Research and Development Project

CO_2 storage by the carbonation of recycled concrete

April 2024

Storing CO_2 in Recycled Concrete Aggregates

Recommendations of the FastCarb National Project

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The FastCarb project has received financial support from the Ministry of Ecological Transition and Territorial Cohesion

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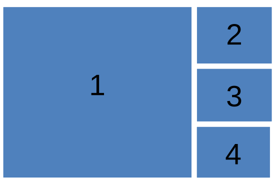

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Summary of recommendations

The FastCarb national project aimed to identify the mechanisms and conditions that would accelerate the familiar phenomenon of the natural carbonation of concrete, with a view to increasing the amount of CO_2 stored in Recycled Concrete Aggregates (RCA) as part of a controlled industrial process, to transform them into Carbonated Recycled Concrete Aggregates (CRCA) and thereby increase their use in new concrete.

The work on the project involved three main phases: a laboratory research and modelling phase, an RCA carbonation phase performed in industrial demonstrators, and a mix design and manufacturing phase for concrete that contains recarbonated RCA to produce concrete elements. The environmental balance and the economics of the Carbonated RCA (CRCA) production process were also analysed.

This document presents a summary of the results obtained during these phases and the ensuing recommendations. It is divided into five chapters, covering everything from the measurement of the trapped CO_2 to the conditions for increasing the use of CRCA.

The project was funded by the French Ministry for Ecological Transition and Territorial Cohesion and 23 academic and industrial partners.

Characterisation of CRCA: method for measuring trapped CO_2

These recommendations propose quantitative, representative and reproducible methods for accurately assessing the CO_2 trapped during the accelerated carbonation of recycled concrete gravel and sand.

The familiar and long-established methods for studying the carbonation of concrete generally consider carbonation over the entire service life of the structure. The aim is not to measure the amount of trapped CO_2 but, more commonly, to check that the entire thickness of the reinforcement cover has not been carbonated to avoid the risk of reinforcement corrosion (e.g. identification of the carbonation front using phenolphthalein). The depth of carbonation is not directly linked to the amount of trapped CO_2, as it depends on the nature of the original cement, its proportioning and the progress of the carbonation reaction.

In the context of the accelerated carbonation of RCA, five methods for characterising and quantifying the phenomenon that enables CO_2 to be stored were evaluated.

Thermogravimetric analysis **(TGA)** is a standard measurement, usually carried out in the laboratory, which is complex to perform. This method is less accurate (in terms of repeatability and reproducibility data) than the other evaluated methods.

The measurement of **Loss on ignition** adapted from cement standard EN 196-2: 2013 requires the use of a furnace capable of reaching temperatures above 950°C, but is straightforward to carry out. The repeatability and reproducibility of this method are satisfactory. As the test lasts 12 hours, it can be used to determine the carbonate content of well-sampled batches of average RCA , before and after carbonation.

The **Bernard Calcimeter** and the **Carbonate Bomb** measure the amount of CO_2 released by the specimen as it reacts with hydrochloric acid. The equipment needed to perform these measurements is easy to use, and the test is rapid. While the carbonate bomb test is simple to perform, the Bernard calcimeter test is slightly more complex. The repeatability of both methods is moderate. Reproducibility is good in the case of the Bernard calcimeter, and even better in the case of the carbonate bomb. These methods are well-suited to production control, for example, to correct drifting in carbonator settings.

Measurement of the **Total Carbon Content** is based on analysis of an infrared signal during combustion at 1400°C under oxygen scavenging conditions. While this measurement is simple and very fast, it requires investment in highly specialised equipment. Its repeatability is good, but we were unable to validate its reproducibility, as only two laboratories used it in the framework of the project. Further evaluation of this method is therefore required.

Recommendation for the measurement of trapped CO_2:

The methods that should be preferred depend on the context in which it is necessary to evaluate the amount of trapped CO_2. For example, while TGA can be used when changing the sources of the materials, loss on ignition is well-suited for characterising average batches before and after carbonation. Calcimetry (Bernard calcimiter or carbonate bomb) can be used for quality control between two loss on ignition measurements.

