Portland Cement Production from Fine Fractions of Concrete Waste

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1 Introduction

The recycling of concrete can reduce the environmental impact of Portland cement production and concrete construction, and decrease the damping and landfilling of demolition waste. Currently, concrete recycling is widely used for aggregate extraction [1], though concrete fines which are a mix of aggregate and the hydrated cement paste are not a part of the recycling process [1]. Research efforts have been directed to the production of new Portland cement from recycled fines, but most research attempts run into problems [2, 3].

The common way to use recycled concrete fines for new cement production is to add them in small proportions, according to chemical and mineralogical limitations, to the traditional raw meal of clinker rotary kiln. But the clinker of acceptable quality has not been obtained. Alite was not synthesized in satisfactory content. In many cases, the only belite was formed and there was an excess of silica [2, 3]. The compressive strength of cement was low and decreased with the increase of concrete fines content in the raw meal [2, 4]. The best results were achieved for mixtures correctly adjusted with the main clinker modulus. The produced Portland clinker had the composition similar to an ordinary Portland cement clinker [3].

The mineral transformations in a burned raw meal containing 22.8% of recycled concrete wastes were studied using X-ray diffraction (XRD). The results indicate that concrete waste fines can be completely recycled to obtain a new Portland cement.

2 Materials and Methods

Normal strength concrete (30 MPa) was prepared with dolomite coarse aggregate and natural sea quartz sand. The concrete was crushed with a jaw crusher and sieved. The fraction below 2.36 was used in the current research. Their mineral composition of the concrete fines as measured by XRD is shown in Table 1. The chemical composition was measured using Inductively coupled plasma (ICP) mass spectrometry test. Table 2 represents oxide mass percent of concrete fines.

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It can be seen in Tables 1 and 2 that fine material contained some contamination of magnesium oxide, whose origin is in the coarse dolomite aggregate, which may pose some problems for clinker burning. For clinker manufacturing, the concrete waste fines were mixed with limestone, bauxite and iron scale. Target Portland clinker composition was calculated according to the main four oxides content to satisfy the general requirements of basic Portland clinker moduli: Lime Saturation Factor (LSF) = 0.92–0.98, Silica ratio (SR) = 2–3, and Alumina ratio (AR) = 1–4. The clinker composition was optimized for maximum concrete fines content in the raw meal according to the limits of the clinker moduli. It was found that concrete waste fines contain sufficient silica and no addition of silica is needed to the raw meal. The optimal calculated raw meal composition and final content in clinker after the loss on ignition (LOI) are shown in Table 3.

Table 1. The mineral composition of concrete fines, % wt.

	Quartz	Dolomite	Calcite	Portlandite	Other minerals	Amorphous
% wt	35.3	19.6	8.8	3.5	8.5	23.9

Table 2. The oxide components % wt of recycled concrete waste fines by ICP.

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	P_2O_5	Na_2O	K_2O	TiO_2	MnO_2
% wt	17.77	61.32	2.28	1.05	1.93	0.86	0.16	0.29	0.33	0.15	0.02

Table 3. The raw material mix design and their content in final clinker for recycled concrete fines, % wt

	Burned clinker				Raw meal			
Ingredient	Concrete waste fines	Lime stone	Bauxite	Iron scale	Concrete waste fines	Lime stone	Bauxite	Iron scale
% wt	29.3	63.4	4.9	2.4	22.8	71.8	3.8	1.6

The burning of the raw meal for clinker production was applied using round nodules of approximately 15 mm in size. The burning took place in the high-temperature bottom-loading laboratory. Phase transformations were tested at steps of 100 °C between 800 and 1100 °C, and at steps of 50 °C between 1100 and 1450 °C. After burning, samples were removed from the furnace at the maximum temperature and air quenched. Burned materials were ground and tested using a Malvern PANAlytical EMPYREAN X-ray diffractometer with a Goniometer radius of 240 mm. An X-ray source was CuKα1, 2 (λ = 1.5408 Å) with X-Ray generator operated at a voltage of 45 kV and a current of 40 mA. The following optical XRD configuration was used: the incident beam optics included 10 mm mask, 0.04 rad Soller slit along with ¼° divergence and 1° anti-scatter fixed slits; the diffracted beam optics consisted of 8 mm anti-scatter fixed slit and 0.04 rad Soller slit. The detector was PIXcel 3D detector used in 1D continuous scan mode. The scan was performed using

Brag-Brentano θ-θ geometry, between 10 and 70 °2θ. Timestep of 80.32 s with a step size of 0.013 °2θ was used resulting in a total measurement time of 25.22 s. The quantitative analysis was performed by means of Rietveld refinement using HighScore Plus software.

3 Results

The phase transformations of a raw meal containing 22.8% of concrete waste fines at burning at temperatures between 800 and 1450 °C are shown in Figs. 1 and 2. Figure 1 demonstrates the content of alite and belite, while Fig. 2. Shows the changes in alumina and iron-containing phases. It can be seen in Fig. 1 that belite gradually forms starting at 1000 °C and alite forms starting from 1300 °C. It can be seen in Fig. 2 that Ferrite (brownmillerite) is present at 800 °C in a small amount and its content gradually increased with temperature. Mayenite has the maximum content of almost 10% at 900 °C gradually decreases with the increase of temperature of burning, while tricalcium aluminate start to form appears only at 1150 °C.

