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Feasibility study on the use of cellular concrete as alternative raw material for Portland clinker production

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HIGHLIGHTS

- Cellular concrete could be used as raw material for Portland clinker production.
- Using cellular concrete as raw material will not have major beneficial advantages.
- The poor grindability of the cellular concrete will act as a serious restriction.
- This study reveals restrictions generalizable for other alternative raw materials.

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ABSTRACT

This paper aims to investigate the use of cellular concrete as an alternative raw material (ARM) for Portland clinker kilns. The possibility to generate a raw material with a stable compositional variation was investigated as well as simulations were carried out to maximise their use in clinker kilns. Based on these simulations, experimental clinkers were produced with dosages that were esteemed as realistic. Because of the presence of important levels of quartz sand in the cellular concrete materials, the energy necessary to grind the alternative raw material in comparison with comparable classic raw materials was investigated as well as the influence of the final particle size distribution of the Cold Clinker Meal (CCM) on the mineralogical composition of the final clinkers. It will be demonstrated that cellular concrete materials can be used as ARM for clinker production although there are some important restrictions that will limit the practical implementation. This investigation will also provide some interesting knowledge on the use of other recycled concrete materials as alternative raw material for Portland clinker production.

1. Introduction

This paper examines the possibility to use cellular concrete material as an alternative raw material (ARM) for Portland clinker production. The use of alternative raw materials which could decrease the use of natural sources as well as counter landfill with construction waste is in line with the Cement Sustainability Initiative [1] described by the World Business Council for Sustainable Development. Several studies were already performed that could improve the ecological impact of Portland clinker production by using secondary or recycled materials as alternative raw material in Portland clinker production [2–8]. Cellular or aerated concrete is a type of lightweight concrete with a high concentration of air

Abbreviations: Ant, Antoing; LiqSimple, Liquid Simple; ACC, Autoclaved Cellular Concrete; LOI, Loss On Ignition; ARM, Alternative Raw Material; Lo, Loam (SiO_2-source); ARM/CCC, Cellular Concrete Clean; Lxh, Lixhe; ARM/CCP, Cellular Concrete Polluted; Maa, Maastricht; CCM, Cold Clinker Meal; Ma, Marl (specific type of limestone); Cl, Clinker; PL, Poor Limestone; CRM, Classic Raw Material; Ref, Reference; Decarb E, Decarbonation Energy; RL, Rich Limestone; DoS, Degree of Sulfatisation; SC, Sabulous Clay (SiO_2-source); FA, Fly Ash (Al_2O_3-source); SR, Saturation Rate; HCM, hot clinker meal; Tu, Tuffeau (specific type of limestone); IC, Iron Carrier (Fe_2O_3-source); XRD, X-Ray Diffraction; LSF, Lime Saturation Factor; XRF, X-Ray Fluorescence.

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voids. Aggregates and cements used in standard concrete compositions on a daily base are found in cellular concrete. This implies that part of the final conclusions of this study, will also apply for regular concrete. An air-entraining agent is used to create the cellular structure of air voids by which the density of the concrete is drastically lowered. Air contents from 30 to 80% are not uncommon [9]. In this way, a wide range of densities can be achieved varying between 500 and 1600 kg/m^3 [10]. Cellular concrete is composed of cementitious mortar surrounding disconnected random air bubbles. The air bubbles are a result of gas formed within the mortar or foam introduced into the mortar mixture [11]. Based on the method of curing, cellular concrete can be classified as non-autoclaved or autoclaved [12]. When the binder consists of other than just portland cement, autoclave curing usually is employed [9]. Within the context of the present paper, only cellular concrete originating from an autoclaved process (ACC) is considered, focusing on the precast masonry products namely the cellular concrete blocks. As presented in Table 2, the investigated materials are made out of very fine quartz, ground sand [13–16], lime, cement sometimes combined with fly ashes [10] and as air-entraining agent, aluminium powder [13] in combination with a foaming agent. Recycled materials coming from rejected autoclaved and non-autoclaved cellular concrete are already reused in the production process itself (Table 2). The aluminium powder will react with the lime or alkaline substances which will bring hydrogen into the cementitious mortar [13], [16]. The foaming agent is used to attract the cement particles into the aerosol foam network by which hydrated portland cement paste is formed around each entrapped air bubble [11]. XRD powder studies have already shown that the main reaction products belong to the tobermorite group of calcium silicate hydrates (C ± S ± H) [14–17] using the calcium from the lime and cement and the silicates from the quartz, the fine sand and cement (Table 2). The reaction products are a mixture of crystalline, semi-crystalline and near amorphous materials with varying degree of crystallinity [14,15,17]. The autoclaved cellular concrete has many applications in building engineering, mainly in the housing, industrial and public utility building [18].

A strategy was chosen to make the simulations and tests with the cellular concrete ARM as realistic as possible, by using three modern reference clinker factories. Simulations were carried out and experimental clinkers were produced to investigate the influence of the grindability of the cellular concrete ARM on the mineralogical composition of the final clinker.

