Minimizing Carbon Footprint in Cementitious Materials through the Integration of TiO_2 Nanoparticles

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Outline

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Motivation	Procedure	Results	Conclusions
Background and framework	Materials and methods used	Findings and discussion	Overview of main findings

C. Moro, V. Francioso and M. Velay-Lizancos (2021). 'Impact of nano-TiO_2 addition on the reduction of net CO_2 emissions of cement pastes after CO_2 curing.' Cement and Concrete Composites, vol. 123, p. 104160.

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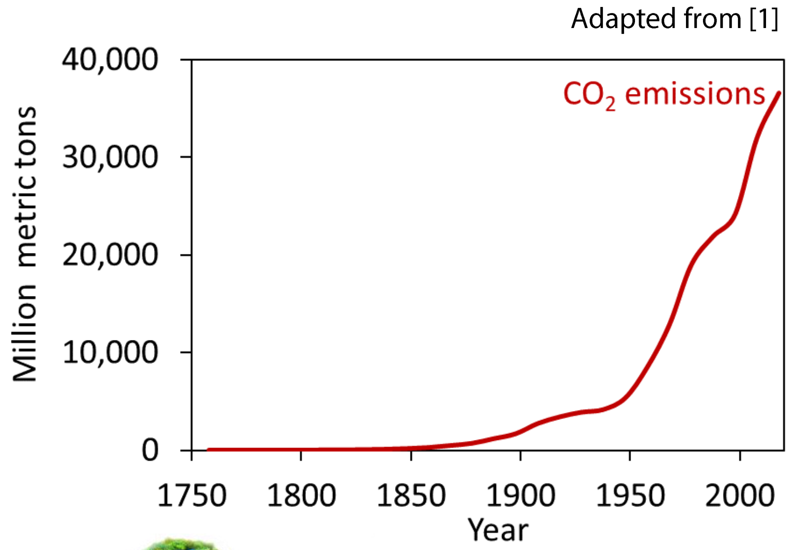
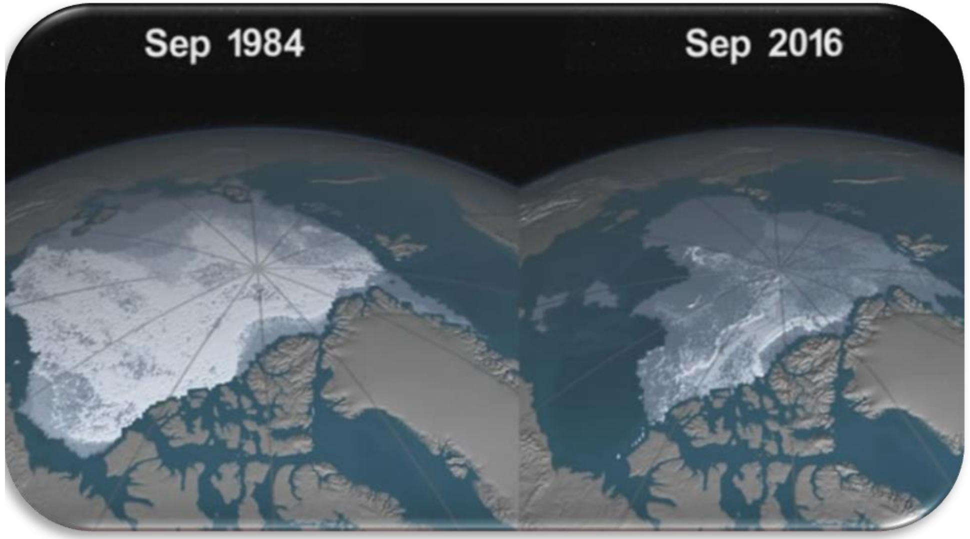
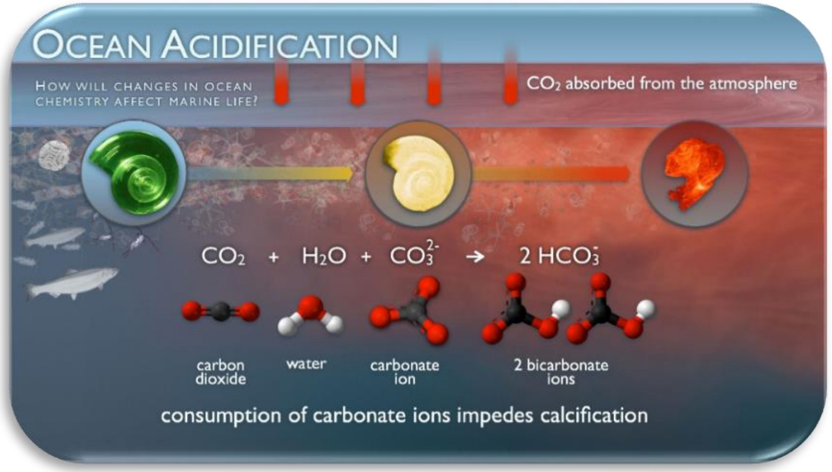




Highest level in 3-5 Million years! [2]