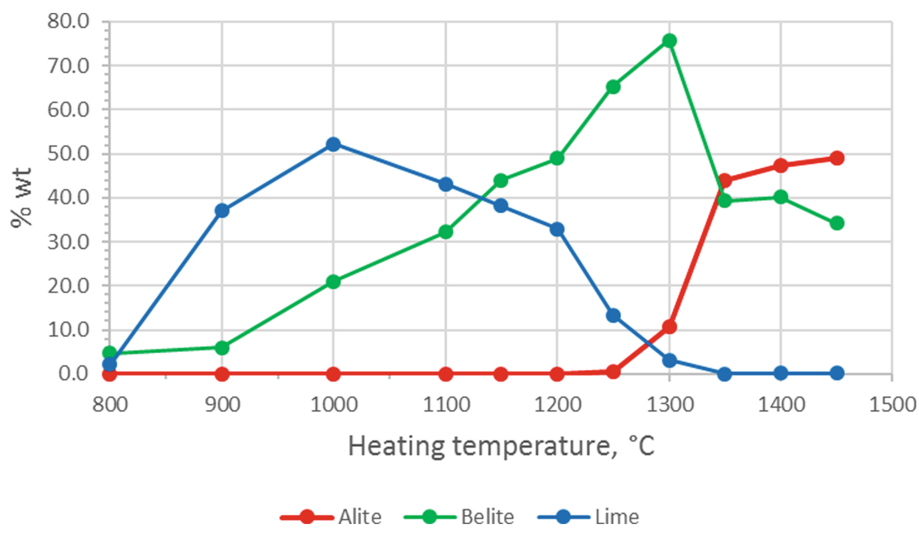

Fig. 1. Alite belite and lime mass percent with the heating temperature of raw meal.

Figure 3 shows the XRD scan and quantification of the final Portland clinker manufactured using recycled concrete waste fines obtained at 1450 °C. It can be seen that clinker with high alite content of 67% and belite content of 19% was obtained that corresponds to a good quality Portland cement. The XRD results show the low amount of Periclase in spite of the relatively high content of magnesia in raw meal. This can be explained by the absorption of MgO by alite.

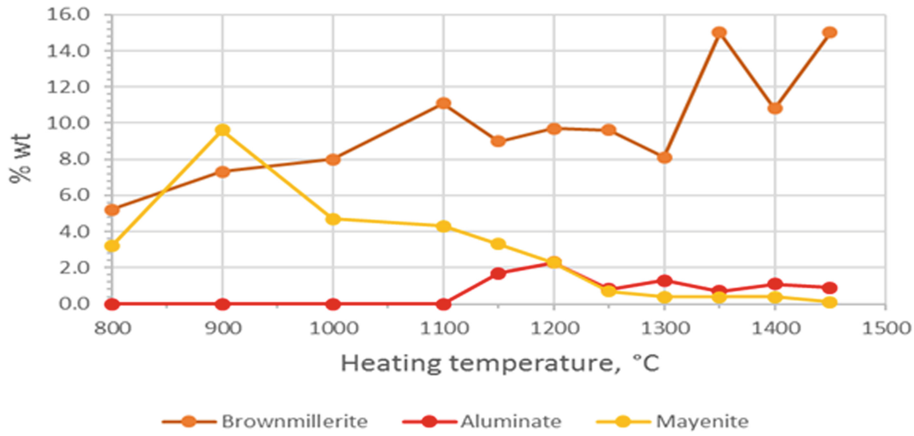

Fig. 2. Alumina and iron-containing minerals mass percent with the heating temperature of raw meal.

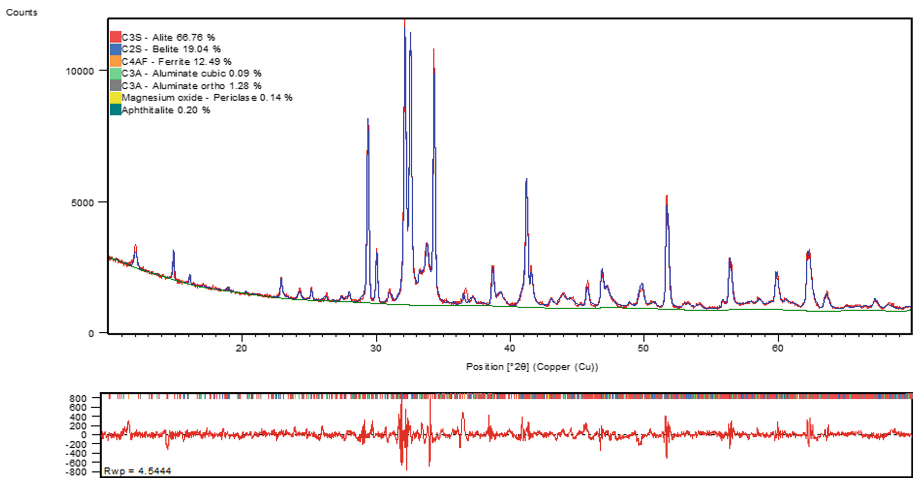

Fig. 3. XRD quantification of Portland clinker, manufactured using 22.8% of recycled concrete waste fines

4 Conclusions

The phase transformations of a raw meal containing concrete waste fines during heating between 800 and 1450 °C and formation of main clinker constituents were studied using XRD. The results of the research demonstrated that a Portland cement clinker can be produced using recycled concrete fines. The mass percent concrete waste fines with dolomite and quartz sand aggregates in raw meal were limited to 22.8% by the content of silica in the concrete waste fines.

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