CO_2 Mineralization in Calcium Silicate Building Products

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Objectives

- *To explore the possibility of sequestering carbon dioxide in calcium-carrying building products through their early age carbonation curing using recovered CO_2 or as-captured flue gas*
  - *The potential carbon uptake by the commercial building products*
  - *The strength gain and durability performance of the carbonated products*
- *To demonstrate environmental, technical and economical benefits of the technology*

The market

- ***Portland cement annual production:***
  - ***70 million tons in USA***
  - ***10 million tons in Canada***
- ***The concrete building product market:***
  - ***Concrete masonry blocks***
  - ***Concrete paving stones***
  - ***Cementboards and fiberboards***
  - ***Precast concrete components with no reinforcing steel***
  - ***Manufactured lightweight aggregates***

Carbonation of Calcium-Carrying Materials

- **Carbonation of calcium silicates:**
  - $3CaO \bullet SiO_2 + 3CO_2 + \mu H_2O \rightarrow SiO_2 \bullet \mu H_2O + 3CaCO_3$
  - $2CaO \bullet SiO_2 + 2CO_2 + \mu H_2O \rightarrow SiO_2 \bullet \mu H_2O + 2CaCO_3$

Theoretical limit for calcium-based materials to uptake CO_2:

Max CO_2 (wt%) = 0.785 CaO + 1.09 MgO + 1.42 Na_2O + 0.935 K_2O

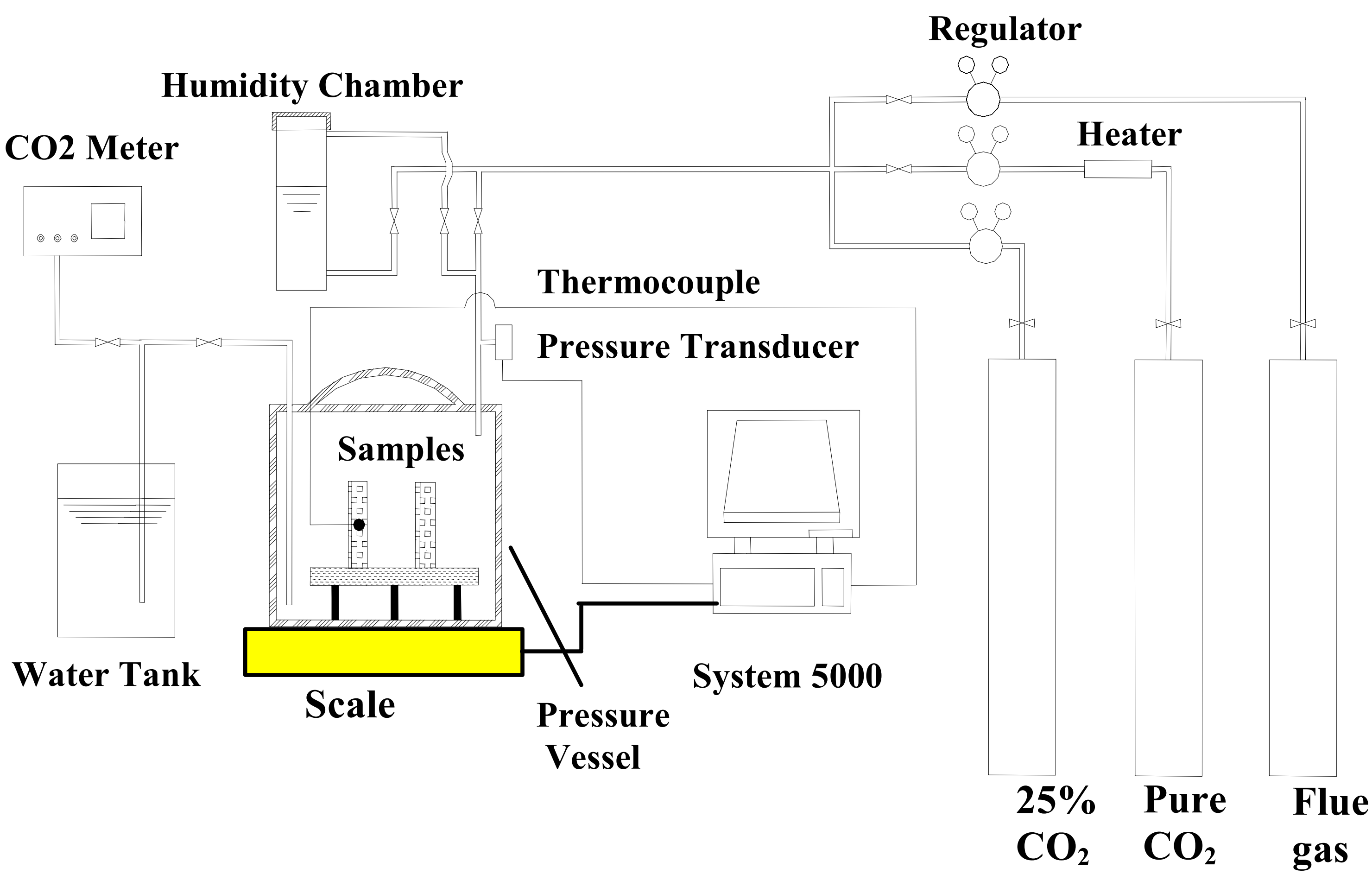
For Portland cement, CaO = 63%, at 100% efficiency, CO_2 uptake = 50% by mass.

