 102 MPa was obtained at room temperature (25 °C).
- The feasibility of obtain hybrid binders using RCBW is demonstrated.

GRAPHICAL ABSTRACT



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ABSTRACT

The synthesis of alkali-activated and hybrid cements based on red clay brick waste was investigated using sodium hydroxide and sodium silicate solution as alkaline activators. The effect on the compressive strength of Na_2O/SiO_2 and SiO_2/Al_2O_3 molar ratios and type of curing was evaluated. The combined presence of Portland cement (20%) and sodium silicate yielded a maximum compressive strength of 102.6 MPa at 28 days and 25 °C; this value is two times higher than the strength obtained in mixtures without Portland cement and 7.3 times higher than when sodium hydroxide is used. The results demonstrated the feasibility of using these materials to produce structural and non-structural construction elements.

1. Introduction

Komnitsas [1] mentions that the sustainable cities of the future apart from having low energy consumption and greenhouse gas emissions should also adopt the "zero waste" principle, which contribute to sustainable development and reduction of carbon footprint. Several wastes, including those from mining, metallurgy, municipal, construction and demolition, which are produced today in huge quantities in each country, can be used as raw materials of other industries [1]. The main barriers for recycling are the quality of these wastes, specially its chemical and physical characteristics (which are very heterogeneous), and the low cost or high availability of some virgin raw materials [2]. Therefore, alkaline activation and geopolymerization are technologies that allows us to use waste (with reactive SiO_2 and Al_2O_3 species) that are unsuitable in other industries. It is noteworthy that the application of these technologies in the production of binders, in addition to promoting the use of waste and / or industrial by-products as raw materials, have additional benefits such as lower energy consumption and

* Corresponding author.
E-mail addresses: rafael.robayo@correounivalle.edu.co (R.A. Robayo), material@univalle.edu.co (A. Mulford), investigacion.gmc@correounivalle.edu.co (J. Munera), ruby.mejia@correounivalle.edu.co (R. Mejía de Gutiérrez).

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reduced level of emissions, which it has been shown in several studies to compare these to traditional Portland cements [3].

Ceramic wastes are generated by construction and demolition processes in the industrial sector and as a result of the ceramic processing. Approximately 45% of construction and demolition wastes (CDW) is attributed to ceramic products such as bricks, tiles, and porcelain [4]. According to Pacheco-Torgal and Jalali [5], the European ceramics industry generates a volume of waste that is equivalent to 3–7% of total production, which indicates that millions of tons of clay per year are disposed in landfills as the reused volume is minimal. Currently, the countries that generate the largest amount of CDW include China, the United States of America and the countries in the European Union, accounting for approximately 605.5 million tons per year; however, this number may be larger due to natural disasters in recent years [6–8]. In some countries, such as Germany, Denmark and the Netherlands, reuse approaches 80%, whereas the average in other countries is 30% [9]. Although a national statistical study of CDW in Colombia is not available, some studies indicate that 12 million tons per year are generated and remain unused in some cities with higher demographic growth, such as the city of Bogota [10,11]. In the capital of Valle del Cauca, Cali, an average volume of 2480 cubic meters of CDW is generated daily. Of this volume, approximately 76.6% (1900 cubic meters) is generated by construction companies and public construction, which is known as "formal generation"; the remaining 23.4% (580 cubic meters) is generated by private construction and remodelling, which is referred as the "informal sector" [11,12].

These large generated CDW volumes have motivated the search for alternatives to enable better use of different component materials (brick, glass, ceramics, and concrete). Alkaline activation technology has been recently considered to be an important option for the reuse of inorganic materials in CDW [3,13–17]. Note that some of these materials, such as red clay brick waste (RCBW), have been subjected to high temperatures for bricks manufacture and in some cases without adequate control, therefore, their reactivity can be reduced [18,19].

