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Review

Development of eco-friendly porous fired clay bricks using pore-forming agents: A review

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ABSTRACT

Today, clay bricks are facing technological challenges and are uncompetitive compared to materials such as concrete. Their performance must be improved if they are to stand up to the competition. Increasing environmental concerns over the accumulation of unmanaged wastes from agricultural or industrial productions have made these good candidates for incorporation into building materials to improve their performance. This process leads to the formation of pores in the bricks, producing lightweight and sustainable building materials.

This paper reviews the different pore-forming agents from renewable or mineral resources as described in the literature. It also presents the impact of pore-forming agents on the physical, mechanical and thermal properties of clay bricks.

1. Introduction

Worldwide, bricks are a major building material and perhaps one of the oldest. Since 3000 BC, as humans started to settle, bricks appeared as an interesting product, resistant, easily workable and usable, meaning that people could effectively protect themselves against the elements such as rain or wind and predators. For many years, bricks were hand-molded and sun-dried giving them rather fragile properties, but around 2500 BC the first fired bricks were produced, allowing people to make larger buildings (Chabat, 1881).

In most countries, the development of bricks continued through the ages and especially at the beginning of industrialization in 1830, with the invention of a brick press by Auguste Virebent. Brick industries started to develop during the Industrial Revolution, grouping into factories, and thus production expanded (Brongniart, 1844).

Since then, bricks have been used continuously for the construction of buildings because of their interesting physical, mechanical and thermal properties, especially their strength, durability and compactness (Kadir and Sarani, 2012; Sutas et al., 2012). It is indeed an economical product with cheap and abundant raw materials (for example clay and sand) and produced via a simple manufacturing process (drying, firing).

With the arrival on the construction market of high performance concrete (HPC) in the 1980's, bricks started to lose their market share and almost disappeared. In 2001, bricks accounted for only 2% of annual sales in the French building materials industry, whereas the concrete sector dominated the market with about 70% of sales (SESSI and Ministère de l'Économie, des Finances et de l'Industrie, 2003). Traditional bricks came up against technological barriers because of their limited thermal insulation properties and high weight, making them difficult to use for tall buildings. Therefore, there is a need to design an innovative material with improved performance (thermal and mechanical).

In order to achieve such improvements, incorporation of particles into the clay mixture could be envisaged, creating voids during the firing process, and thus positively modifying brick properties. Nowadays and especially over the past twenty years, wastes have

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often been used for this purpose (Devant et al., 2011). This could be an alternative way to reuse these materials, instead of dumping or burning them, while enhancing thermal and mechanical properties of bricks. Moreover, with the increasing popularity of environmentally friendly products, it could be of interest to produce a material that benefits the environment, while retaining the requisite performance (Dhanapandian and Gnanavel, 2010).

2. Generalities on porous clay bricks

Brick manufacturers have always wanted to develop products exhibiting the best insulation properties, because of environmental regulations and the growing demand for such a product (Demir et al., 2005). A way to reduce thermal conductivity would be to create cavities within the structure (Gualtieri et al., 2010), thus, increasing the porosity, giving more air contained and so thermal conductivity would fall.

In order to raise porosity, additives can be incorporated into the clay mixture before firing (Eliche-Quesada et al., 2012a), and the amount and nature of the matter chosen have a direct impact on the physical properties of the bricks developed. Actually, addition of materials that burn during the firing process lead to the creation of pores that decrease the product's density and thermal conductivity, but also unfortunately its mechanical resistance, by modifying its composition and microstructure (Bánhidi and Gömze, 2008; Eliche-Quesada et al., 2012a). It is thus necessary to find a compromise between thermal and mechanical properties in order to produce a competitive brick.

The focus, for the purposes of this review, will be restricted to fired clay-bricks containing pore-forming agents.

2.1. Pore-forming agents

Most of the pore-forming agents can be divided into two groups: those from renewable resources and those from mineral resources (those not classifiable in either of these groups will not be dealt with here). Renewable additives are affordable, abundant and have little impact on the environment (Demir et al., 2005). During the firing step, they break down completely, creating pores with different sizes and forms (Bánhidi and Gömze, 2008) and giving off energy that can be used in the firing furnace (Demir et al., 2005). Similarly, the agents from mineral resources are interesting as they also generate gases during firing. However, a larger quantity of material needs to be added to obtain such an effect than with renewables, leading to a more expensive product. They also induce negative changes in the plasticity of the mixture by increasing the water demand to obtain the desired rheology (Demir et al., 2005).