- **Climate Change**
- Air Pollution



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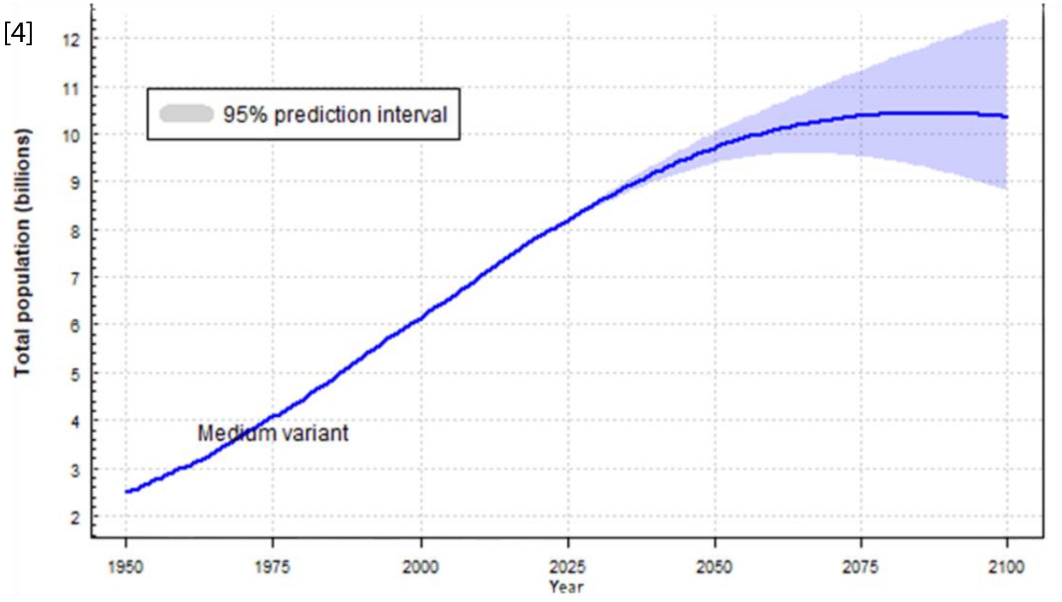
4.2 million premature deaths per year!

[3]

- Climate Change
- **Air Pollution**

[4]



Even more impacts if we continue along this line!

[5]

More than 40% are directly related to sustainability!

Top priority!

Coarse aggregate

Fine aggregate

Cement

Water

Source: World cement

8% of the total

CO_2 emissions each year [6]

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Second most used material in the world (after water) with **30 billion** tons each year [7]

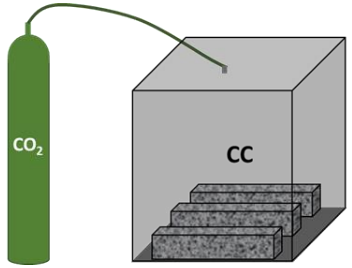
Cement-based materials are known for sequestering CO_2 during their service life.

43% of the CO_2 produced by cement industry 1930-2013 (excluding fossil use).

[8]

Passive

Active



CO_2 curing
(set-up)

Alite [C_3S] + water [H] $\rightarrow$ **C-S-H + 3CH + Heat**

Belite [C_2S] + water [H] $\rightarrow$ **C-S-H + CH + Heat**

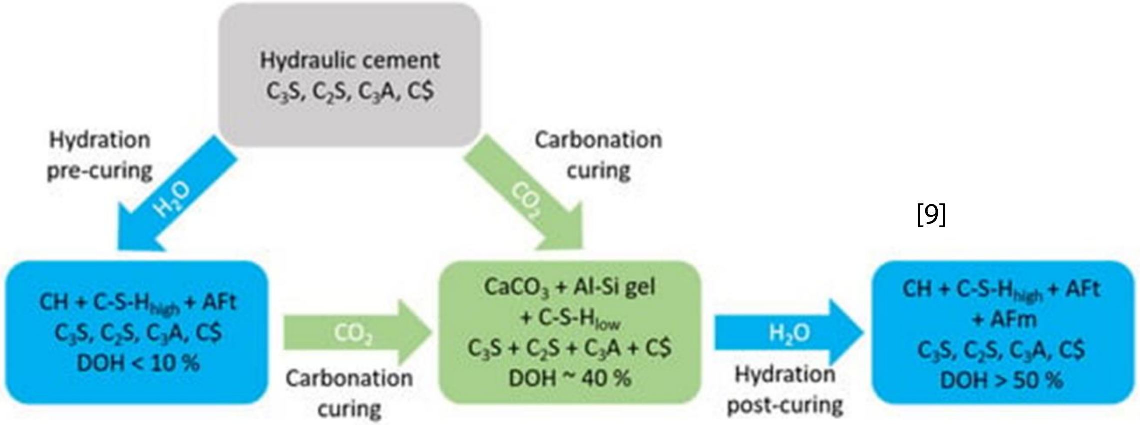
Calcium hydroxide
CH or $Ca(OH)_2$

+

Carbon dioxide
CO_2

=

Calcium carbonate
$CaCO_3$



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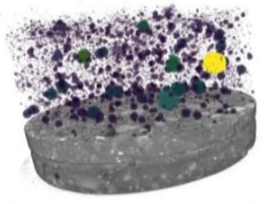
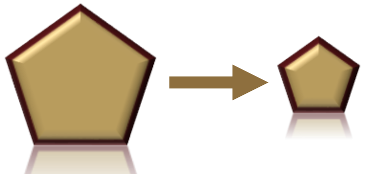


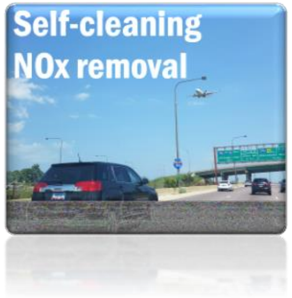
Porosity reduction (filling effect)[10-12]



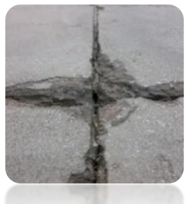
Restriction of $Ca(OH)_2$ size [15-16]

Nano-TiO_2

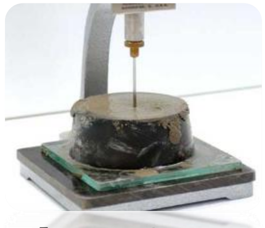
Compressive strength [13,15-16]



[20]



Durability improvement [17-19]



Acceleration of hydration (nucleation effect) [13-14]