For EAF Steel slag, CaO = 36%, at 100% efficiency, CO_2 uptake = 28% by mass.

Technical and Economical Benefits

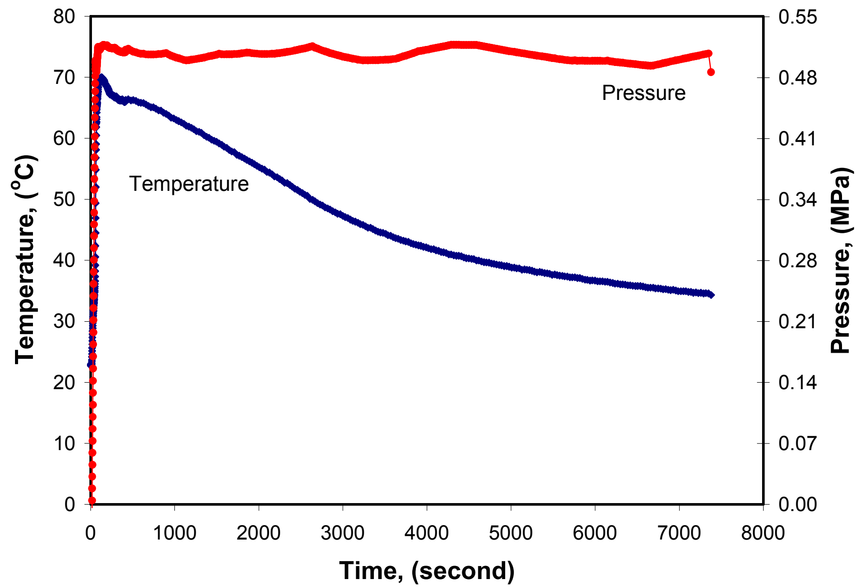
- ***Technical:***
  - ***Eliminated [$Ca(OH)_2$] for better durability***
  - ***Reduced pH for compatibility of fibers or aggregates***
  - ***Increased early age strength***
- ***Economical:***
  - ***Fast production by accelerated curing***
  - ***Tax credits / carbon credits***

