Mortars with recycled CO_2

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Outline

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- Tests on cement-based pastes with CO_2
  - Maximum absorption capacity
- Tests on cement-based mortars with CO_2
  - Mechanical properties and statistical analysis
- Conclusions
- Future works

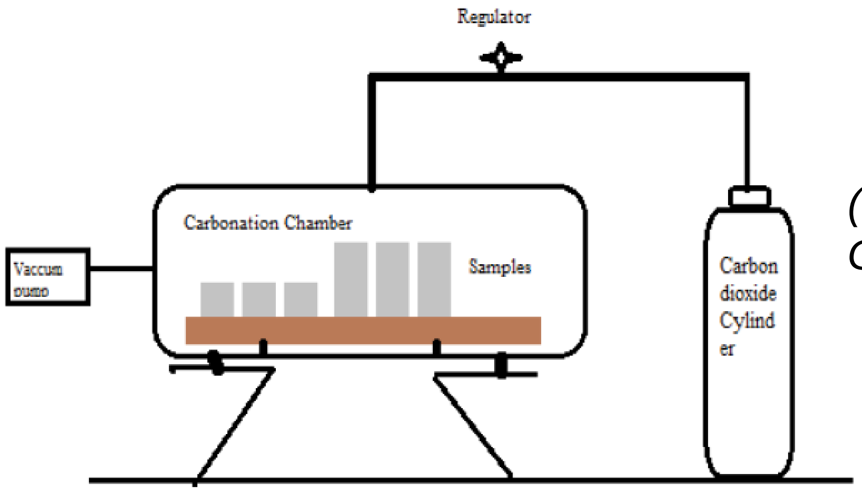
The recycle of CO_2

- In several chemical processes, carbon dioxide CO_2 is produced.
- The recovery and the recycle of CO_2 lead to economic and environmental advantages, because of the reduction of Greenhouse Effect gases emissions in the atmosphere.
- It can be recycled in the cement-based materials, by carbonating the calcium hydroxide:

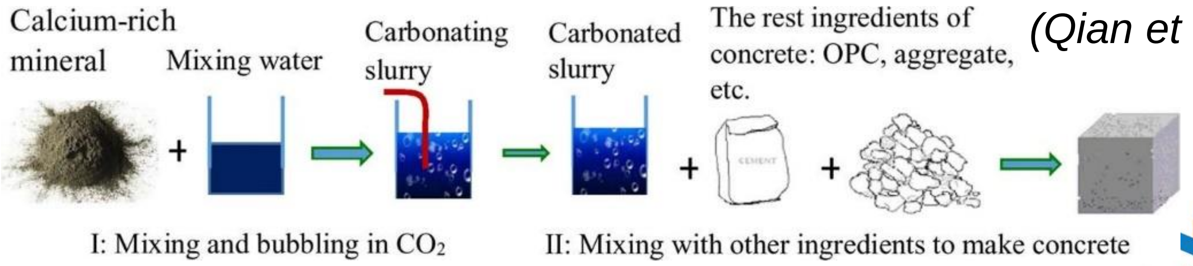
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

The carbonation in cementitious systems

- Three approaches
  - **Post-carbonation:** after casting, concrete manufacts are left in a carbonation chamber exposed to CO_2 for some time (carbonation curing)
  - **Pre-carbonation:** a mixture of calcium hydroxide is produced by adding CO_2 in a calcium-rich mineral water. Such a mixture is then added to the traditional components of concrete



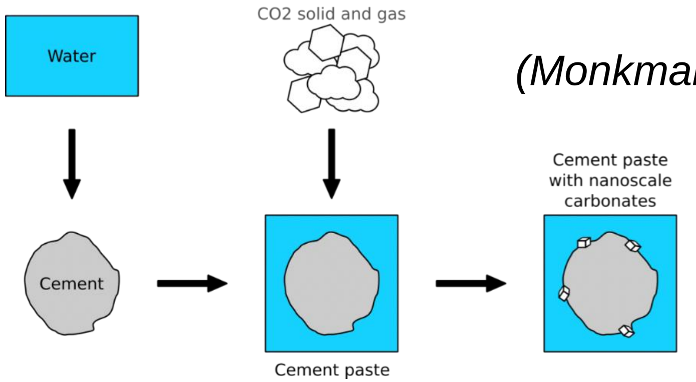
(Kashef-Haghighi and Ghoshal, 2010)