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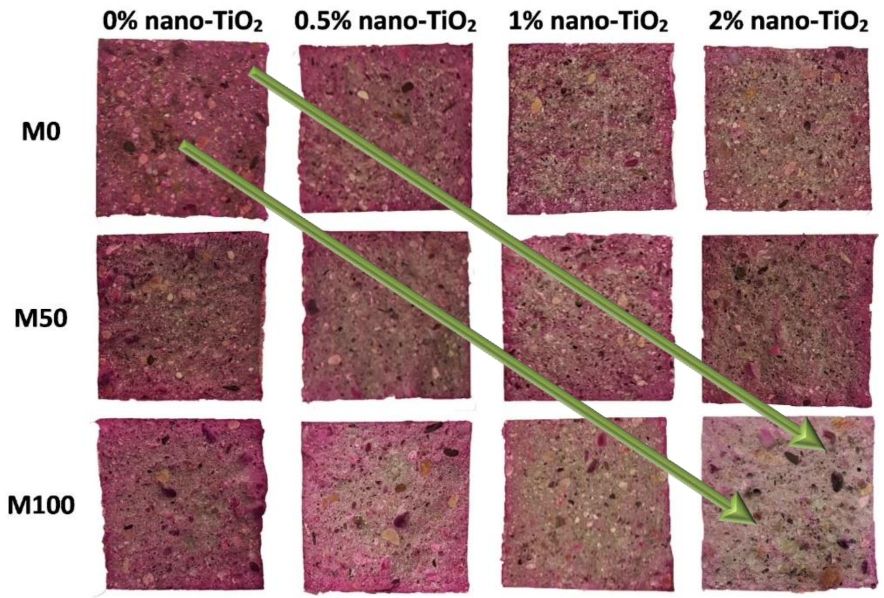
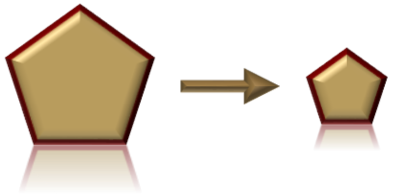
Nano-TiO_2



[21]



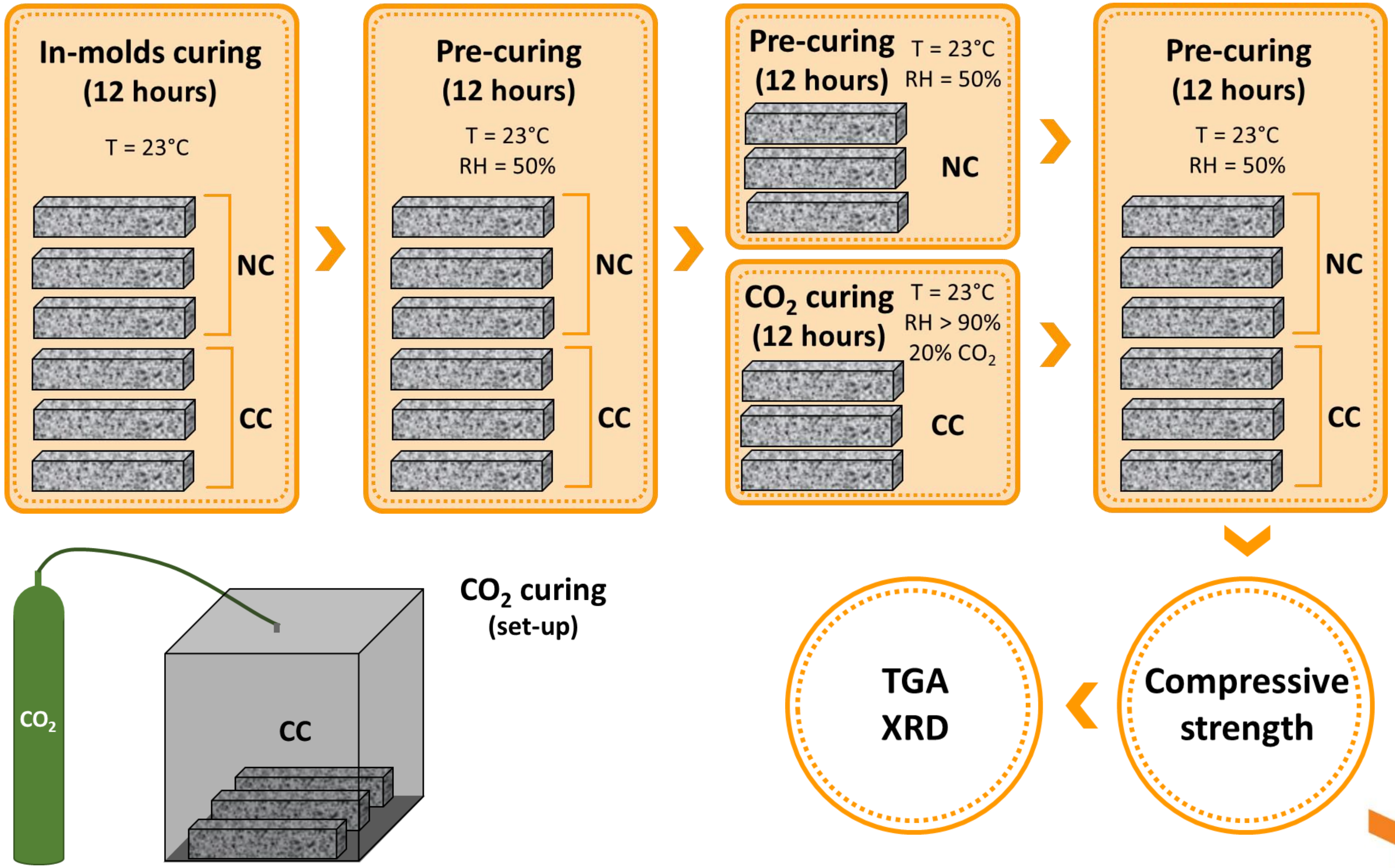
Restriction of $Ca(OH)_2$ size [15-16]

