

CO₂ uptake by fine fractions of CDW

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Abstract

Current concrete recycling consists of crushing waste concrete and use it again as aggregate for new concrete, according to specifications which are based on local regulations in different countries. Construction and demolition waste recycling is generally limited to the use of the coarser fraction as aggregate for new concrete. The quality of RCA is lower than that of natural aggregates, due to presence of residual mortar: for this reason, when dealing with concrete recycling, a differentiation between coarse (nominal size > 5 mm) and fine aggregates (maximum size < 5 mm) is generally done. While coarse recycled concrete aggregates (CRCA) are commonly used in partial replacement of natural aggregates in concrete, fine recycled concrete aggregates (FRCA) are less useful as aggregates in concrete as they can be highly detrimental for what concern strength, workability and durability.

The problem with FRCA is mainly related to the presence of hydrated cement pastes and unreacted clinker phases. Interestingly, these phases are valuable materials when carbon uptake is considered. Interaction of cement pastes with environmental CO₂ is a well-known phenomenon that has always been undesired due to the bad consequences on reinforcement bars. Only recently, the attention of scientific community moved into the direction of considering this interaction a resource in the environmental CO₂ reduction: it is estimated that almost the half of CO₂ emitted during clinker processing is reintroduced in the cement during its service life.

In this paper, the potential CO₂ uptake by carbonation of different simulated CDW is evaluated.

Keywords: CO₂ storage; recycled concrete aggregates; cement paste; construction demolition waste.

Introduction

Recycling is the issue for sustainable development: this is a mandatory topic for all industries, including sector of construction. In Europe about of 180 million tons of concrete demolition waste (CDW) are produced every year, corresponding annually to 500 kg for each citizen [1]; this amount represents around 31% of all the waste produced in the European Union [2].

For long time concrete and brickwork wastes have only been used as a filling material or disposed to landfill. Nevertheless, in the late 20th century concrete recycling gained more and more importance, due to the increasing attention towards environmental protection and to the progressively reducing landfill capacity. Current concrete recycling consists of crushing waste concrete and use it again as aggregate for new concrete [3], according to specifications which are based on local regulations of different countries.

The quality of RCA is generally lower than that of natural aggregates, due to presence of residual mortar [4]. Generally, a differentiation between coarse (nominal size > 5 mm) and fine aggregates (maximum size < 5 mm) is done. Coarse recycled aggregates (CRCA) are used in partial replacement of natural aggregates in concrete [5], however the concrete mix design has to be adjusted in order to correct the worsening of final properties, with a

significant impact on the cost of the final product especially due to the higher dosage of additives required [6]. On the contrary, fine recycled concrete aggregates (FRCA) are less useful as aggregates in concrete as they can be highly detrimental [7]. Their use in pre-cast concretes [8] or in special application (such as geopolymers binders [9] or in clinker production [10]) has been investigated, revealing that the high content of cement paste and residual unreacted silicates can cause many problems.

If an efficient separation of hydrated cement waste (HCW) from FRCA could be obtained, a recycled material of great interest in the cement industry would be recovered. First of all, HCW is an inorganic material whose chemical composition is the same as raw clinker meal and its use in replacement of natural quarried minerals would reduce the consumption of non-renewable material. Moreover, its high affinity towards environmental carbonation make it an appealing material in the field of CO₂ storage. In the following, the CO₂ storage ability of different cements, simulating the HCP components recovered by CDW, is evaluated and discussed.

Experimental

The investigated cements were supplied or produced by the R&D Buzzi Unicem Laboratory and were (see the mineralogical composition in table 1):

- an Ordinary Portland Cement (CEM I 52.5 R)
- a low-CO₂ binder based on experimental belitic clinker (Belitic cement)
- a low-CO₂ binder based on sulfoaluminate cement (CSA cement)
- a mixed system (A) based on CSA cement and a CEM I 52.5 R 40:60
- a mixed system (B) based on CSA cement and a belitic cement 40:60

Table 1. Mineralogical composition of the investigated cement

<i>Phases</i>	<i>CEM I 52.5 R</i>	<i>Belitic cement</i>	<i>CSA cement</i>
C ₃ S	70.9	22.2	-
C ₂ S	8.2	61.0	23.0
C ₃ A	13.3	2.1	6.3
C ₄ AF	4.5	7.9	6.7
C₄A₃\bar{S}	-	-	42.1
Anhydrite/Gypsum	1.8	4.0	18.1
Minor phases	1.3	2.8	3.8

For each binder, one sample of paste (w/c = 0.5) was prepared and stored (after 24 hours) in water for 7 days. The pastes were then crushed ($\varnothing < 2$ mm) and treated in a carbonation chamber with 4% CO₂, 70% RH and 20°C for three days, in order to ensure the complete carbonation of the paste. The pastes were characterized before and after the accelerated carbonation treatment, by means of TG/DSC and XRD.