Puertas et al. [20] performed alkaline activation of different ceramic wastes with a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) at a concentration of 6 M and reported a compressive strength after 8 days of curing of 13 MPa. They attribute this relatively low strength to the semi-crystalline nature of this type of raw materials . Allahverdi and Kani [21] carried out alkaline activation of construction brick waste with a mixture of NaOH and Na_2SiO_3 (silica modulus 0.6) at a ratio of 8% Na_2O with respect to the precursor and obtained a compressive strength of 40 MPa after 28 days of curing. In a subsequent study, the author reported a maximum strength of 50 MPa using a mixture of 60% concrete waste and 40% brick waste activated with NaOH and Na_2SiO_3 solution (solution ratio: 1.4) as a precursor and the same percentage of Na_2O in the mixture. The authors emphasise the importance of taking into account the efflorescence phenomena, which suggests the addition of additives that are abundant in alumina to achieve better crosslinking of the geopolymer and lower mobility of the alkali [19]. Zaharaki et al. [16] obtained similar results (39.4 MPa) using NaOH 10 M and thermal treatment at 80 °C. Sun et al. [22] obtained a compressive strength of 71.1 MPa with urban ceramic waste activated with a mixture of KOH and NaOH and subjected to a treatment process at 60 °C for 28 days. Reig et al. [4,23] produced RCBW geopolymer pastes and mortar with a precursor:sand ratio of 1:3 activated with NaOH (7 M) and sodium silicate with a SiO_2/Na_2O ratio of 1.60. The authors report a compressive strength of 30 MPa at 7 days of curing at 65 °C and relative humidity above 90%. According to the authors, the optimization of variables such as the liquid/solid ratio can significantly increase the strength, with a maximum value of 50 MPa. Reig et al. [24] with the addition of calcium aluminate cement (40%) accelerate the reaction and to obtain, at room temperature and 3 days of curing, 50 MPa. Recently, Komnitsas et al. [25] investigated the potential for geopolymerization of different construction wastes; bricks, tiles and concrete, and reported maximum compressive strengths of 49.5 MPa and 57.8 MPa for brick and tile waste, respectively. However, the reported value for concrete waste was only 13 MPa with the use of NaOH (14 M) and a curing treatment at 90 °C for seven days, which is 43% higher than the value reported by Pathak and Kumar [26].

This study presents the evaluation of the mechanical and microstructural properties of RCBW when is activated with NaOH and Na_2SiO_3 to obtain an alkali-activated cement (100% RCBW) and a hybrid cement (RCBW + ordinary Portland cement (OPC)). RCBW was supplied by a bricks factory. The effect on the compressive strength of the following synthesis variables was analysed: Na_2O/SiO_2 and SiO_2/Al_2O_3 molar ratios, type of curing (room temperature curing at 25 °C and thermal curing at 70 °C for 24 and 48 h) and quantity of added OPC (between 5 and 20% by weight with respect to the RCBW content).

2. Materials and experimental methodology

2.1. Materials

The raw materials employed in the production of alkali-activated and hybrid cements were RCBW and OPC, respectively. The RCBW was selected from a pile of debris from a brick factory in the region (Cali, Colombia). This waste is generated during the production process, because the bricks are broken during the firing and transportation steps. The comminution of RCBW required the use of a ball mill. The chemical compositions of these materials, as presented in Table 1, were determined by X-ray fluorescence (XRF) using a MagiX-Pro PW–2440 Phillips spectrometer equipped with a Rhodium tube with a maximum power of 4 kW. In RCBW, the high molar ratio of SiO_2/Al_2O_3 (5.58) is significant. The particle size analysis was performed by laser granulometry in a Mastersizer-2000 device by Malvern Instruments, coupled with a Hydro2000MU dispersion unit, in which distilled water was applied as a dispersing medium. The average particle sizes D [4;3] for RCBW and OPC were 24.25 μm and 21.65 μm, respectively.

Fig. 1 shows the X-ray diffractogram of the RCBW, which indicates the semi-crystalline nature of the precursor and the presence of quartz (SiO_2) (Ref. Pattern: 01-079-1910) as the main phase. The following crystalline minor components were identified: hematite (Fe_2O_3) (Ref. Pattern: 01-085-0987), muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$) (Ref. Pattern: 00-002-1019) and plagioclases, albite $NaAlSi_3O_8$ (Ref. Pattern: 01-076-0898) and anorthite ($CaAl_2Si_2O_8$) (Ref. Pattern: 01-086-1706).

Table 1
Chemical composition of the raw materials (% oxides).

Element	Material	
	OPC	RCBW
SiO_2	21.13	65.92
Al_2O_3	4.92	20.08
Fe_2O_3	4.88	9.10
CaO	64.27	0.73
Na_2O	0.26	0.44
MgO	1.61	0.86
K_2O	0.25	0.97
TiO_2	0.24	1.09
Others	4.42	0.81
LOI	4.14	–
Molar ratio SiO_2/Al_2O_3	7.88	5.58