



Recycling of porcelain stoneware scraps in alkali bonded ceramic composites

Valentina Medri, Elena Landi*

CNR-ISTEC, National Research Council of Italy, Institute of Science and Technology for Ceramics, via Granarolo, 64, I-48018 Faenza, Italy

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Abstract

Ground porcelain stoneware scraps have been recycled as a partially reactive filler in alkali bonded ceramic composites. Sandwich panels were prepared by varying the dimension and amount of scraps in the core and skins. The alkali bonding was realized by using highly reactive metakaolin powder and alkaline $\text{KOH}/\text{K}_2\text{SiO}_3$ aqueous solution. The setting was performed at 80°C for 24 h. The thermal conductivity of the panels at room temperature was $0.7\text{ W m}^{-1}\text{ K}^{-1}$. Investigations on the extent of capillary water absorption and water release indicated the possibility to exploit the water retention properties of the binder for cooling by water evaporation.

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1. Introduction

With an ever increasing environmental awareness, industrial waste recycling is becoming a priority. Many industrial ceramic and glass wastes could be reused to produce construction and refractory materials [1,2].

The wall and floor ceramic tile industry produces a large amount of waste such as polishing sludge as well as discarded tiles. Regardless of the kind of product being manufactured, the starting mix for traditional ceramic must include three types of materials: a plastic material (clay), a fluxing agent to facilitate melting (such as feldspars, nepheline, etc.) and a non-plastic material to provide structural strength (such as sand and chamotte). Chamotte is a porcelain material made from recycled tiles that are wet ground and milled as scraps. However, the quantity of chamotte required by industrial processes is well below the total amount of waste tiles produced, which must necessarily end up in a landfill, with the consequent high costs of transportation and disposal.

The possibility to recycle residue coming from the industrial polishing process of porcelain stoneware tiles by using it in a porcelain stoneware body mix was studied by Rambaldi et al. [3]. Moreover, scraps from porcelain stoneware tiles can be used as fillers and aggregates to limit shrinkage and add mechanical strength to hydraulic cement systems, such as Portland cement concrete [1]. An example of the use of fired ware scraps, another type of ceramic waste material from the automobile industry, in Portland cement concrete (PCC) and hot-mix asphalt (HMA) has been evaluated by Huang et al. [4] with the purpose of replacing fine aggregates in paving material.

In addition to hydraulic cements, alkali-aluminosilicate binders, the so called geopolymers [5], are proving to be promising inorganic alternatives to organic matrices for the preparation of composite materials. They belong to the alkali bonded ceramics category, i.e. materials obtained from the reaction of an aluminosilicate powder, such as coal fly ash, calcined clay and/or metallurgical slag, with a highly concentrated alkali hydroxide solution (KOH, NaOH) and/or with alkaline silicate (KSi_2O_3 or NaSi_2O_3) solution, which leads to the formation of a synthetic alkali-aluminosilicate. Unlike calcium-based cements (such as Portland cements), geopolymers do not take in hydration water within the crystal structure

*Corresponding author. Present address: CNR-ISTEC, Via Granarolo 64, 48018 Faenza, Italy. Tel.: +39 0546699757; fax: +39 054646381.

E-mail address: elena.landini@istec.cnr.it (E. Landi).

and, although they are processed at temperatures below 120 °C, they can resist up to 1200 °C, depending on their composition [5]. Today the primary application of geopolymer technology is in the development of reduced-CO₂ construction materials as an alternative to ordinary Portland cements.

Geopolymer matrices consist of nano-precipitates [6,7] that may act as a binder for introduced fillers (glass, ceramic, metal or organic powders or fibres) forming a composite material. Obviously, different fillers can be used to tailor specific physical and thermo-mechanical properties, depending on the applications for which the alkali bonded composites are designed [8–12].

In this study, alkali bonded ceramic composites were used to produce panels with a sandwich structure for thermal insulation and passive cooling, following the idea of an eco-efficient process:

1. by recycling in the composition up to 80 wt% of porcelain stoneware scraps with different granulometry from discarded tiles (manufactured in the ceramic districts of Sassuolo-Scandiano Emilia Romagna, Italy);
2. by using a synthetic alkali-aluminosilicate as a chemically active binder (which allows chemical consolidation at low temperature), to avoid resorting to high temperatures (typically used in ceramic consolidation) during the production process of the panel and to exploit the water retention properties of the geopolymer for cooling by water evaporation [13].