2.1.1. Renewable agents

The development of world agricultural and industrial production has led to the accompanying production of large quantities of waste. Most of these residues are not adequately managed and are often landfilled or burned (Demir and Orhan, 2003; Alonso-Santurde et al., 2011). Nowadays, with increasing concern for the environment, researchers are interested in the production of new building materials, for instance clay bricks incorporating these wastes, especially the organic ones (Algin and Turgut, 2008).

Products or by-products of agricultural crops have for example been used, as they are abundant and quite cheap: wheat straw, corn cob, several seeds (rape, maize, wheat and sunflower (Saiah et al., 2010)), grass (Demir, 2008), olive mill solid residue (de la Casa et al., 2012; La Rubia-García et al., 2012), sunflower seed shell (Bánhidi and Gömze, 2008), rice husk (Carter et al., 1982; Chiang et al., 2009; Sutas et al., 2012), rice husk ash (Sutas et al., 2012) and rice peel (Bánhidi and Gömze, 2008).

Industrial wastes have also been incorporated into bricks: from the wood industry – resinous wood fibers (Saiah et al., 2010) or sawdust (Bánhidi and Gömze, 2008; Demir, 2008), from the tobacco industry – tobacco waste (Demir, 2008) or cigarette butts (Kadir et al., 2010), from the brewing industry – spent grains (Russ et al., 2005) or bagasse (Eliche-Quesada et al., 2011; Martínez et al., 2012), from the paper industry – Kraft pulp residues (Demir et al., 2005), recycled paper processing residues (Sutcu and Akkurt, 2009) or concentrates of bleach plant membrane filtration (Shukla et al., 2010), from the biodiesel industry – glycerin and spent earth from filtration (Eliche-Quesada et al., 2012a), from the sugarcane industry (Faria et al., 2012), from the tea and coffee industry (Demir, 2006; Eliche-Quesada et al., 2011), from biomass incineration (Pérez-Villarejo et al., 2012) and from charcoal production (Phonphuak and Thiansem, 2012). Wastewater and sludge have also been reused in clay bricks: from olive mill (Mekki et al., 2008; Eliche-Quesada et al., 2011), from acidic processes (Koseoglu et al., 2010) or from various plants (Giugliano and Paggi, 1985; Wiebusch and Seyfried, 1997; Basegio et al., 2002; Weng et al., 2003; Eliche-Quesada et al., 2011; Herek et al., 2012).

Table 1 shows most of the "organic" pore-forming agents found in the literature that have been tested, how they are generally used, and the quantity incorporated (by weight) into clay bricks. What is noteworthy is that the chosen materials are locally available and cheap (or even free), and more or less recycled, which explains their diversity; they were not particularly chosen for their composition or properties but more for their abundance.

2.1.2. Pore-forming agents from mineral resources

In order to produce lightweight construction bricks, pore-forming agents from mineral resources have also been incorporated. During the firing step as renewable agents they break down, producing carbon dioxide (essentially by decomposition of calcium carbonate), leading to porous materials, with different pore sizes. The properties of the bricks obtained are interesting but depend, among other things, on the nature and quantity of the pore-forming agent added.

Various types of wastes have been added to bricks: sands (Alonso-Santurde et al., 2011; Quijorna et al., 2012 combined with slags), slags (Shih et al., 2004; Dondi et al., 2010), ashes and dust (Domínguez and Ullman, 1996; Cultrone and Sebastián, 2009; Lin, 2006; Koseoglu et al., 2010), tailings (Uslu and Arol, 2004; Menezes et al., 2005; Topçu and Işıkdağ, 2007; Chen et al., 2011), marble residues (Saboya Jr. et al., 2007; Montero et al., 2009; (Eliche-Quesada et al., 2012b) or even marble and granite powder (Dhanapandian and Gnanavel, 2010), waste glass (Lin, 2007; Dondi et al., 2009) or waste from phosphoric acid plants (Abalı et al., 2007).

Table 2 summarizes the "inorganic" products described in the literature, how they are generally used and the percentage incorporated (by weight) into clay bricks.

2.2. Methodology for manufacturing porous bricks

Porous bricks are usually prepared using the following process (Fig. 1). The raw materials (clay, pore-forming agents) are first chosen and characterized, then mixed together with addition of water. The resulting mixtures are then molded manually or by extrusion. Finally, the drying and firing steps lead to the desired bricks.

Various types of bricks with different shapes (bricks, cubes, cylindrical test pieces) have been produced and described in the literature. Several methods for molding (molding box, manual compaction, extrusion, press) and conditions of drying and firing