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Utilization of water treatment plant sludge in structural ceramics

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ABSTRACT

Industrial solid waste generated by a water treatment plant (WTP) at a pulp mill was used for manufacturing construction bricks. The sludge from the WTP was mixed with three types of waste obtained via recovery of chemicals generated by the same pulp mill and with waste obtained by crushing and grinding granite rock. The formulation of these mixtures was based on the grain size distribution of the residues and the proportions of calcium, sodium, and potassium oxides in the mixtures. Specimens of these mixtures were then fired at 850, 950, and 1050 °C in order to obtain crystalline phases (anorthite, albite, gehlenite, and mullite) that would confer good mechanical properties. The technological properties of the specimens were evaluated after drying and firing. The statistical analysis of technological properties of the proposed mixtures suggests that sludge can be used as a substitute for clay in the formulation of clay masses and the mixtures B, C, D, and F at 850 and 950 °C, should be tested in the ceramic industry on a pilot scale in order to evaluate their suitability for the production of interior coatings or acoustic bricks. The utilization of WTP sludge in brickmaking eliminates an environmental problem, several economies related to the replacement of a natural raw material are generated. Finally, by using WTP sludge in the manufacturing of acoustic bricks and other products, it is shown that cleaner production practices promote innovation in the pulp mill and the red ceramic industry, leading to environmentally friendly practices.

1. Introduction

To maintain a high environmental performance, the pulp and paper industry has made important investments in more efficient production processes and technologies (Ghose and Chinga-Carrasco, 2013), and the adoption of CP methodologies and the potential reduction in the negative environmental impact have been major concerns. Cleaner production is an integrated approach to handling waste and pollutants in industries (Visvanathan and Kumar, 1999). This approach entails an economic environmentally friendly production system that encompasses improvements in energy use, raw material use, and a reduction in emissions and waste. In addition, the importance of CP has motivated leaders of different countries at diverse levels of industrial development to establish national strategies or programs to accelerate the implementation of CP (Ghazinoory and Huisingh, 2006).

The CP principle involves the continuous use of industrial processes and products to increase efficiency and to reduce their impact on humans and the environment. CP represents viable preventive environmental approaches for the reduction of pollution at the source. In addition, the ability of cleaner production practices to improve production systems and generate economic and social benefits has been demonstrated (Zarkovic et al., 2011; Giannetti et al., 2008).

In a pulp mill, cleaner production can be developed by using the following two approaches (Huang et al., 2013): (1) developing a complete cleaner production technology and applying an innovative process route for the whole production process; and (2) improving production efficiency, waste reduction, and recycling by promoting cleaner production practices in a key production process. The former is convenient for upgrading the entire industry; however, the long research cycle and large investment requirement make it a high-risk approach in the new process route development (Huang et al., 2013). As we are focusing on solid waste management, i.e., the utilization of water treatment plant sludge in structural ceramics, which represents one portion of the entire production process in the pulp mill, the second approach is more suitable for our research.

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Cleaner production has allowed industrial production to find a place in this vision by recasting negative impacts of polluting industrial processes and products into positive images of news technologies that are materials-conserving, energy- efficient, non-polluting and low-waste, and that produce ecologically friendly products, like which are responsibly managed throughout their lifecycle (Geiser, 2001).

Solid waste management is very important from the public health, as well as from the socio-environmental performance and industrial perspectives because continuously increasing quantities of materials, hazardous or non-hazardous, must be discarded in a safe and economical manner or, preferably, recycled.

Like any other industrial segment, drinking water treatment plants produce residues from the processes of decantation and filter washing. A large quantity of water treatment residues is generated each year from fresh water treatment plants (Huang et al., 2005). The usual practice is to discharge these residues into rivers without any treatment. This procedure is not in accordance with cleaner production practices since its degrades not only the quality of the rivers increasing the concentration of solids, silting, causing color changes and turbidity, inhibiting biological activity, and increasing the concentrations of aluminum, iron, and some other elements; but it also poses a danger to the lives of current and future human generations.

In Brazil, procedures for adequate disposal of sludge generated by treatment of natural surface waters are already known. However, problems arising from inadequate disposal of residues seem far from being resolved and significant amounts of these residues are still being discharged in rivers.