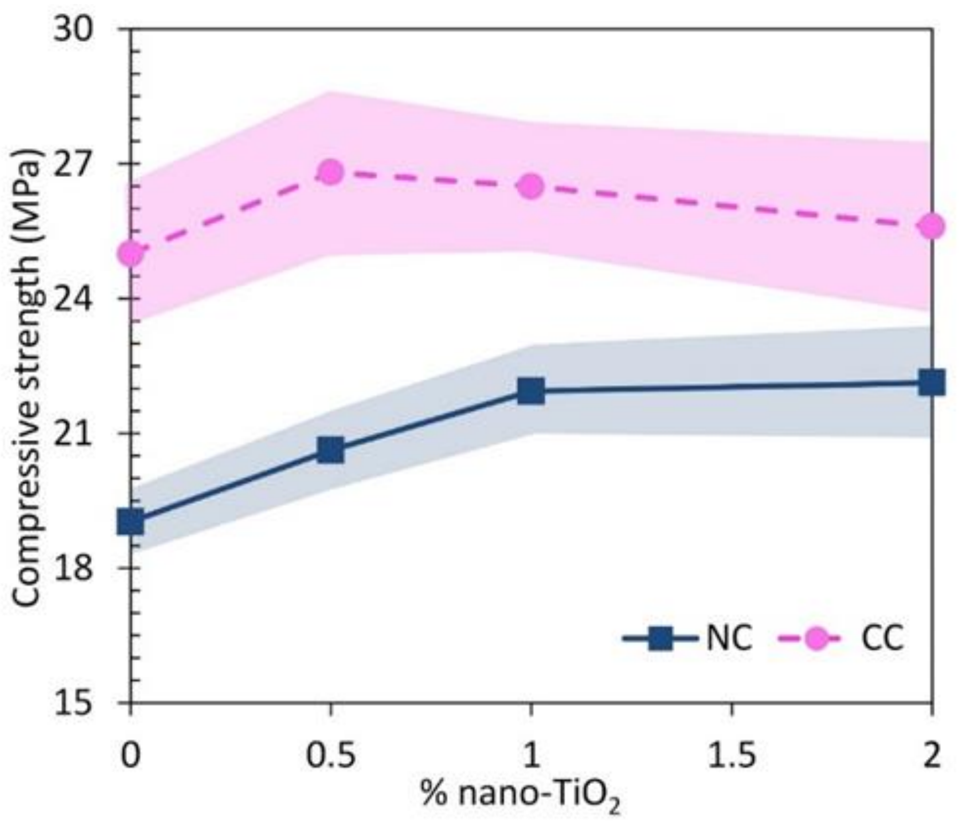
4 percentages of nano-TiO_2: (0%, 0.5%, 1% and 2%)

Compressive strength

XRD

TGA





Different optimum % of nano-TiO_2 depending on the curing type

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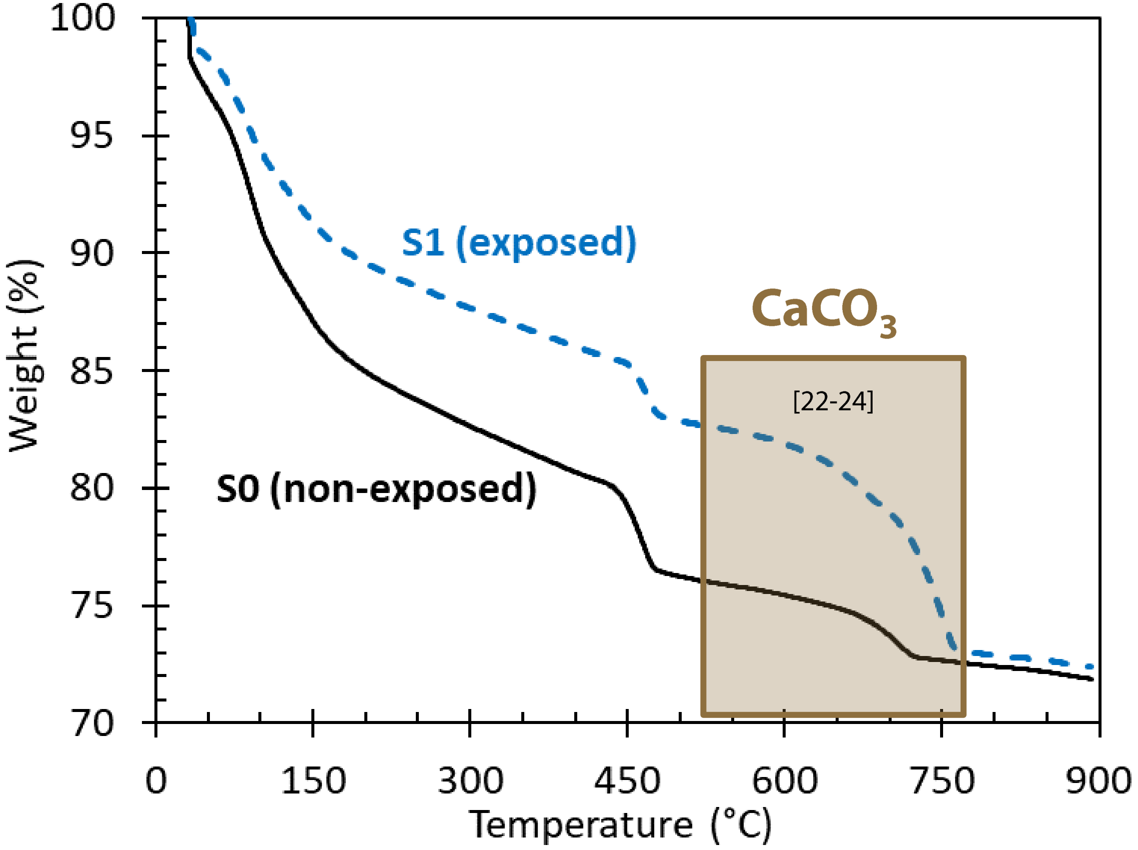

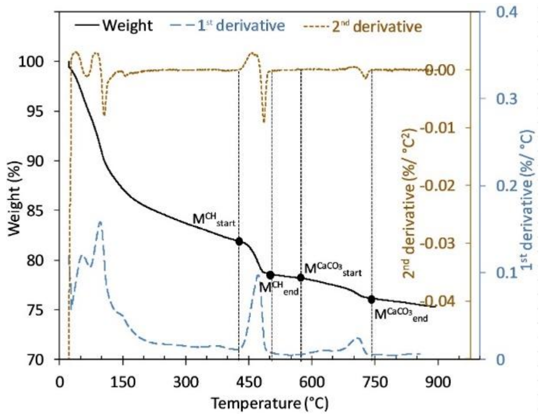

$$\mathrm{CaCO_3\ (g/100\ g)} = 100 \cdot \frac{100.1}{44.0} \cdot \frac{1}{\mathrm{M_c}} \cdot \left[\left(\mathrm{M_{start}^{CaCO_3}}\right) - \left(\mathrm{M_{end}^{CaCO_3}}\right)\right]$$

