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Review

On the production of fired clay bricks from waste materials: A critical update

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HIGHLIGHTS

- An up-to-date list of works on waste incorporation into clay ceramics is discussed.
- Fuel-containing wastes may reduce energy to produce clay bricks to less than 1 kW h.
- Brick production in Brazil uses mostly wood as fuel bringing neutral CO_2 emission.
- For the next 2 decades Brazilian bricks will be mainly fabricated by firing.
- Thereafter geopolymerization might replace firing and cementing in brick production.

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ABSTRACT

Recently, the production of bricks from waste materials was reviewed by Zhang in Construction and Building Materials. The main focus was a division into three producing methods: firing, cementing and geopolymerization. Both firing and cementing methods were indicated to consume significant amount of energy and release large quantities of greenhouse gases. Based on these drawbacks and taking into account the need to protect clay resources, it was concluded that geopolymerization seems to be the trend to follow. Most of the reviewed works on the firing method, published since 1987, were related to wastes incorporated into clay ceramics. In the present work, starting from previous review articles, additional information was added to extend the knowledge, not covered by Zhang, on the incorporation of wastes into clay ceramics. The particular case of Brazil, in which large and easy to mine clay deposits support an extensive network of ceramic industries, is surveyed. Fuel containing wastes contribute to save in firing energy, while fluxing wastes improve the ceramic properties. At least for the next decades, clay ceramic incorporation seems to be the most realistic solution for recycling industrial wastes in countries, such as Brazil, with vast clay resources.

Contents

1. Introduction

In a recent work, Zhang [1] presented a relevant state-of-the-art review on the utilization of waste materials to produce bricks. An

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extensive list of publications associated with several different types of wastes was introduced to the reader with corresponding summary of processing methods and main results. Zhang [1] divided the methods of brick production into 3 categories: firing, cementing and geopolymerization and these were discussed in terms of specific advantages and drawbacks. In particular the firing method, in most cases related to the conventional clay brick production, has the advantage of easy execution using well known and traditional procedures and equipments. By contrast, making bricks through firing, as pointed out by Zhang [1], has the drawbacks of consuming a significant amount of energy, on average 2.0 kW h, per brick, and release a large quantity of greenhouse gases, about 0.41 kg of CO_2, quoting the work of Reddy and Jagadish [2]. Another environmental concern noted by the author was a shortage of clay in many parts of the world. This motivated countries such as China to start limiting the use of bricks made from clay. In conclusion, Zhang [1] indicated that the geopolymerization method, which is claimed to consumes much less energy and is associated with a smaller carbon footprint, seems to be the trend to follow. As a long term future prognostic, one cannot disagree on Zhang [1] conclusions. However, many aspects of his review work deserve a second opinion regarding the firing method.

The reader should pay attention to two points in the present work. First, although Zhang's proposal by its title "production of bricks from waste material" [1] may appear limited to specific process of fabrication of rectangular blocks, it certainly concerns to the recycling of wastes. Regardless the type of fired ceramic piece (brick, tile, pipe, block, etc.) the important point is the feasibility of incorporating a given waste. Results in terms of advantages and drawbacks to the fired ceramic, as compared to cementing and geopolymerization, were the main focus of Zhang' review [1], not the shape of the product. A second point to be noticed is that a number of quoted articles in the present work is written in Portuguese. Far from trying to bring difficulty to the reader, the idea is of emphasize the waste incorporation into fired ceramic as a more relevant recycling procedure in Portuguese speaking countries. In particular, the reasons for Brazil will be further highlighted along this presentation. It will be shown that today, and for the next two decades, different from some other countries, the advantages strongly justify the recycling of wastes by incorporation into fired clay ceramic.