(Qian et al., 2018)

The carbonation in cementitious systems

- Three approaches
  - **CO_2 as additive:** a specific quantity of solid and gasiform CO_2 is progressively added to the cement paste



(Monkman and Cail, 2019)

Significance of a new research

1. Measure the content of absorbed CO_2 added with dry ice pellets
2. Simplify of the procedure:
   - Not only for concrete
   - CO_2 must be added by unskilled workers
3. Analyse other properties
   - Flexural strength (previously only compressive strength)
   - Statistical distribution of strength in presence of CO_2

→ Tests campaign on cement-based pastes (item 1)

→ Tests campaign on cement-based mortars (items 2–3)

Dry ice pellets

Test on pastes

- Cubes of cement paste (70 ⨯ 70 ⨯ 70 mm^3)
- 3 series (17 pastes) with:
  - dry ice CO_2
  - CEM I 42.5
  - water/cement =0.5
  - hardening accelerator
  - CaO expansive additive

Series	Specimens	Cement (g)	Water (g)	AC 50 CF (g)	SRA 155 (g)	CO_2 (g)	CO_2/Cement (%)
	#0_1			0	0	0	0
#0	#0_2			0	0	7.20	1.6
	#0_3			0	0	14.4	3.2
	#1_1			13.5	0	0	0
	#1_2			13.5	0	3.60	0.8
	#1_3			13.5	0	5.40	1.2
#1	#1_4			13.5	0	7.20	1.6
	#1_5			13.5	0	14.4	3.2
	#1_6	450	225	13.5	0	18.0	4.0
	#1_7			13.5	0	21.6	4.8
	#2_1			0	31.5	0	0
	#2_2			0	31.5	3.60	0.8
	#2_3			0	31.5	5.40	1.2
#2	#2_4			0	31.5	7.20	1.6
	#2_5			0	31.5	14.4	3.2
	#2_6			0	31.5	18.0	4.0
	#2_7			0	31.5	21.6	4.8

Hardening accelerator (3% the mass of cement)

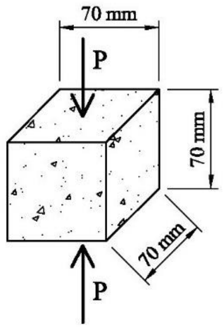
Expansive CaO-based agent (7% the mass of cement)

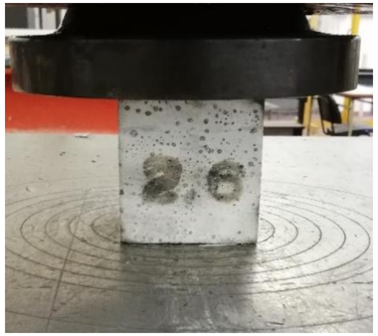
Test on pastes

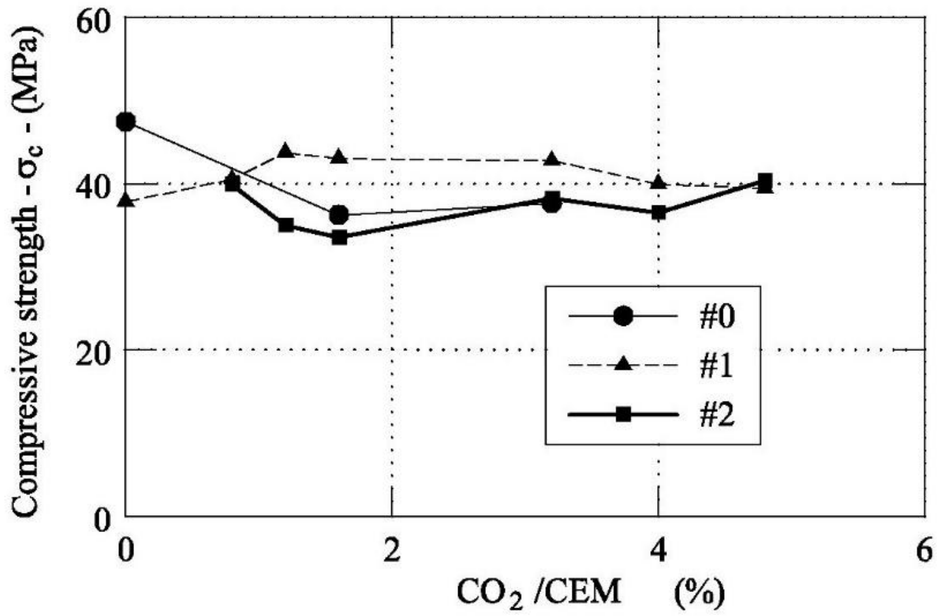
- Uniaxial compression tests on cubes after 28 days
- Evaluation of compressive strength