Parameters to be monitored during the accelerated carbonation of CRCAs

The optimisation of CO_2 mineralisation in recycled concrete aggregates depends on several parameters. Laboratory studies and modelling have identified the following:

Parameters related to RCAs:

- **The initial natural carbonation state** of the aggregates affects the CO_2 storage potential. Spraying with a coloured indicator such as phenolphthalein allows qualitative checking of whether there is potential for further carbonation.
- The **water content** is the most important factor. The optimum water content of recycled aggregates for maximum carbonation is between 65% and 85% of the 24-hour water absorption value of RCAs.
- The **aggregate size** has a significant impact on the CO_2 storage rate. The storage rate of the sand fraction can be double that of 12-20 mm gravel.

- **The type of cement** in the original concrete influences the CO_2 storage potential. The storage potential of recycled aggregates containing CEM III may be up to three times lower than that of those containing CEM I.

The parameters associated with accelerated carbonation processes are as follows:

- A higher **temperature (**40°C and above) has a beneficial effect on carbonation. The gain from a **partial pressure** of CO_2 in the gas of over 15% is not significant. For these two reasons, gases leaving cement kilns (with a CO_2 content of around 15% and a temperature of between 70 and 90°C) **are suitable for accelerated carbonation**.

- **The presence of other combustion products** in the gas (SO_2, NO_2) can significantly disrupt the kinetics of CO_2 mineralisation.

- The granular agitation is more effective than carbonation in a gravel bed filter. However, granular agitation also produces attrition with both desirable and undesirable effects on the aggregates (creation of carbonate fines conducive to CO_2 storage, reduction in aggregate angularity).

- The forced gas flow in the aggregate bed improves the kinetics of carbonation. The **gas pressure** also plays a significant role in increasing the storage rate. However, if the pressure gradient is too high (> 1.5 bar), a condensation phase is observed, limiting CO_2 penetration.

- As one would expect, a **longer treatment time** increases the quantity of CO_2 stored. However, this effect is limited by clogging of the pores and the greater saturation of the medium which slows down the carbonation kinetics.

Industrial accelerated carbonation processes

Several industrial demonstrators (rotary dryer and fluidised bed in cement works, simple containers) as well as a trial installation (gravel filter in a laboratory) have been developed.

These experimental trials confirmed that it was entirely possible to implement industrial processes for the accelerated carbonation of recycled concrete aggregates at sites that emit CO_2.

The main lessons learned from these industrial trials are as follows:

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- The use of cement plant gases with a CO_2 content of around 15% (by volume) is completely suitable for accelerating artificial carbonation, with the optimum relative humidity being between 50 and 70% and the temperature between 70 and 90°C.
- The treatment of the fine fractions of recycled concrete aggregates must be carried out relatively quickly (if possible within 3 months) after their production and availability to limit natural atmospheric carbonation, which restricts the potential for accelerated re-carbonation.
- For industrially carbonated recycled concrete aggregates, **average capture rates of between 31 and 39kg CO_2/T for sand and between 5 and 12kg CO_2/T for gravel have been measured after, typically, 1 hour of treatment** (contact with the gas) in cement works.
- In the demonstrators, which were constructed by converting existing process equipment, **control of the three parameters of CO_2 concentration, moisture and gas temperature is crucial to maximise the rate of CO_2 capture**.
- In the case of the gravel filter, CO_2 capture rates depend on the same parameters as for industrial installations, namely the three that have just been mentioned. The combination of the main gas (N_2) and the secondary gases (SO_2 and NO_x) does not lead to the precipitation of specific compounds but can nevertheless negatively affect the actual carbonation rate.

To industrialise the processes, it will be necessary to optimise the management of key parameters such as the relative humidity, temperature and treatment time for the equipment, as well as the water content of the recycled aggregates. The site will also need to have a reliable method for determining CO_2 capture rates to be able to take these values into account when calculating the Environmental Product Declarations for the CRCAs, but also to economically exploit the CO_2 that is not emitted.