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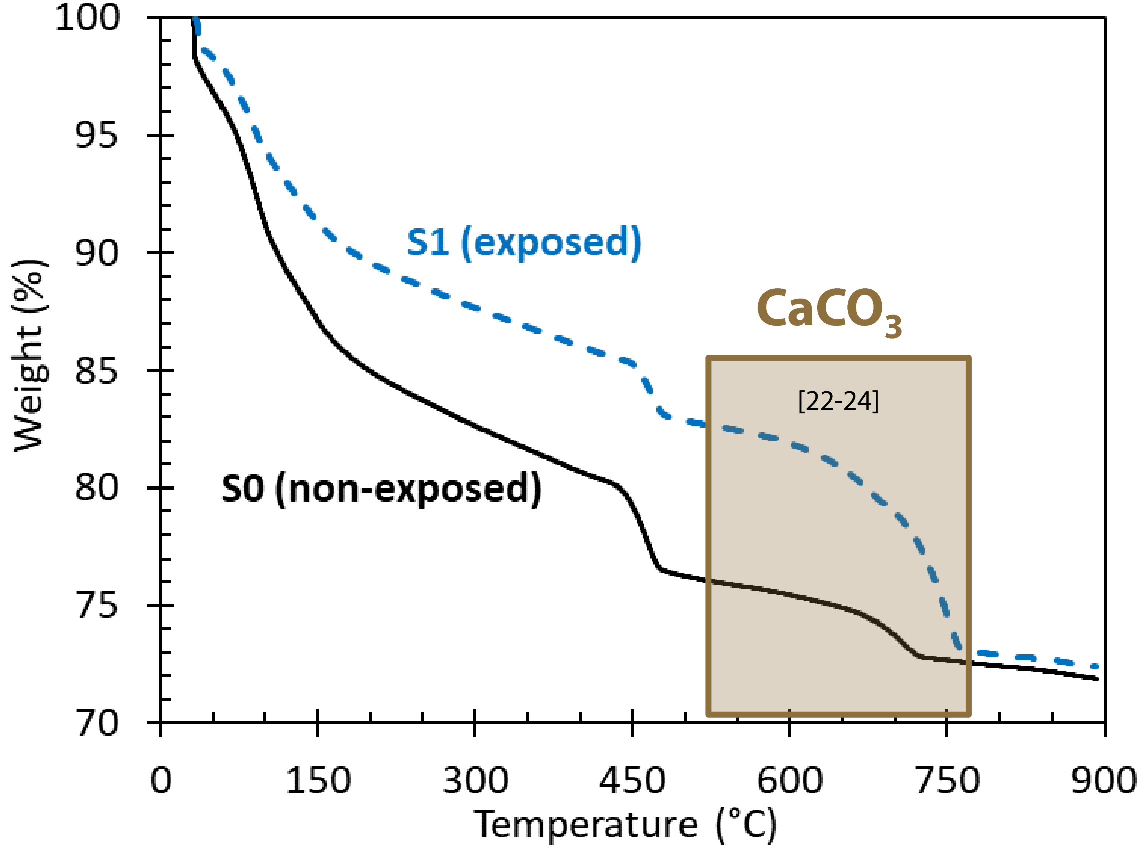

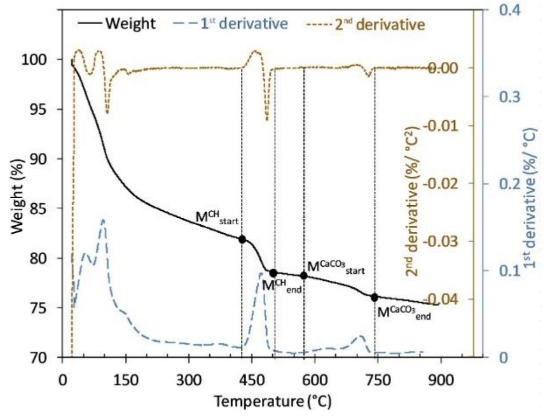

$$\mathbf{CO_2\ uptake\ (g/100\ g)} = \left[\left(\mathrm{CaCO}_3^{\mathrm{exp,sample}}\right) - \left(\mathrm{CaCO}_3^{\mathrm{nonexp,sample}}\right)\right] \cdot \frac{44.0}{100.1}$$

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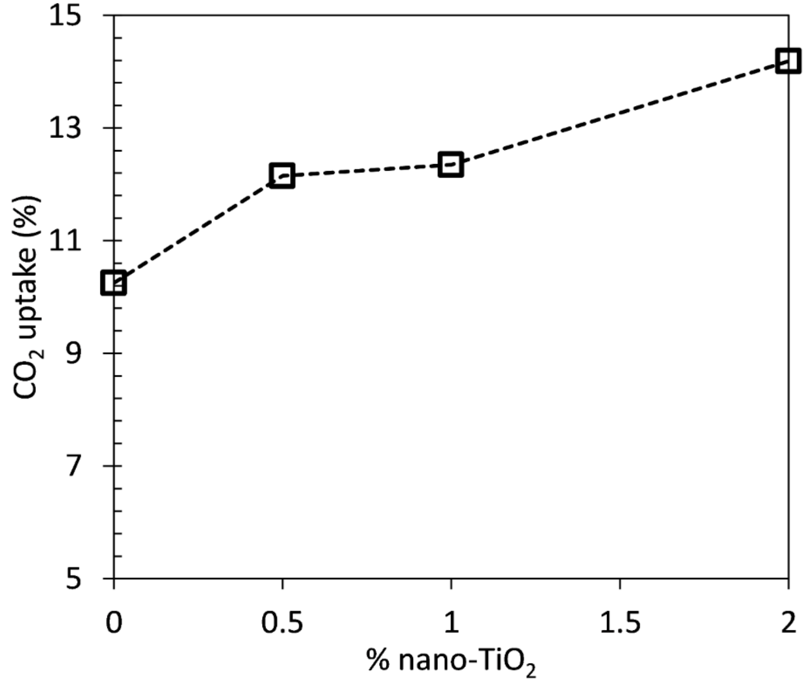
From TGA results