2. Materials and methods

2.1. Classic raw materials (CRM)

As representative CRM, materials are selected that are used at a daily base in three reference clinker factories. These factories are CBR Antoing (CRM/Ant) and CBR Lixhe (CRM/Lxh) in Belgium and ENCI Maastricht (CRM/Maa) in the Netherlands, all belonging to the Heidelbergcement Benelux group. CBR Antoing uses two kinds of limestones, rich (CRM/Ant/RL) and poor (CRM/Ant/PL), CBR Lixhe uses tufa (CRM/Lxh/Tu) and loam (CRM/Lxh/Lo) and ENCI Maastricht a typical marl (CRM/Lxh/Ma) and sabulous clay (CRM/Lxh/SC). All of the 3 factories use fly ash (CRM/Ant,Lxh,Maa/FA) as Al_2O_3 source and an artificially produced Fe_2O_3 source (CRM/Ant,Lxh,Maa/IC). These CRM were already described in detail [2]. The chemical analyses of the CRM which directly influence the current investigation namely CRM/Lxh/Tu, CRM/Lxh/Lo, CRM/Maa/Ma and CRM/Maa/SC are presented in Table 1.

Table 1
Average chemical analysis of the limestones and SiO_2-sources of CBR Lixhe and ENCI Maastricht.

CRM (wt%)	CRM/Lxh/Tu	CRM/Lxh/Lo	CRM/Maa/Ma	CRM/Maa/SC
CaO	51.8	5.6	50.8	2.66
SiO_2	4.7	68.9	7.1	86.83
Al_2O_3	0.4	7.4	0.8	3.73
Fe_2O_3	0.3	3.8	0.4	2.58
K_2O	0.07	1.68	0.13	1.14
Na_2O	0.02	0.71	0.20	0.14
SO_3	0.09	0.06	0.21	0.05
MgO	0.7	0.8	0.8	0.28
Cl	0.011	–	–	0.01
LOI 975 °C (O_2)	42.03	10.1	40.18	3.43

Table 2
Composition of autoclaved cellular concrete blocks.

Raw materials	Quantity (wt%)
Ground quartz sand (90 wt% SiO_2)	43.6
autoclaved cellular concrete (ARM/CCC)	14.0
Cement	12.6
Lime	12.4
Non-autoclaved cellular concrete	11.4
Fine quartz (99.5 wt% SiO_2)	3.3
Anhydrite	2.6
Aluminium (fine)	0.09
Aluminium (coarse)	0.02
Sum	100.0

2.2. Alternative raw material (ARM): cellular concrete

The cellular concrete materials used within this study were selected from two sources, polluted recycled cellular concrete (ARM/CCP) and production waste of clean cellular concrete (ARM/CCC). The ARM/CCP came from a demolition plant KOK in the Netherlands. Six samples spread over a period of two months were delivered and chemically analysed (Table 3). The ARM/CCC samples were recovered from the factory of Xella/Ytong Burcht in Belgium during twenty-eight weeks. Each week, samples were taken out of the crushed material flow of rejected cellular concrete blocks which were re-entered in the cellular concrete production of Xella Burcht as described in Table 2. These rejected cellular concrete blocks were withheld because of their unsuitable dimensions. These samples were afterwards 2 by 2 homogenised which delivered a total of fourteen samples that were further analysed and investigated (Table 4). Because the process is quite sensible to the smallest changes, it was foreseen that the chemical variation was quite small. Changes could influence the rising, dimensioning and curing of the cellular concrete blocks. The ARM/CCP have some inorganic and organic contaminants which will be further explained in Section 4.2. It was decided to investigate the influence and the restrictions of cellular concrete on Portland clinker production with the ARM/CCC materials to avoid too many influencing variables that could make an objective evaluation impossible. The ARM/CCP will give, based on their chemical analysis, additional information about the expected chemical variation and the possible contaminations if real recycled cellular concrete should be used as ARM for Portland clinker production.

2.3. Testing of raw materials, Cold Clinker Meals (CCM) and clinker properties

To prepare the different CCM compositions, raw materials were dosed to achieve 500 g of CCM in line with the clinker feed calculation described in Section 3.3. All CCM materials were ground for 5, 10, 20, 30 min at 300 rpm in a laboratory ball mill to obtain different degrees of fineness. These were determined by Sympatec laser diffraction. The CCM materials ground for 10 min were, after a granulation phase, sintered in an electric high temperature static kiln (Carbolite BLF1800) as described in [2]. After evaluation of the mineralogical composition it was decided to sinter the alternative CCM with a grinding time of 20 and 30 min to investigate the influence on the clinker mineralogy.

The classic raw materials loam and sabulous clay used as SiO_2 source in the factories of CBR Lixhe and ENCI Maastricht and the alternative raw material ARM/CCC/S3 were ground in succession for 1–10 min with an interval of 1 min in the Siebtechnic disc mill to compare their grindability. The fineness was also determined by Sympatec laser diffraction.

XRF analyses were determined with a Philips PW2404, total C and S content were analysed with a Leco CS230, TGA/DTA analyses were performed using a Netzsch STA 449F3 and finally XRD analyses refined by Rietveld method by a Bruker D8 ADVANCE. The X-ray diffraction pattern was measured using a Bruker D8 ADVANCE diffractometer. An X-ray diffraction analysis based on Topas (DIFFRAC.SUITE) profile and structure analysis software was used to quantify the different clinker phases. The data was collected with a vertical Theta–Theta goniometer with $-110° < 2\theta < 168°$ goniometer control using a step size of 0.0001°. Background, zero shift, scaling factor, cell parameters and shape parameter were refined. The used crystal structure models are listed in Table 5.