$$\sigma_c = \frac{P_{max}}{70 \times 70\, mm^2}$$

- Compressive strength does not vary significatively with the addition of carbon dioxide
- σ_c is more or less equal to that of cement (i.e., 42.5 MPa), regardless of the ratio CO_2/CEM
- The presence of additives does not modify this trend

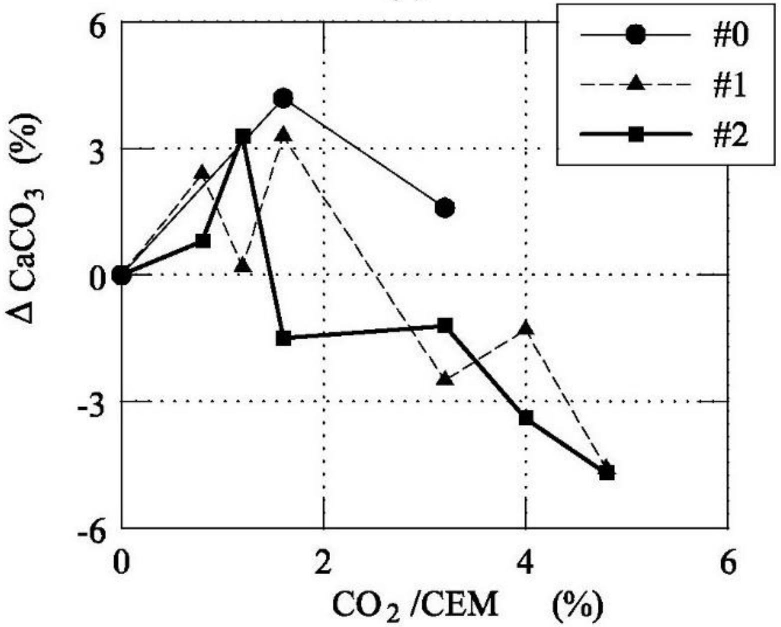






Test on pastes

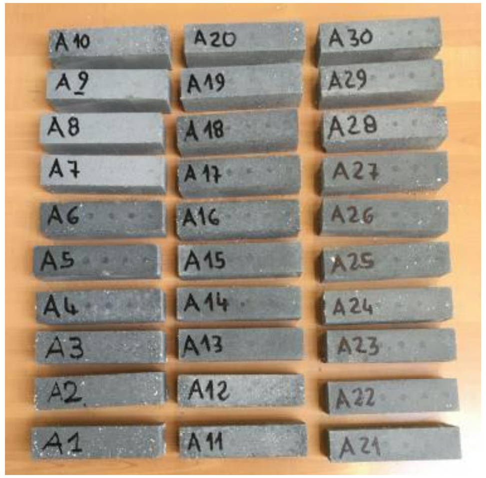
- Calcimetry test is used to measure the percentage of $CaCO_3$, which is a function of the carbon dioxide added to the mixture (or the ratio CO_2/CEM)
- The maximum increment of $CaCO_3$ with respect to the paste without additives is obtained when CO_2/CEM=1.6%
- Further increments of CO_2 are not absorbed by the concrete system
- The decrement of $\Delta CaCO_3$ when CO_2/CEM > 1.6%, is probably due to the reduction of the temperature produced by the dry ice pellets



Test on mortars

- UNI EN 196-1
- Prisms of cement mortar (40 × 40 × 160 mm^3)
- 2 series (of 30 prisms) with:
  - water/cement =0.5
  - Standard sand
  - Addition of dry ice pellets
  - CO_2 /CEM =1.6% (the maximum)
  - No other additives

