Low Carbon Cement LC^3 in Cuba: Ways to Achieve a Sustainable Growth of Cement Production in Emerging Economies

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Abstract. Through a collaborative work established between CIDEM and the Laboratory of Construction Materials at EPFL, a new cementitious system based on a synergetic combination of calcined clay and limestone as Portland's clinker replacement was developed. The novelty of the system was that despite the low clinker content (50%) the resulting cement reached similar performance to pure Portland cement. The Cuban cement industry has collaborated with the introduction and take up of LC^3 since early 2011, and it has gathered experiences, which could be useful for other cement makers around the globe. This paper discusses the roadmap followed by the technical team to introduce LC^3as a mainstream product. The main areas of engagement were: (i) identification of reserves of suitable clay for the production of LC^3, (ii) Realization of industrial trials for the manufacture of LC^3, (iii) assessment of economic and environmental feasibility of the production, and (iv) formulation of new standards which cover the formulation of the new cement as well as its application in concrete. Results of the work of the multi-disciplinary team dealing with the introduction of LC^3 shall be presented, including the formulation of the material with local raw materials, considerations about the process, and performance and durability of concrete.

1 Introduction

Cuba has entered a process of economic reforms since 2009, and a boost on overall demand of cement for the forthcoming years is foreseen. Cuban cement consumption has historically been following the same trend of production output, since demand exceeds the supply by far. Forecasted demand based on the cement group's estimations would be in the order of 18, 15 and 10% growth rate by the subperiods 2016–2020, 2020–2025, 2026–2030, respectively [1].

To meet the demand, a short-term strategy should be devised. Increasing the availability of clinker is a long term and expensive path. An alternative could be increasing the amount of blended cements based on a modest increase of clinker production. Cuba's average clinker factor is in the range of 0.7–0.95, thus there is a huge potential for improvement [2].

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2 Identification of Suitable Clay Deposits

Selection of clay deposits was made based on its geological characteristics and its potential reactivity. The main criteria were preliminary identification of clay mineral type 1:1, and sufficient availability of resources. Five clay deposits were surveyed and representative samples from the clay deposits were studied for reactivity at lab conditions. Table 1 presents the main tests carried out to assess reactivity, as well as the kaolinite content of the clay and the potential reserves. With the exception of clay deposit "Cayo Guam" the rest are linked to the cement plant Siguaney [4].

Table 1. Clay deposits studied and experimental program carried out

Clay deposits	K %	Reserves (M ton)	XRF/XRD	TG/DTA	Strength	Soluble Al
Pontezuela	40–50	0.5–1	x	x	x	x
La Loma	40–50	1–2	x	x	x	x
Loma Sur	45–50	0.5–1	x	x	x	x
Yaguajay	40–45	4–6	x	x	x	x
Cayo Guam	60–70	>5	x	x	x	x

Pontezuela was used for a preliminary and exploratory industrial trial to assess the properties of the ternary cement LC^3 [2], and Yaguajay was selected as the clay deposit to use for commercial production, mainly because of the proximity to the cement plant and the volume of reserves.

3 Realization of Industrial Trials

The Cuban cement industry decided to make an industrial trial at cement factory Siguaney, which was carried out in 2013. [4] The target ternary cement should have clinker content around 50%. The trial included the calcination of 110 tonnes of clay from the clay deposit Pontezuela; mixing and homogenizing of the calcined material with limestone in a 2:1 ratio; and co-grinding of the synergetic materials with clinker and gypsum by using a ball mill with a double chamber grinding system.

The total production of LC^3 cement was 130 tonnnes. The material was characterized following the protocol established for blended cements in Cuban standards. Results are presented in Table 2. Different kinds of concrete and mortar applications were made successfully with the 1:1 substitution of Portland cement [2].

Table 2. Results of physical and mechanical test of the industrial low carbon cement

Material	Retained 4900 Sieve (%)	Consistency (%)	Setting time		Volume Stability (mm)	Compressive strength (Mpa)		
			Initial (min)	Final (hr.)		3d	7d	28d
LC3	12.0	25.0	135	2.9	0.3	11.0	17.5	30.3

Trial productions of several types of concrete were made using the LC3 produced at the industrial trial. Among several applications, 25 MPa precast concrete elements was cast. Table 3 presents the results of this concrete, where Portland cement has been replaced on a 1:1 basis by LC3.

Table 3. Results of compressive strength of concrete made for prefabricated elements with OPC and LCC

Material	Cement consumption (kg/m^3)	Average compressive strength at 3d (MPa)	Average compressive strength at 7d (MPa)	Average compressive strength at 28d (MPa)
LCC	360	–	21.0	31.4
OPC	360	20.4	–	33.2

4 Economic and Environmental Analysis

The production of LC^3 in Cuba was studied aided with the Life Cycle Assessment tool (LCA). The analysis was carried out for various technological levels of investment.

1. The first level (Pilot) considers no investment. The data used for energy and material consumption were measured during the first industrial trial [2].
2. The second technological level considers a low investment throughout retrofitting a wet cement kiln into a clay calciner, as a low CAPEX alternative to produce calcined clay.
3. The third technological level considers massive investment in Best Available Technology (BAT), with state of the art equipment for both the calcined clay and the clinker production.

The study shows that the LC^3 technology is an energy and cost efficient technology. Savings in term of greenhouse gases emissions as well as production and investment costs are significant. LC3 has therefore a great potential to provide a viable opportunity to meet an increase in cement demand with low CO2 released and low cost investment.

5 Standards

European Standards do only allow up to 65% of clinker for blended cements, and also the common practice in the industry is to limit the amount of limestone to 5%. [5] The ASTM standard C595/C595M–14, “Standard Specification for Blended Hydraulic

Cements", launched in 2016, provides a solution to accept lower clinker contents and higher amount of limestone. This standard describes a ternary blended cement consisting of an intimate and uniform blend produced either by intergrinding, by blending or by a combination of intergrinding and blending Portland cement or clinker with several SCMs. This cement is described as type IT. The type IT cement shall have a maximum limestone content of 15% by mass and is permitted to contain hydrated lime. All other ternary blends shall have a maximum pozzolan content of 40% by mass of the blended cement, and the total content of pozzolan, limestone and slag shall be less than 70% by mass of the blended cement. Further, the loss on ignition is limited to 10%, mainly due to the inclusion of a higher limestone content.

6 Conclusions

The interdisciplinary endeavour carried out by the technical team Switzerland-Cuba has proven that the innovative cementitious system can be a real alternative for developing countries with a rise on cement demand. The team has carefully followed all steps needed for the introduction of the technology, and commercial production is scheduled to begin in 2018, so the entire process took approximately 10 years for completion.

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