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Assessing the environmental and economic potential of Limestone Calcined Clay Cement in Cuba

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ABSTRACT

Cement is the most produced material around the world. Developing countries face a growth of population involving an increasing need of infrastructures. Due to this situation, the cement industry needs to find the best comprise between increasing the cement production and without increasing the negative environmental impact. A promising solution has been found in the use of supplementary cementitious materials (SCM), these materials are used to replace clinker in cement because of their pozzolanic reactivity. In this paper, a method was developed to assess the details of the economic and environmental potential of the specific Limestone Calcined Clays Cement LC^3 technology in the Cuban context. A comparison with traditional Portland cement and the current commercial blended cement with zeolite (PPC) sold in Cuba was made. The results provide evidenced based data for the development of a strategy to adopt the LC^3 technology by the Cuban market. This assessment method can then be easily extended to markets in other developing countries.

1. Introduction

Worldwide demand for cement and concrete has increased exponentially in the last twenty years which was a result of the combination of strong ongoing trends such as the growth of population and the increased need for infrastructure and housing. Consequentially, this demand has been fulfilled by the expansion of cement plants, increasing the extraction of raw materials, increased consumption of fossil energy and negative environmental impact.

The cement industry has faced significant pressure and made efforts to improve its production efficiency (Ishak and Hashim, 2015) as well as its environmental impact (Kajaste and Hurme, 2016). Amongst the main improvements, the development of dry calcination process instead of a wet one, and an increased use of alternative fuels has drastically reduced the energy consumption and associated CO_2 emissions in cement production (Deja et al., 2010; Feiz et al., 2015a, 2015b). However, these improvements in the production process were not sufficient to face the increasing demand and at the same time achieve low CO_2 emissions.

A promising solution has been found in the use of supplementary cementitious materials (SCM) (OECD/IEA and WBSCD, 2009; Scrivener, 2014). These materials were used to replace clinker in cement because of their pozzolanic reactivity. Their use was intended to prevent the emissions that would have been created by producing the equivalent quantity of clinker. SCMs were generally industrial by-products or waste such as fly-ashes and slags. Numerous studies have assessed the potential of these resources which depend on their availability as well as their efficiency to replace clinker (Scrivener, 2014; Damtoft et al., 2008). As an example, slags can replace 70% of clinker but the available amount of slag was only 5% of the amount of clinker produced which therefore does not place slag as a global alternative for cement. Fly ash was available in larger amounts but a large part was not suitable for cement production and its replacement as SCM in cement was often limited to 30%. Faced with the limited availability of traditional SCMs and/or their limited efficiency, alternative SCMs should be studied. Clays which become reactive after calcination at temperatures between 600 and 800 °C have been used as SCM for a

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long time. It was the Roman mortar that was made with lime and calcined clay. Its development in the late 1970s in India and South America has been important as clay deposits were abundant and have a worldwide distribution. However, as fly ashes, their substitution potential was limited to around 30%.

Recently, it has been shown that a coupled substitution of limestone with calcined clay could significantly enhance most properties. Limestone reacts with the alumina in the presence of calcium hydroxide (Damidot et al., 2011; Lothenbach et al., 2008; Matschei et al., 2007). This reaction was enhanced in the presence of extra alumina provided by the calcined clay. Carbo aluminate hydrates were formed and filled the pore space which increased the strength of the entire mortar as shown in equation (1):

$$A_{(\text{from calcined clay})} + Cc + 3CH \rightarrow C_3A{\cdot}Cc{\cdot}H_{11} \quad (1)$$

The potential of this ternary blend of limestone, calcined clay and clinker which we call LC^3 has been demonstrated by Antoni et al. (2012) and recently with a large panel of clays by Avet et al. (in press). These studies show that this blend gave good mechanical performance with only 50% clinker content. Moreover, industrial trials have been already carried out with success in Cuba (Vizcaíno-Andrés et al., 2015).

The Cuban economy was currently experiencing large structural changes. The Cuban government has declared an expected annual economic growth from 3 to 5% (Murillo, 2014). In this situation the construction sector – which was strongly related with development and the economy – was projected to grow. The Cuban Ministry of Construction was planning to reach a production of 3.5 Mt of cement per year by 2019. Considering that current production was under 2 Mt/year, the demand should increase around 15–18% yearly to reach that amount in 2019. This was a gigantic challenge considering that at the same time, CO_2 emissions have to be reduced in order to stay below the 2 °C increase of global temperature (Meinshausen et al., 2009).