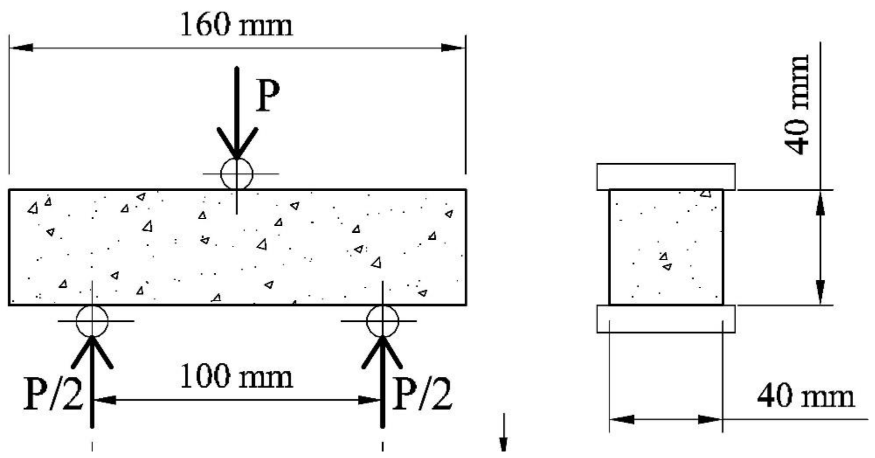


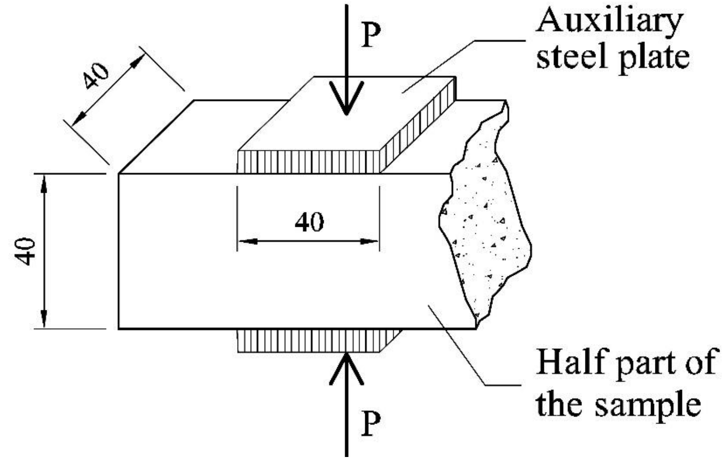



Series	Cement (g)	Water (g)	Sand (g)	CO_2 (g)	CO_2/Cem (%)
A-Plain	4500	2250	13500	0	0
B-Carbon	4500	2250	13500	72	1.6