Production of concrete containing CRCAs - Results and recommendations

The properties in the fresh or hardened state of concrete made with carbonated recycled aggregates from the FastCarb national project demonstrators are comparable to those of concrete made with non-carbonated recycled aggregates. Their use therefore has no impact on the tendencies observed for the properties of concrete (in terms of its fresh state, mechanical strength and durability).

These results can certainly be improved, as they are linked to the intrinsic properties of RCAs (such as particle size and water absorption) and to the quantity of CO_2 stored in their cementitious matrix. In particular, the potential for optimising industrial processes could make it possible to obtain some of the properties of carbonated aggregates that are described in the literature in the resulting concretes.

The results from the FastCarb project regarding the properties of concretes made with CRCA comply with the limits adopted in France for recycled aggregates. The requirements of standard NF EN 206+A2/CN are therefore applicable to concrete made with carbonated recycled aggregates.

Prerequisites for increasing the use of CRCAs

RCAs have the potential to become carbon sinks. Future RCA carbonation facilities will only be able to develop if it is environmentally and economically attractive for operators to create an activity that brings RCA closer to CO_2 sources and delivers the resulting CRCA to construction sites in a way that creates the smallest possible carbon footprint.

The results obtained from the industrial demonstrators show that the carbonation of one tonne of fine RCA fraction captures between 31 and 39kg of CO_2, while that of the coarser fraction captures between 5 and 12kg of CO_2. On the other hand, the project data indicate that 11kg of CO_2 are emitted when one tonne of CRCA is transported 30km from the recycling site to the carbonation site and then 20km from there to the ready-mix concrete production unit. The balance of CO_2 emissions under these conditions is therefore -1kg of CO_2 per tonne of gravel and -28kg of CO_2 per tonne of sand.

Recommendations for the production of CRCA:

- The location of deconstruction concrete recycling facilities should be optimised to reduce the impact of transport on the environmental balance , by encouraging modal shift (to waterways or rail) where possible; this action is consistent with one of the objectives of the EPR (Extended Producer Responsibility) for construction products, which is to increase the number of facilities that can handle deconstruction wastes.
- Continue practical work on the types of crusher to be used in concrete recycling to concentrate the cementitious fraction, which recarbonates, unlike the granular fraction, whose core is aggregate with no potential for recarbonation.

Given the initial results, it seems more profitable (from the environmental and economic point of view) for the accelerated carbonation facility to be fed exclusively with the sand fraction of the RCA since this captures more CO_2.

Recommendations for the production of concrete containing CRCAs:

If we apply these findings to the case of an exterior wall concrete (XC4/XF1), with 500kg of carbonated recycled gravel and 180kg of carbonated recycled sand, the saving is 7.3kg of CO_2 per m3 of concrete compared with the use of natural aggregates. By using the performance-based approach to validate a mix design containing, for example, 100% recycled gravel and 50% recycled sand, 17.4kg of CO_2 per m3 of concrete could be saved, i.e. around 10% of the concrete's impact.

Recommendations for continuing to promote the recycling of concrete:

Regarding RCA resources, the study by the Union Nationale des Producteurs de Granulats (the French national union of aggregates producers) has concluded that the amount of recycled concrete aggregates available for carbonation in France is of the order of 20 million tonnes, with the majority of the sources being located in major metropolitan areas. Improving the sorting of wastes at all stages of the deconstruction process (construction sites, subgrades, etc.) should make it easier to identify, locate and flag up concrete so that it can be directed towards recycling channels, increasing the tonnages of RCA and ultimately CRCA.

Recommendations for CO_2 sources:

The study carried out as part of the project identified more than 3,500 point sources of CO_2 emissions in France, including those subject to the ETS Directive and those monitored under the Facility Classified for Environmental Protection (ICPE) regulation, as well as methanization plants that inject methane into gas networks.

For companies subject to the ETS Directive, one tonne of CO_2 captured in RCAs saves an allowance valued between €80 and €90. For the others, the reduction in emissions can allow them to obtain Carbon Offset Credits which, like the unused CO_2 quotas, will increase the profitability of future CO_2 capture projects.

Where this is possible, the use of compressed CO_2 to carbonate RCAs on the deconstruction site or at a recycling facility will limit transport-related CO_2 emissions.