The higher the % nano-TiO_2 , the higher the CO_2 uptake

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$$CO_2 \text{ uptake } (g/100\ g) = \left[\left(CaCO_3^{exp,sample}\right) - \left(CaCO_3^{nonexp,sample}\right)\right] \cdot \frac{44.0}{100.1}$$

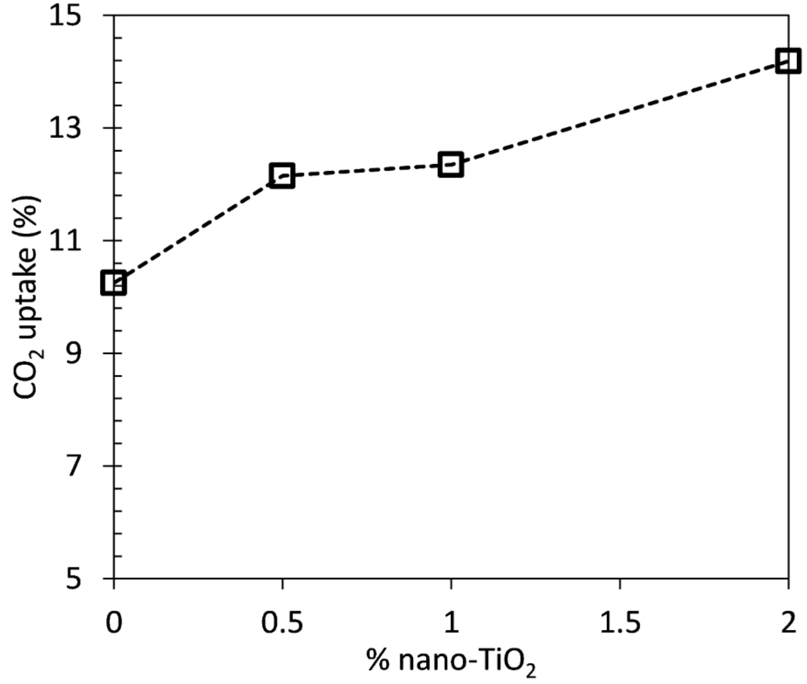
From XRD results

Mixtures		Phase content (%)							
		C_3S	C_2S	C_3A	C_4AF	Ettringite	CH	$CaCO_3$	Minor phases
Normal curing	CP0-NC	14.25	$\boxed{15.34}$	3.59	7.96	13.09	26.46	18.46	0.85
	CP0.5-NC	10.46	15.10	3.31	7.74	13.69	28.01	18.84	2.88
	CP1-NC	10.65	16.57	3.90	5.95	14.99	29.97	13.88	4.09
	CP2-NC	8.76	16.30	4.35	4.31	15.55	27.87	17.14	5.67
CO_2 curing	CP0-CC	14.53	$\boxed{7.37}$	4.69	8.77	6.29	3.64	52.93	1.77
	CP0.5-CC	12.82	7.70	4.11	9.00	4.10	5.52	54.27	2.49
	CP1-CC	11.49	3.71	5.84	8.58	5.87	4.49	56.36	3.67
	CP2-CC	13.96	2.33	4.00	10.70	2.64	1.10	61.03	4.25

CO_2 curing promotes the carbonation of belite. [23-24]

In CC samples, the use of nano-TiO_2 increases the consumption of belite, especially in CP1 and CP2.

From TGA results



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$$CO_2 \text{ uptake } (g/100\ g) = \left[\left(CaCO_3^{exp,sample}\right) - \left(CaCO_3^{nonexp,sample}\right)\right] \cdot \frac{44.0}{100.1}$$

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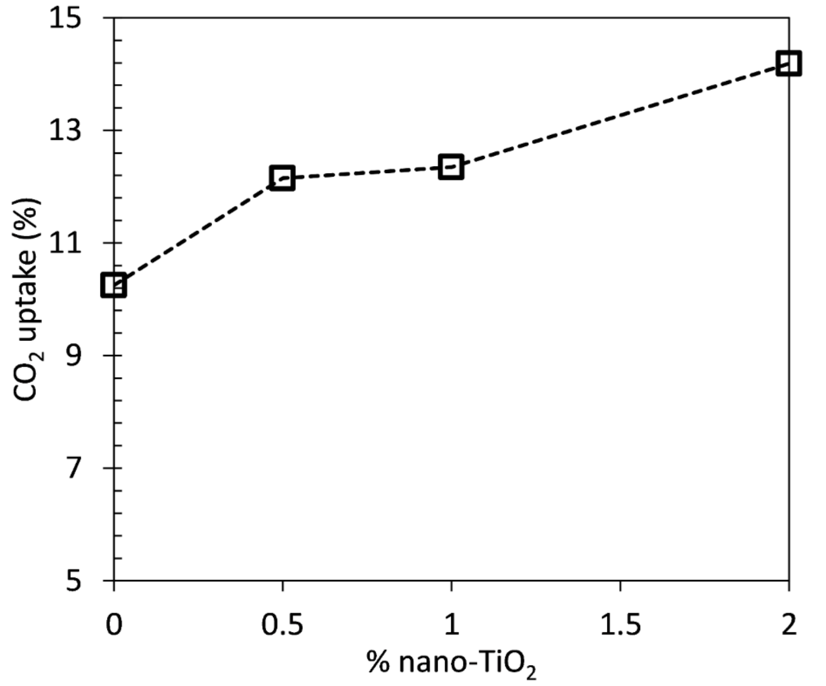