Test on mortars

- Three-point bending tests and uniaxial compression tests





Flexural strength

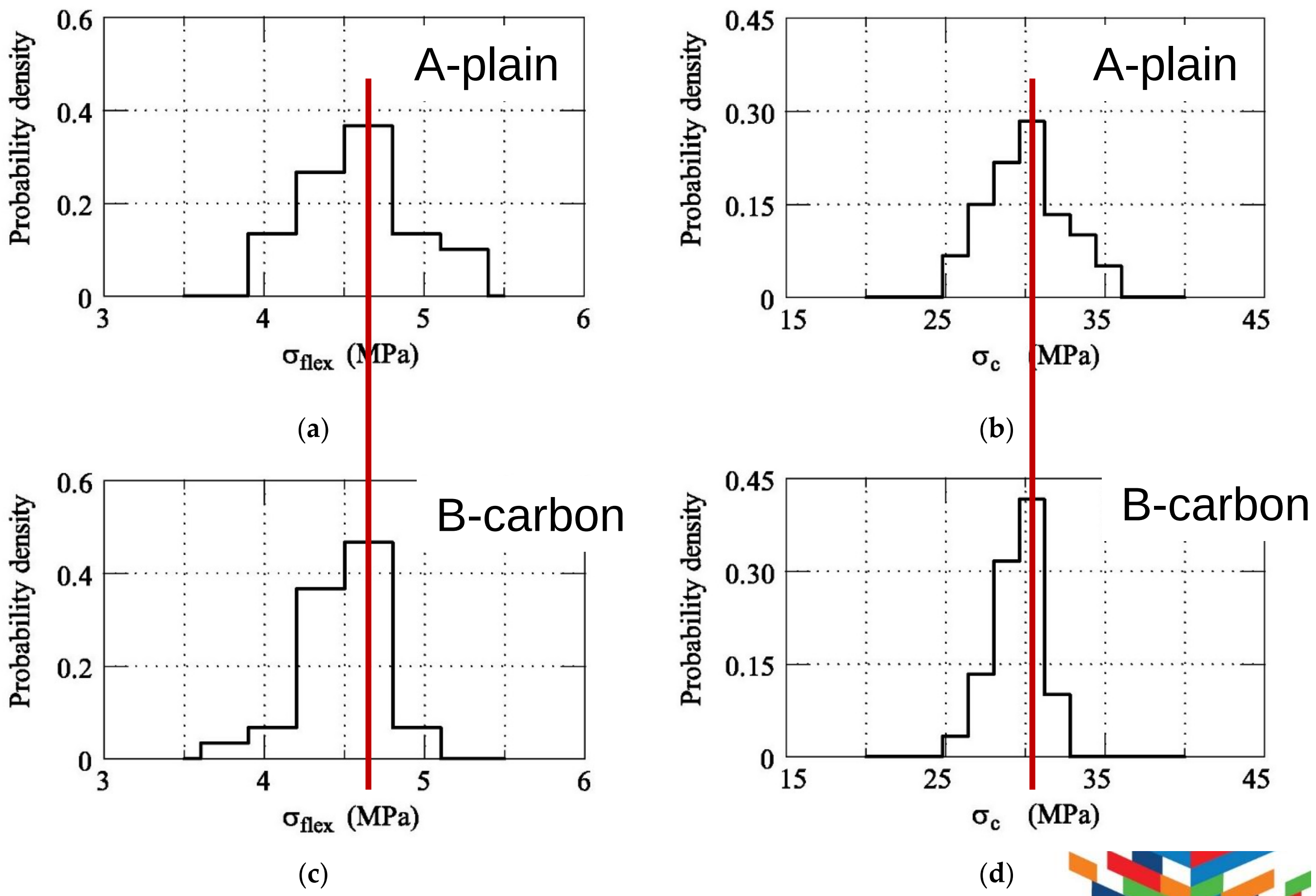
$$\sigma_{flex} = \frac{3\,PL}{2\,BH^2}$$

Compressive strength

$$\sigma_c = \frac{P_{max}}{40\ \times\ 40\,mm^2}$$

Test on mortars

- Probability density of both flexural and compressive strength
- The modal value is the same
- The distribution around the modal value is larger in the mortars A-plain (without the presence of CO_2 in the mixture)



Test on mortars

- Referring to the gaussian distribution, the average values μ of both the strengths does not vary with and without CO_2
- The addition of CO_2 produced a reduction of standard deviation δ (22 % for σ_{flex} and 35 % for σ_c). In the tests performed by Monkman and Cail (2019) on concrete in compression, δ reduced of 25%.
- F-test on σ_c demonstrates that A-plain and B-carbon are two different systems

Mechanical property	σ_{flex}		σ_c	
Type of mortar	A-plain	B-carbon	A-plain	B-carbon
μ (MPa)	4.59	4.48	30.0	29.4
δ (MPa)	0.319	0.250	2.40	1.53
Degree of freedom	29		59	
F-test	$F = 1.63 < f_{0.05} = 1.86$		$F = 2.44 < f_{0.05} = 1.54$	
Equal variances	Yes		No	

Conclusions

1. Cement-based mortars can absorb CO_2 in the form of dry ice pellets
2. The maximum absorption capacity is CO_2 /CEM =1.6%, which is similar to those already measured by other researchers
3. Such a content of CO_2 does not modify the average values of flexural strengths (and pH as well)
4. However, the scatter of the strength (or the standard deviation) with respect to the average value remarkably reduces when CO_2 is added

Thus, by recycling CO_2 the quality of cementitious mortars improves

Future works

1. Use different cements
2. Application to concrete
3. Addition of CO_2 made with ^{13}C