In Brazil, NBR 10.004 (ABNT, 2004), in which sludge generated by WTPs are classified as solid waste that must be processed for final disposal, Law 9433 (Brasil, 1997), which established the National Policy on Water Resources, and Law 9605 (Brasil, 1998), the Environmental Crimes Law, have already been established. Considering these laws and the need for sanitation companies to show good environmental performance in order to obtain national and international funding, a new procedure is required for safe disposal of these residues in a way that minimizes the environmental impact.

The sludge produced by WTPs can be a potential substitute for brick clay because its chemical composition is very close to that of brick clay (Hegazy et al., 2012). In addition, the use of sludge in the construction industry is considered to be an economic and environmentally sound option (Ramadan et al., 2008).

The concentration of sludge that can be incorporated into clays in order to produce bricks depends partly on the sludge properties (grain-size distribution and chemical and mineral composition) but even more so on the properties of the raw materials used (Teixeira et al., 2011). Using bench-scale experimentation, Alleman and Berman (1984) showed that conventional clay and shale ingredients for bricks could be partially supplemented with sludge. They called this clay product “biobrick”.

Bricks manufactured from dried sludge collected from an industrial wastewater treatment plant were investigated by Lin and Weng (2001) and Weng et al. (2003). These reports showed that the sludge proportion and the firing temperature were the two key factors determining brick quality. In accordance with a previous study, bricks produced from sewage sludge of different compositions were investigated by Liew et al. (2004). Results of the tests also indicated that the sludge proportion is a key factor in determining the brick quality. Increasing the sludge proportion resulted in a decrease in brick shrinkage, bulk density, and compressive strength. Brick weight loss on ignition was mainly due to the contained organic matter from the sludge being burnt off during the firing process and the inorganic substances found in both clay and sludge.

The literature also discusses the use of WTP sludge in conjunction with other alternatives. For instance, Huang et al. (2005) and Chiang et al. (2010) discussed the use of scrap glass in conjunction with WTP sludge for manufacturing building bricks. Due to the similar mineralogical composition of clay and WTP sludge, Hegazy et al. (2012) proposed the complete substitution of brick clay by sludge incorporated with some agricultural and industrial wastes, such as rice husk ash and silica fume. Toya et al. (2007) proposed the use of waste generated during the beneficiation of silica sand and plastic clay in manufacturing glass ceramics.

The search for adequate solutions for solving environmental problems is an important condition for cleaner production in the pulp industry. Such solutions would eliminate or minimize the environmental impact of these residual materials, promote continuous improvement of environmental management in production processes, take into account technical, economic, and environmental perspectives, and promote sustainability with a strategic outlook toward future generations.

In this study, industrial solid waste generated by a WTP at a pulp mill was used to manufacture construction bricks. The recycling of such waste to fabricate structural ceramics can be technologically, economically, and environmentally attractive because it produces materials with greater flexural strengths and provides for adequate treatment of the WTP sludge. This article does not include the life cycle assessment methodology analysis.

The process is innovative because it uses only waste from pulp (WTP sludge, dregs, grits, lime mud) and from crushing and grinding granite rock (granite fines) to produce structural bricks. Therefore this technological innovation for manufacturing news products able to minimize the impacts of WTP residues can be seen as an environmental performance of industrial solid waste from WTP.

In this context, clay extraction is reduced, thereby natural resources are preserved, spending on the rehabilitation of exploited clay sites is reduced; and the amount of waste coming from the pulp industry and released in industrial landfills is reduced. Therefore, the proposed process can promote the safe disposition of WTP sludge.

2. Materials and methods

2.1. Waste characteristics

The sludge used in this study was generated by the WTP at a pulp mill that performs kraft pulping, located at Belo Oriente in the state of Minas Gerais (Brazil). The nominal installed capacity of this mill is 1,190,000 ADT[1]/year [100% elemental chlorine-free (ECF) bleaching agent]. Also, this mill employs a conventional water treatment method, that involves coagulation with aluminum sulfate, flocculation, sedimentation, filtration, and, finally, pH correction.

WTP sludge, three types of solid waste (dregs, grits, and lime mud) generated by the same plant from the recovery of chemical reagents, and granite fines from Teófilo Otoni in the state of Minas Gerais (Brazil) were used as raw materials for the fabrication of building bricks classified in Brazil as structural ceramics or red ceramics.

For the production of ceramic masses, the Winkler diagram was used to define the grain size composition by weight percentage: 25% clay, 40% silt, and 35% sand (Winkler, 1954). Noting that oversized grains of granite and grits could damage the rolling mill, the particle size of the materials was reduced to a maximum of 1.2 mm

[1] Tons of air-dried cellulose pulp.

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