The higher the % nano-TiO_2, the higher the CO_2 uptake

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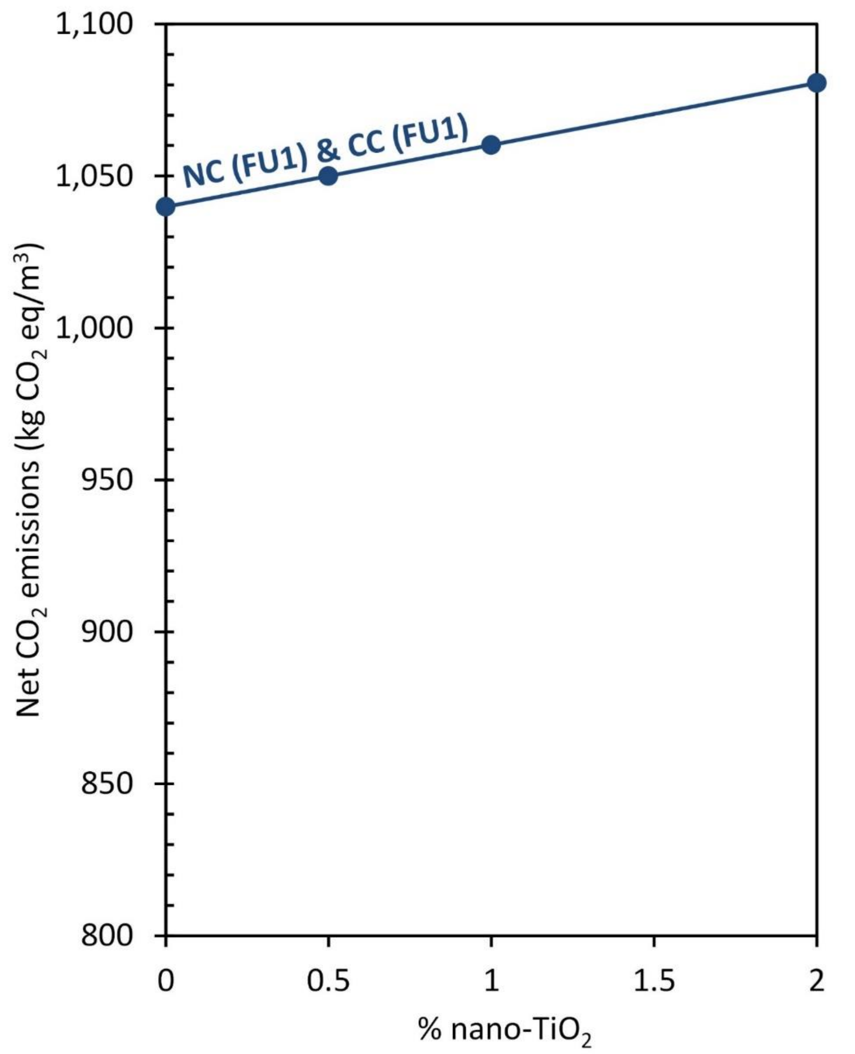
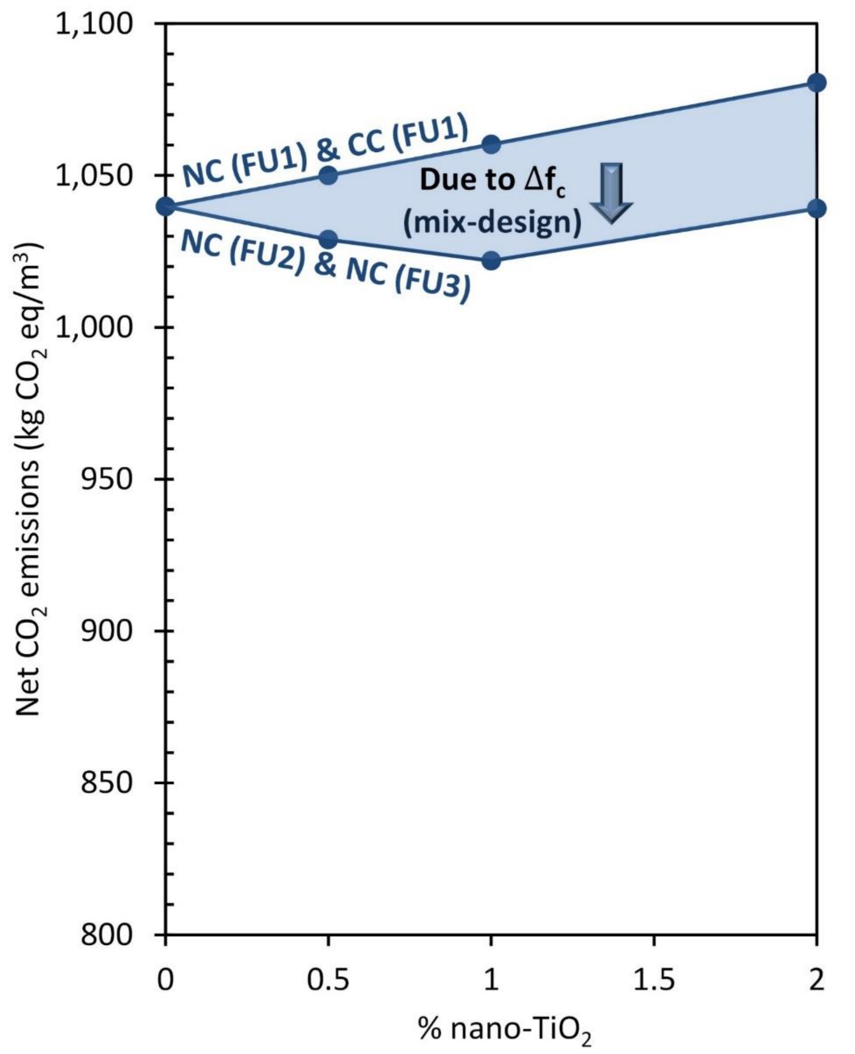


- **FU1 results (Volume)**
- **FU2 results (Volume + Compressive strength)**
- **FU3 results (Volume + Compressive strength + CO_2 uptake)**