This low temperature production process reduces the impact on the environment by reusing scraps, that would otherwise be dumped in a landfill. The use of ceramic waste also offers benefits in terms of recovering the energy previously stored during their production. In fact ceramic factory wastes, regardless of the reason for which they have been discarded (breakage-deformation or over- or under- firing defects) are “fired clay”, which means that they have been thermally activated (900–1200 °C) during the manufacturing process. Therefore different rejects with different chemical and mineralogical compositions might have similar reactive properties. Moreover, in fired porcelain stoneware, crystalline phases such as mullite, quartz and feldspars are embedded in a glassy matrix having a quartz-feldspathic composition that ranges between 40 and 75 wt% [14]. The alumino-silicatic glassy phase is more likely to dissolve into an alkaline solution than

the embedded crystalline phases, and porcelain stoneware scraps may play the role of partially reactive fillers. Indeed, the glassy nature of both fly ashes and ground granulated blast furnace slags are the reason for the high geopolymer reactivity of these industrial wastes [5].

Finally, the panels being presented here could be cast and cured directly at the ceramic district site, since the required raw materials (such as kaolin, metakaolin and alkali silicates) are commonly used by the ceramic tile industry, thus reducing transportation costs. The presence of ceramic production and waste recycling sites in the same location would hence consolidate the peculiar and typical features of the ceramic industry sector that has grown and is still developing around specific “clusters”, where companies working in the same or related sectors are located in the same geographical area.

2. Experimental

2.1. Binder and scrap-based composites preparation

The alkali-aluminosilicate binder was prepared by using metakaolin as raw powder. Metakaolin was prepared by calcining commercial kaolin (BS4, AGS Mineraux, Clèrac, France) at 750 °C for 15 h in an electric kiln. The main characteristics of the BS4 kaolin source for the metakaolin raw powder are reported elsewhere [15].

Potassium silicate solutions with a SiO₂:K₂O molar ratio equal to 2.00 and a H₂O:K₂O molar ratio equal to 23.00 were prepared by dissolving KOH pellets (purity > 99%, Merck, Germany) into a potassium silicate aqueous solution with a SiO₂:K₂O molar ratio equal to 3.57 (KSil 35Bè R3.5, Ingessil, Italy) by magnetic stirring. Geopolymer with SiO₂:Al₂O₃ molar ratio equal to 4.00 was prepared by mixing metakaolin with the KOH/K₂SiO₃ aqueous solution mechanically for 2 min at 100 r.p.m. The resulting slurry was then placed in plastic moulds and cured in a heater at 80 °C for 24 h.

Two grades of ground porcelain stoneware scraps (Fig. 1) were used as filler:

- S1- humidity: 2.99%; granulometry: > 5 mm = 2.52%; 2–5 mm = 39.50%; 1–2 mm = 23.72%; 400 μm–1 mm = 16.88%; < 400 μm = 17.38%.

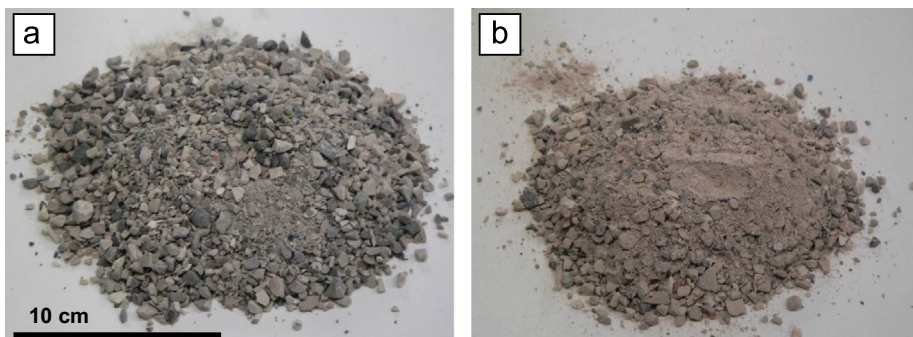


Fig. 1. Ground porcelain stoneware scraps S1 (a) and S2 (b).

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