2. Previous reviews on waste incorporated clay ceramics

Perhaps by considering beyond the scope of his review, Zhang [1] failed to quote previous review articles that are now worth mentioning. Indeed, in 1997 Dondi et al. [3,4] presented an earlier two parts review on the recycling of industrial urban wastes into clay ceramics for brick production. This review was based on a literature survey since 1977 covering works from selected countries such as Italy, UK, Spain, Germany and USA. Works from other countries were disregarded. The main focus of Dondi et al. [3,4] review was a classification of the wastes into 5 categories associated with the major characteristics, which affects the clay brick. These are: fuel; fly-ash; fluxing; plasticity reducing and plasticifying wastes. The reader might be particularly interested in several earlier references in the review of Dondi et al. [3,4], not mentioned by Zhang [1], presenting a substantial amount of information in terms of waste characterization, process parameters and properties of incorporated ceramics.

More recently, an up-to-date review was presented by Vieira and Monteiro [5] on the incorporation of wastes into clay ceramics. In this later review, modifications were introduced in the original Dondi et al. [3,4] categories to allow a wider variety of wastes to be considered. Additionally to fuel and fluxing wastes, a more general category of property affecting wastes embodied the earlier proposed fly-ash, plasticity reducing and plasticifying waste categories. The consideration of a category such as fuel wastes in both reviews [3–5] enables an important distinction of residues with heat power enough to sensibly contribute to a saving in the ceramic processing and reduce the fired clay brick embodied energy. Several works investigated the incorporation of oily residues from industry and petroleum operations [6–16]. These works reported practical advantages such as the increase in processing speed, reduction in equipment wear, enhancement of mechanical properties and saving in fuel consumption. Blast furnace sludge was included as fuel waste because it still has a significant amount, up to 25%, of coke [17,18]. Sludge from pulp and paper making industry, also considered as a fuel waste, contributed to a saving in energy during the firing stage of incorporated clay ceramics [19,20]. The category of fluxing wastes, discussed in Vieira and Monteiro review [5], comprised industrial residues that would form low melting temperature phases and thus improve the linear shrinkage, water absorption and mechanical strength of clay ceramics. These are the sludge from ornamental rock processing [21–30], glassy residues [31–37], and flux-containing residues [38–40].

The general category of wastes, without heat power or fluxing action, that affect the ceramic properties encompass distinct industrial types. As in the first two categories, several works failed to be reviewed by Zhang [1]. These works investigated the following types of wastes: spent ceramic powder, also known as grog or chamotte [41–48], water treatment sludge [49–55], steel slag [56–61], ashes [62–69], electrolytic/galvanic sludge [70–76], catalyst reject [77], textile industrial slurry [78], metallurgical smelting sand rejects [79,80], tannery sludge [81], construction/demolition leftover [82,83].

3. Recent works on waste incorporated clay ceramics

After Vieira and Monteiro review [5], many other works were dedicated to the incorporation of wastes into clay ceramics. Zhang [1] listed 8 papers in a more recent period after 2008 up to 2012 but several additional ones might deserve to be reviewed. These recent additional papers will be also chronologically listed. However, as a general classification, they are divided into two categories regarding the type of incorporated waste: (3.1) fuel or organic and (3.2) fluxing or inorganic. To shorten the summary of each paper, both the amount of incorporation (wt%) and processing/firing temperature (°C) will be shown inside parenthesis. Whenever available, changes in the microstructure and properties will be indicated.

3.1. Fuel or organic wastes

Pinheiro and Holanda [84] investigated clay ceramics (uniaxially pressed/800–1000 °C) incorporated (up to 30 wt%) with encapsulated petroleum waste. The authors showed that for 30 wt% incorporation in firing at 1000 °C, the linear shrinkage decreases (3.6%), the water absorption decreases (16.5%) and the compressive strength also decreases (8.2 MPa). As for the structure, no incorporated ceramic showed surface stains and black core defects that might result from the petroleum waste. These results justify the petroleum waste incorporation as a technically adequate procedure, which causes less environmental impact. Hajjaji and Khalfaoui [85] investigated the effects of oil shale addition (up to 20 wt%) into clay ceramic (extruded/700–1075 °C). The results showed that the oil shale addition lead to development of anorthite and diopside and a drastic decrease of the ceramic glassy phase. SEM microstructures revealed shrinkage and weak cohesion