Assessment of Sustainability of Low Carbon Cement in Cuba. Cement Pilot Production and Prospective Case

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Abstract This study combines two techniques for the assessment of sustainability in cement and concrete production: Life Cycle Analysis and Eco-efficiency. The first technique is used to assess the environmental impact of Low Carbon Cement (LC3) production from quarrying to the factory´s gate. The LCA is developed in order to compare three Cuban cements and its associated impacts: OPC, PPC and LC3. For that purpose, an inventory is developed using official statistics of the cement sector, calculated productive and economic indexes and emission factors. Global warming and energy use, are the main identified impacts. The second method is employed for the calculation of the improvement potential derived from the substitution of OPC by LC3 in a model house built with LC3 in Santa Clara city. A considerable improvement of 54 percent in the eco-efficiency indicator has been achieved as a result of using blended cement that is a proper combination of clinker, metakaolin, gypsum and limestone. The results become a challenge for Cuban construction sector in order to generalize the technology as a sustainable product from the economic, social and environmental point of view.

1 Introduction

Concrete, made with Portland cement, is second only to water in total volume produced and consumed annually by society [1]. Due to its large consumption, it has a significant environmental impact at global scale, mainly associated with cement production. Among all the solutions proposed to solve the negative impact

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of cement industry worldwide, clinker substitution is proven to be the most effective to reduce carbon emissions. The production of a new cement with a 0.50 clinker ratio, denominated Low Carbon Cement (LC3) it's presented as a good solution with attractive production costs and minimum capital investment. To prove that in 2013 an industrial trial was carried out in Cuba. This paper presents the assessment of sustainability in LC3 cement and concrete produced in the Cuban industrial trial, through two techniques: Life Cycle Analysis and Eco-efficiency. Both methodologies are widely use to assess environmental impacts of cements in literature [2–6].

In the first part, a description of LC3 production is given. Then, costs, energy and environmental impacts are evaluated using Life Cycle Assessment approach to compare with Portland cements traditionally produced in Cuba. Finally, the eco-efficiency of a house built with LC3 is assessed and compared with OPC use in the same structure. Combining both methods a complete study is made about the impact of LC3 production in Cuba, in order to generalize its production.

2 Production of a Low Carbon Cement in Cuba, Industrial Trial

An industrial trial was carried out in 2013 to produce a large amount of the new cement (LC3) under real conditions at cement factory *Siguaney*. After calcination, according with Vizcaino et al. [7] the reactivity of the material calcined in the rotatory kiln compared with the material calcined at the lab, indicates that the industrial calcination was successful. After grinding process, a production of 110 tons of Low Carbon Cement was obtained. Thus, of the remaining tonnes approximately 10 tons were pack in sacks for lab testing and the rest were stored in bulk in a silo. Table 1 presents the chemical composition of the cement obtained (LC3) and the used as reference for the impacts assessment.

The rest of the material was distributed among builders and building material manufacturers, whom (under strict supervision) focused on two main cement applications: (1) manufacture of hollow concrete blocks (500 x 200 x 150 mm) and (2) manufacture of 25 MPa precast concrete elements at a prefabrication plant [7].

Table 1 Composition of cements taken for impacts assessment

Cement Type	Cements composition (%)				
	CK	CC[1]	Gypsum	Ccl	Zeolite
OPC (P-35 in Cuba)	0.88	0.05	0.07	–	–
PPC (PP-25 in Cuba)	0.75	–	0.05	–	0.20
LC3(industrial trial)	0.50	0.14	0.09	0.27	–

[1]Calcium carbonate

3 Assessment of Case Study Production of LC3, Cuba

To assess LC3 production under industrial trial conditions, costs were calculated in two steps: 1) breakdown of calcined clay, clinker and other raw materials production costs; 2) breakdown of LC3, Ordinary Portland Cement (OPC) and Pozzolanic Portland Cement (PPC) production costs. Results show that, with LC3 production, as is shown in Fig. 1, it is possible to reduce costs of cement substituting a portion of clinker by limestone and calcined clay. Present substitution levels rises 13 % with PPC production and savings are around 10 % in this case. With LC3 savings are between 4-40 % in comparison with PPC costs depending on transport costs of kaolinite clay.

Energy balance was calculated in Mega Jules (MJ) using real consumption indexes of energy [8] and the average caloric power of Cuban crude oil which is the fuel used in Siguaney. As was expected clay calcination process uses less energy intensive. Higher reduction is presented in thermal energy for calcination process. There is observed a reduction of more than 1500 MJ per ton of cement produced.

To estimate CO_2 emissions was followed the methodology of the Intergovernmental Panel for Climate Change, 2006 (IPCC) [9], whereas clinker (CK) production is multiplied by an emission factor. The emissions caused by the chemical decomposition of $CaCO_3$ y $MgCO_3$ contained in raw materials (grey limestone and clays), were deduced through stoichiometry calculations with by calculating the differences in the CaO and MgO content of the raw materials before been introduced in the kiln and at the exit (CK or calcined clay) [10]. The CO_2 emissions in the phase of cement grinding, are associated with the electricity consumption in the ball mill. Other sources of emissions are considered negligible and thus discarded. The final calculation of CO_2 emissions is presented in Fig. 2.