The amount of CO₂ stored by the different systems after the accelerated carbonation treatment has been quantified by TG analysis on the basis of the weight loss due to the dehydration of Ca(OH)₂ around 500°C. The results, shown in table 2, reveal that the sulfoaluminate cements and the mixed systems have a reduced ability to store CO₂ than the other two cements.

The ordinary Portland cement and the innovative belitic cement show the higher carbonation degree: this can be ascribed to the presence of portlandite as main hydration product, which easily reacts with the environmental CO₂ to form calcium carbonate:

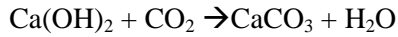


Table 2. Amount of CO₂ stored by the different investigated systems

Sample	Stored CO ₂
CEM I 52.5 R	17.7%
Belitic cement	32.5%
Sulfoaluminate cement	3.7%
Mixed system A	6.6%
Mixed system B	10.8%

The DSC patterns of the ordinary Portland cement and of the belitic cement are shown in Fig. 1, revealing that the latter has a lower amount of portlandite, despite the higher CO₂ uptake capacity.

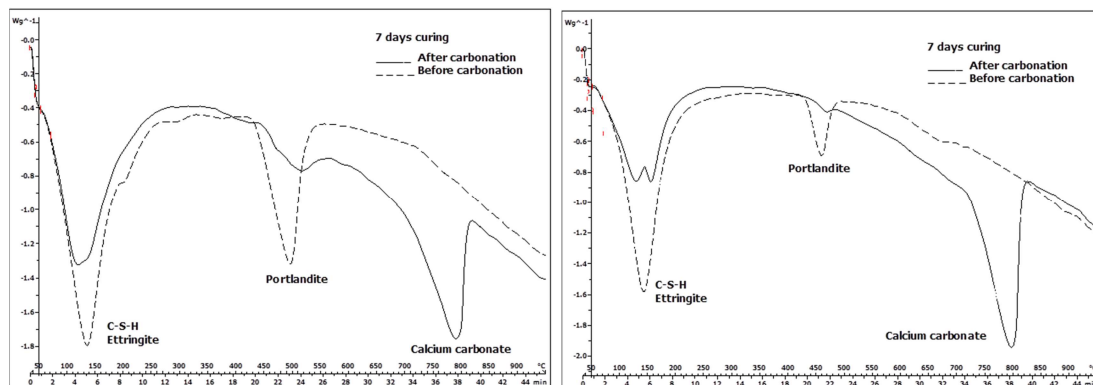


Figure 1. DSC pattern of the sample of CEMI 52.5R (left) and belitic (right) cement pastes before and after the accelerated carbonation treatment.

The explanation can be found in the amount of unreacted belite, which is instead higher in the belitic cement, 29% against 12% in the ordinary Portland cement, as revealed by semi-quantitative Rietveld-XRD analyses. Calcium silicates are actually able to react with CO₂ to produce calcium carbonate and polymerized silica [11], moreover the CO₂ uptake capacity of C₂S is higher than that of C₃S.

Conclusion

The results of this study demonstrate that hydrated cement pastes, having high affinity towards environmental carbonate ions, can be conveniently used as CO₂ storage media, for example for CCS application.

A comparison among ordinary Portland cement and innovative binders, with a reduced CO₂ impact in the production cycle, shows that: (I) belitic cement has a the higher CO₂ uptake ability despite a lower hydration degree and a lower amount of portlandite; (II) sulfoaluminate cement, poor in silicate phases, have low affinity towards CO₂ because of a different hydration behavior; (III) mixed systems are influenced by the CSA component, thus showing a reduced carbonation degree.

Belitic cements combine the reduced CO₂ emission during the production cycle (lower limestone in the raw meal and lower burning temperature) with the higher ability to store CO₂, thanks to the high amount of residual unhydrated C₂S.

The use of OPC for CCS purpose can be envisaged in the future, but efficient methods for the separation of cement paste from CDW must preliminarily be found.

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