Setup for Carbonation Curing Using Recovered CO_2 or As-Captured Flue Gas

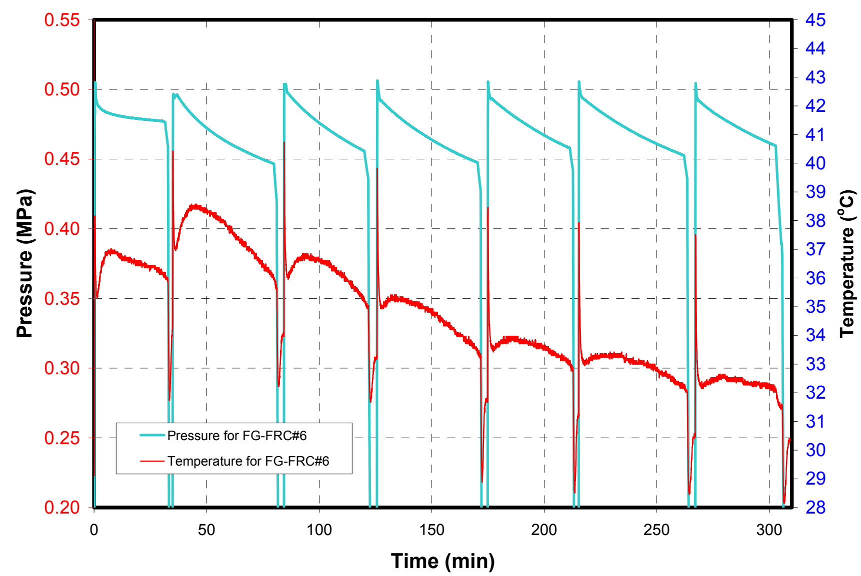


Process Parameters

- *With recovered CO_2:*
  - *CO_2 concentration = 99.5%*
  - *Duration = 2 hours*
  - *One injection*
  - *Pressure = 73psi (0.5Mpa)*

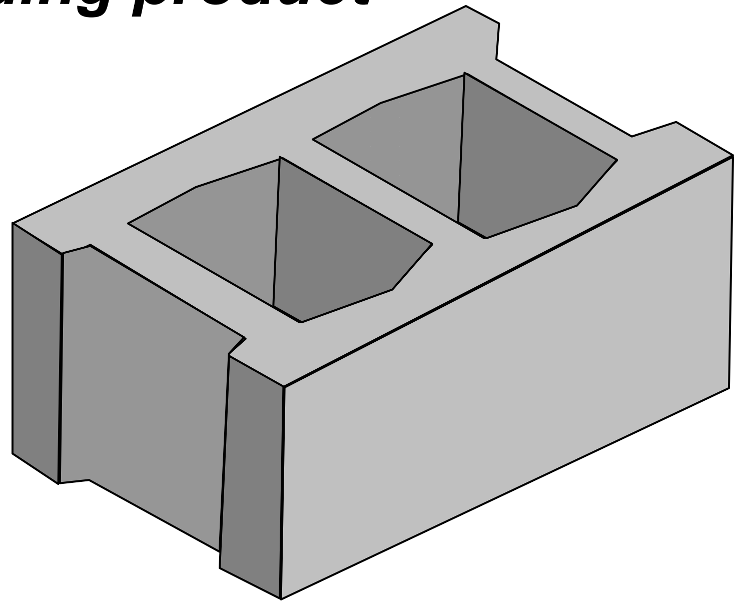


- *With as-capture flue gas*
  - *CO_2 concentration = 11.4%*
  - *Duration = 5 hours*
  - *Multiple injection process*
  - *Pressure = 73 psi (0.5Mpa)*



Materials and Products

- *Ordinary Portland cement* ***as binder***
  - ***CaO = 63%, particle size < 40 μm***
- ***Industry waste*** *steel slag* ***as aggregates***
  - ***CaO = 36%, crushed and sieved to < 150 μm***
- ***Concrete masonry block as building product***



Measurement of CO_2 Uptake

- ***Direct mass gain:***

$$\%Mass\ gain = \frac{(Mass)_{aft,CO2} - (Mass)_{bef,CO2} + Water_{collected}}{(Mass)_{dry\ binder}}$$

- ***Infrared analysis***

$$\%CO_2(byCO2analyzer) = \frac{(CO2)_{evaparated@800C}}{(TotalMass)_{binder+w+calcite}}$$