The low carbon cement produced in non-optimized conditions during industrial trial, reduces approximately 360 kg CO_2/tonnes in relation to OPC (P-35), this is

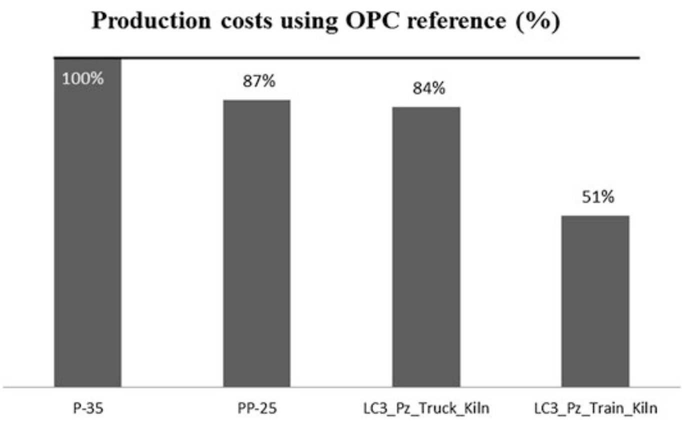


Fig. 1 Production costs of LC3 (%) compared with OPC and PPC reference

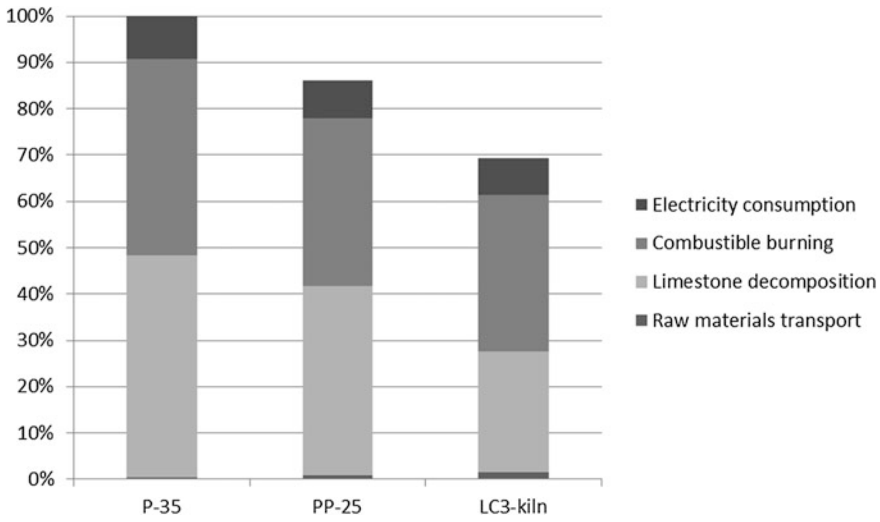


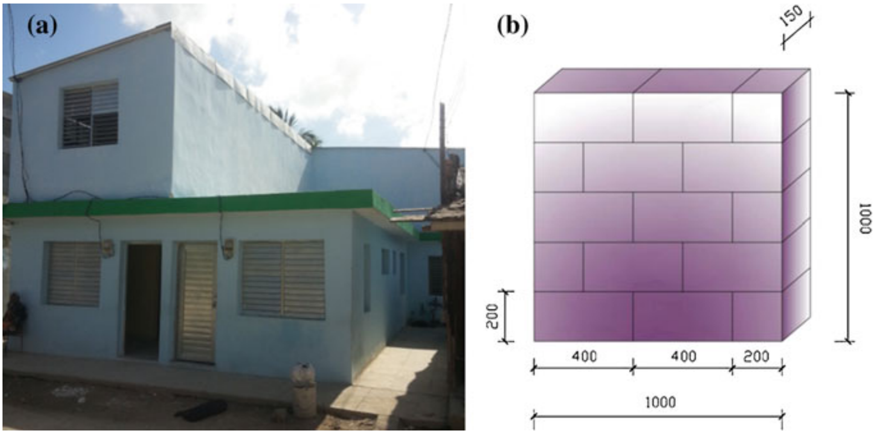
Fig. 2 CO_2 emissions associated to LC3 production with 45 % of SCM and compared to the reference cements P-35 and PP-25

approximately 31 %. Reduction in reference to traditional Cuban blended cement (PP-25) is in the range of 155 kg CO_2/tonne. A small increase is reported in transport emissions due to the amount of new raw material that needs to be carry, but this is negligible if we compare reductions generated during cement production process.

4 Eco-Efficiency Model House Built with LC3, Cuba

To assess the eco-efficiency of a model house built with LC3 in Santa Clara city (Picture 1a) having a square meter as functional unit (Picture 1b), a new eco-efficiency calculation method was developed by Cancio, 2014 [11]. Main steps of this methodology are: stablish the functional unit to analysis, design and analyze the supply chain, calculate eco-efficiency indicators, results comparison and evaluation.

In Cuban case, three scenarios were evaluated as is shown in Table 2. Results show that a house built entirely with LC3, or some components (Scenarios 3 and 2) presents higher eco-efficiency compared with the house built with OPC traditional cements (Scenario 1). That proves LC3 use in house construction is feasible with a reduction of CO_2 emissions and associated costs between 30 and 40 %.



Picture. 1 **a** Model house built with LC3 in Santa Clara city, **b** Functional unit: m^2

Table 2 Eco-efficiency calculation results in different scenarios

Scenarios	Scenario definition	Emissions (kg co_2/m^2 wall)	Market price based-cost (usd/m^2 wall)	Value added (usd/m^2 wall)	Eco-efficiency indicator (usd/co_2/m^2 wall)
1	PPC Mortars/ OPC Blocks	24	5.2	495	20
2	LC3 Mortars/ OPC Blocks	22	3.7	496	22
3	LC3 Mortars/ LC3 Blocks	16	3.2	497	30

5 Conclusions

- LC3 production in Cuba will have positive economic and environmental impact, with a reduction of the production cost between 4 and 40 % and savings of CO_2 between 15 and 30 %. This will depend on the technology used to produce the calcined clay and also the kaolinite clay deposit select for its production.
- LC3 use to build houses increases the eco-efficiency of this activity with a significant reduction of carbon emissions and production costs along all the productive chain.

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