In other industrial sectors and in country-specific studies, a classic way to assess the balance between an increase in product demand and technology improvement was to use the Holdren/Ehrlich framework that was known as the I = PAT equation, where I represents impact (here the cement demand), P is the population size, A is the affluence per capita and T is the effect of technology (Ehrlich and Holdren, 1971). This equation has already been used to determine the future of cement demand (Szabó et al., 2003). In Szabó's study, cement production evolution was linked with economic activity and the levels of industrialization and infrastructures development of the country. These parameters can be expressed as an intensity of cement use that refers to the amount of cement used per unit of GDP (kg/unit of GDP). Note that a Unit of GDP was here adjusted to 1000 constant dollars (base year: 2000) and expressed in term of Purchasing Power Parities (PPP) which were the rates of currency conversion that eliminate the differences in price levels between countries. The intensity of the use of cement differs between countries according to economic growth (GDP) and economic structure.

In this paper, a method was developed to assess the details of the economic and environmental potential of the specific LC^3 cement technology in the Cuban context. A comparison with traditional Portland cement and the current commercial blended cement with zeolite (PPC) sold in Cuba was made. The results provide evidenced based data to provide guidance on the strategic position to be adopted for the LC^3 technology on the Cuban market. This assessment method can then be easily extended to markets in other developing countries such as India which has a fast growing cement demand.

2. Assessment method

Two methodologies were used to assess Low Carbon Cement (LC^3) impacts:

- Life Cycle Assessment (LCA)

Through a Life Cycle Assessment (LCA), environmental evaluation was done. It was a method for evaluating the environmental load of processes and products during their life cycle, from cradle to grave ("ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework," 2006). LCA has been used in the building sector since 1990 (Fava, 2006) and was now a widely used methodology (Cabeza et al., 2014; Feiz et al., 2015a, 2015b; Monahan and Powell, 2011; Zabalza Bribián et al., 2011). The LCA method was divided into 3 main stages ("ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework," 2006). First, the functional unit and the system boundaries had to be defined (Section 2.1). Secondly, the inventory phase covered the identification and the quantification of all input and output from the considered system. Finally, once the Life Cycle Inventory has been done, the environmental impact categories have to be defined. These three stages were detailed in Section 2.3.

- Capital and Operational Expenditures analysis.

Concerning the economic impact assessment, the Capital and Operational Expenditures analysis were performed. The same system boundaries and functional units were used for both calculations.

2.1. Choice of the functional unit

This study focused on the production and transport of the cement constituents. The analysis did not include every stage of the product's life cycle (cradle to grave) but ended at an intermediate stage (cradle to gate) as shown in Fig. 1. This can be done when the production, such as cement, which has multiple specific applications in civil engineering (beams, pillars, pavements, houses, bridges, etc.) does not allow a unique life cycle to be defined. This type of partial analysis was useful for the further construction of complete life cycles for specific cement products on a larger scale. The functional unit used in the study was 1 tonne of cement.

Three cements were compared:

(1) The standard Ordinary Portland Cement (OPC). It was to be noted that in Cuba it was made with 5% of Calcium Carbonate (OPC)

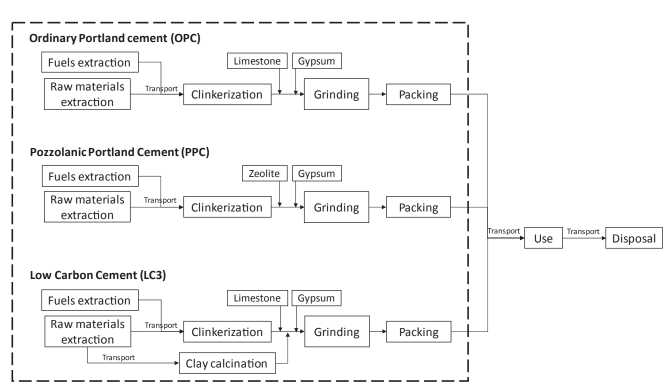

Fig. 1. Production scheme for each cement.