- FU1 results (Volume)
- **FU2 results (Volume + Compressive strength)**
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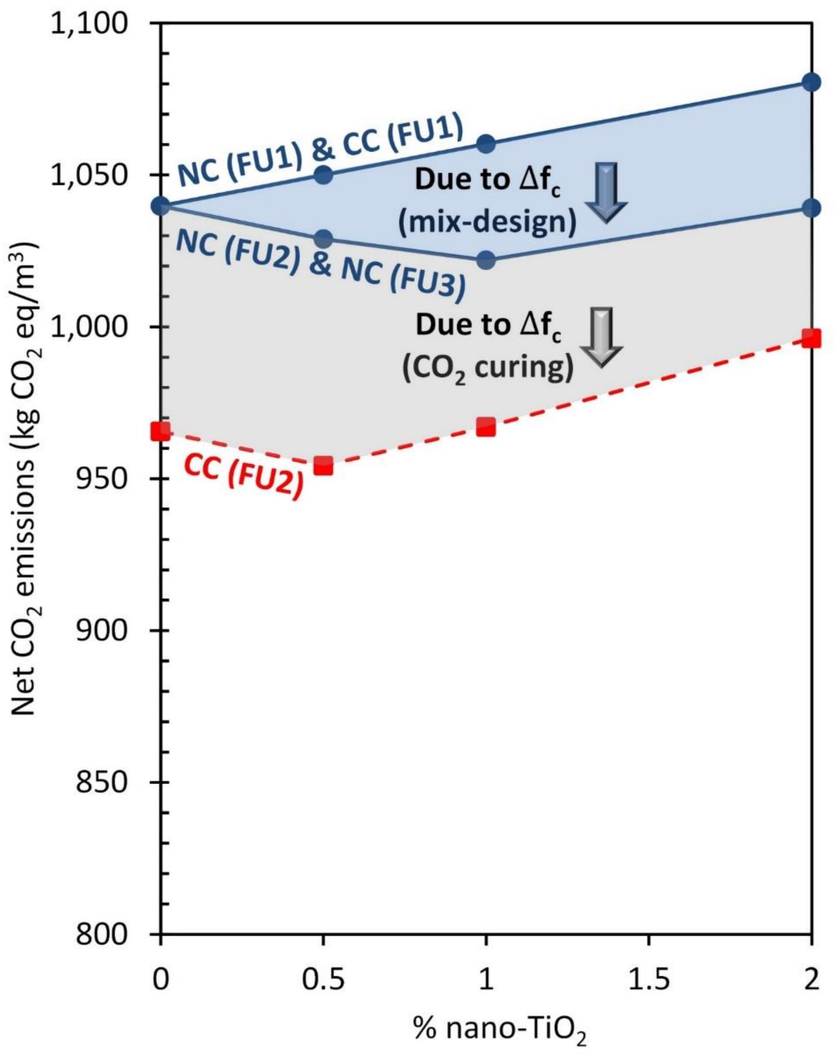

- FU1 results (Volume)
- FU2 results (Volume + Compressive strength)
- FU3 results (Volume + Compressive strength + CO_2 uptake)

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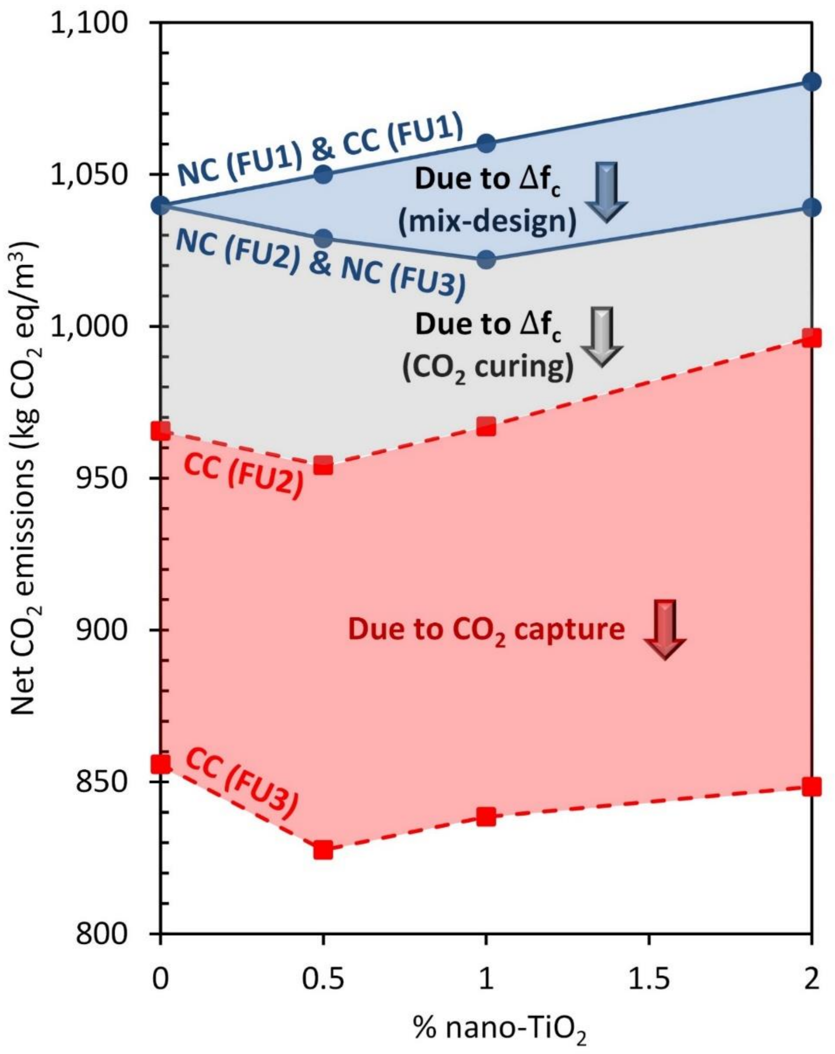

- FU1 results (Volume)
- **FU2 results (Volume + Compressive strength)**
- **FU3 results (Volume + Compressive strength + CO_2 uptake)**

- Nano-TiO_2 addition **increases the CO_2 uptake** during CO_2 curing.
- Nano-TiO_2 addition **promotes the carbonation of belite** during the CO_2 curing.
- The use of nano-TiO_2 **may decrease net CO_2 emissions** of cementitious composites after CO_2 curing considering the positive effects of the nanoparticles (enhancement of compressive strength and promotion of CO_2 uptake).

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