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Fines extracted from recycled concrete as alternative raw material for Portland cement clinker production

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ABSTRACT

This paper aims to examine the use of fines generated out of recycled aggregates production as an alternative raw material for Portland clinker kilns with enumeration of possible limitations. Different technical set-ups were used to separate these fines from the recycled aggregates. The relationship between the particle size distribution of the generated fines fraction and their chemical composition as well as the relationship between the final filler (<63 μm) content [*wt%*] and the water demand of the treated sand fraction were investigated. Numerical simulations were carried out to maximise the fines fractions as raw materials in clinker kilns based on which experimental clinkers were produced. The final clinkers were fully analysed and evaluated on possible mineralogical influences.

1. Introduction

The production of recycled aggregates in concrete is already well studied and is especially used in practice in Belgium, Denmark and the Netherlands where recycling rates of more than 80% are attained [1]. This limits landfill and the use of natural resources. The use of recycled aggregates is less common in the Southern European countries, where landfill is widely practiced to get rid of demolition waste [1,2]. The most frequently asked question is what the impact of the recycled aggregates on the durability and strength development [3] of the final concrete will be. The overall quality of recycled concrete aggregates is generally lower than that of natural aggregate, due to the mortar that remains attached to the natural aggregate [4]. Studies on the use of recycled concrete aggregates in concrete show that the compressive strength [3,4], drying shrinkage [3], creep [5], shear resistance [5], freeze and thaw resistance [6,7], abrasion resistance [4], sulphate content [4] etc. can be improved, if the attached mortar can be separated better from the recycled aggregates. It was proven that the performance regarding durability and strength development is related to the attached mortar content in the recycled aggregate. Some researchers even came to the conclusion that only recycled aggregates with an attached mortar content lower than 44 wt% can be used for structural concrete [4]. Different researchers have investigated ways to separate as much of this cement stone from the recycled aggregates as possible [8]. When using a classic recycling process, exhibiting only one crushing action by a jaw or impact crusher, approximately 50 wt% of recycled aggregates and 50 wt% of recycled sand extremely high in filler [*wt%*] (<63 μm), can be obtained (Table 2). When incorporating a second crushing action by a Vertical Shaft Impactor (VSI) to clean the recycled aggregates, the sand fraction is increased and the amount of recycled but improved aggregates is decreased [8]. Improving recycled aggregates by decreasing the attached mortar content, will therefore generate more low grade sand which is unsuitable for high end concrete production. To improve this sand quality, the filler

Abbreviations: Ag, aggregates; Ant, Antoing; ADR, Advanced Dry Recovery; ARM/ADR, ADR fines fraction; ARM/CTP, CTP fines fraction; ARM/KHD, KHD fines fraction; CCM, Cold Clinker Meal; CL, Clinker; CRM, Classic Raw Material; CTP, Centre Terre et Pierre; DoS, Degree of Sulfatisation; FA, Fly Ash (Al_2O_3-source); HCM, Hot Clinker Meal; KHD, KHD Humboldt Wedag AG; IC, Iron Carrier (Fe_2O_3-source); LSF, Lime Saturation Factor; LiqSimple, Liquid Simple; LOI, Loss on Ignition; Lo, Loam (SiO_2-source); Lxh, Lixhe; Maa, Maastricht; Ma, Marl (specific type of limestone); PL, poor limestone; Ref, Reference; RL, Rich Limestone; SC, Sabulous Clay (SiO_2-source); SR, Saturation Rate; Tu, Tuffeau (specific type of limestone); VSI, Vertical Shaft Impactor.

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content (<63 μm) has to be lowered to have an acceptable water demand for high end concrete production [1], improved mechanical properties [1] and better durability performances [9,10].

In the current paper, three different separation techniques were applied, generating fines fractions which could be used as possible alternative raw material (ARM) for Portland clinker production. Other applications for these fines were already investigated, for example as filler in asphalt production [11]. The paper examines the possibility to use these fines fractions as an alternative raw material (ARM) for Portland clinker production. Therefore a strategy was chosen to make the simulations and tests as realistic as possible by using three reference clinker factories. The goal of these simulations was to maximise the dosage of the fines fractions in the Cold Clinker Meals (CCM) of the Portland clinker process. Furthermore, experimental clinkers based on these simulations were produced and evaluated as a function of possible limitations. Encouraging the increased use of alternative raw material in Portland clinker production is in line with the Cement Sustainability Initiative [12] as key action in the sustainable development of the cement industry [13].

Additionally, the treated sands coming out of the three separation installations separated from their fines fractions were tested on their water demand to determine whether or not they were suitable for the production of high end concrete.

2. Materials and methods

2.1. Classic Raw Materials (CRM)

The materials used on a daily basis in three modern clinker factories are selected as representative CRMs. 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 Heidelberg Benelux group. They can be considered as examples of modern clinker factories. 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/Maa/Ma) and Sabulous Clay (CRM/Maa/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 CRMs were already described in detail elsewhere [14]. The chemical analyses of the CRMs directly influencing the current study are presented in Table 1.

2.2. Alternative raw material (ARM): Recycled concrete fines

About 282 tons 0/200 concrete material was recovered from an old concrete construction which generated different recycled materials as shown schematically in Table 2. The recycled concrete was crushed on an impact crusher Nordberg LT 1213 by which 53 wt% recycled 0/63 aggregates and 47 wt% recycled 0/8 sand out of the 0/200 concrete material was generated and separated by a power screen Chieftain 400. The recycled 0/63 aggregates were crushed for a second time on a VSI crusher Magottaux 2400 to remove the attached mortar even more from the recycled aggregates as described in [3]. This action made the recycled aggregates smaller (0/14). The crushed material (0/14) delivered by the VSI crusher was homogenised with the recycled 0/8 sand which recompleted the recycled material to 100 wt%.

Three separation installations were incorporated in this study to separate the concrete fines of the demolished concrete. First, the use of the Advanced Dry Recovery (ADR) installation developed by TU Delft for the separation of bottom ashes was studied. This installation is a sort of wind sifter that by the use of kinetic energy and air knifes, can separate crushed recycled concrete in coarse aggregates, sand and fine (ARM/ADR) fractions [15]. The two other installations could only be used to separate sand from fines (ARM) fractions because of their technical specifications. The CTP (Centre Terre et Pierre) installation, situated in the research department of the Centre Terre et Pierre (Tournai/Belgium) [16], consists out of a ball mill that can be heated with a hot air stream and is connected to a dynamic separator. The ball mill was not filled with balls for this test, but was only used to throw the sand in the hot air stream which fed the dynamic separator with the entrained fine sand fraction. After the separation, set at 250 μm, the fine sand fraction returned to the ball mill and the fines fraction (ARM/CTP) was recovered. Comparable installations can already be purchased for industrial practice. Next, a static KHD separator [17] under lab conditions was investigated in the research department of KHD (Cologne/Germany). The sand was first dried to a maximum humidity of 4 wt% before it was completely fed to the static separator which was also set to cut the material at 250 μm. The separation generated the third fines fraction (ARM/KHD).

A batch of 1.5 tons of the recompleted recycled material after the two crushing actions was sampled to serve as feed material for the ADR installation without drying, being the way the installation works in practice. The separation by the ADR installation generated three fractions: a coarse fraction (0/12.5), a 0/4 sand fraction (Ag/Sa04/ADR) and a fine fraction (ARM/ADR) which in fact is a sand 0/2. Furthermore, the same homogenised crushed material as fed to the ADR installation was inserted to a power screen Chieftain 400 which separated the recycled 0/20 aggregates fraction (9 wt%) from the sand fraction (91 wt%) which was a recycled 0/6.3. It may seem bizar that by a separation action the coarse fraction has a higher D_{max} (20 mm) than its starting material (14 mm). In fact, the nomination of D_{max} is a statistical determination out of the particle size distribution [20,21]. It may therefore happen that the D_{max} of the coarse fraction increases compared to the starting material when the generated finer fraction after separation is high, in this case 91 wt% of 0/6.3 aggregates. Two batches of 1.5 tons were sampled to serve as feed for the CTP and the KHD installations. The reason that the batch for the ADR installation [15] was taken before the power screen in contrast to the two other

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

CRM (wt%)	CRM/Ant/PL	CRM/Ant/RL	CRM/Lxh/Tu	CRM/Lxh/Lo	CRM/Maa/Ma	CRM/Maa/SC
CaO	42.9	50.1	51.8	5.6	50.8	2.66
SiO_2	15.1	6.4	4.7	68.9	7.1	86.83
Al_2O_3	2.2	0.9	0.4	7.4	0.8	3.73
Fe_2O_3	0.9	0.4	0.3	3.8	0.4	2.58
K_2O	0.68	0.21	0.07	1.68	0.13	1.14
Na_2O	0.25	0.25	0.02	0.71	0.20	0.14
SO_3	0.90	0.57	0.09	0.06	0.21	0.05
MgO	1.1	0.9	0.7	0.8	0.8	0.28
Cl	–	–	0.011	–	–	0.01
LOI 975 °C (O_2)	35.04	40.18	42.03	10.1	40.18	3.43