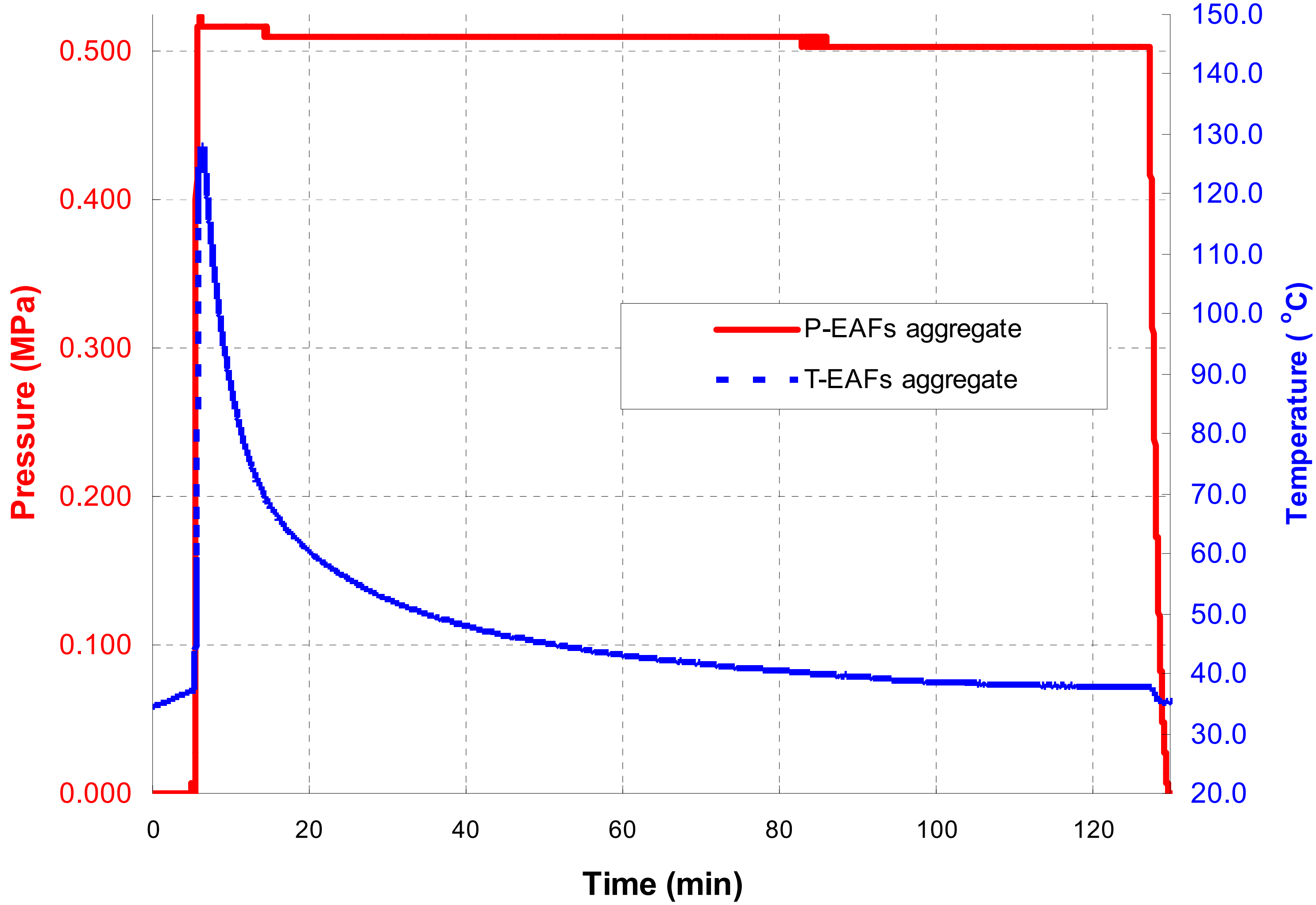
- ***Scanning electron microscopy***
- ***CO_2 concentration change***

Carbonation with recovered CO_2

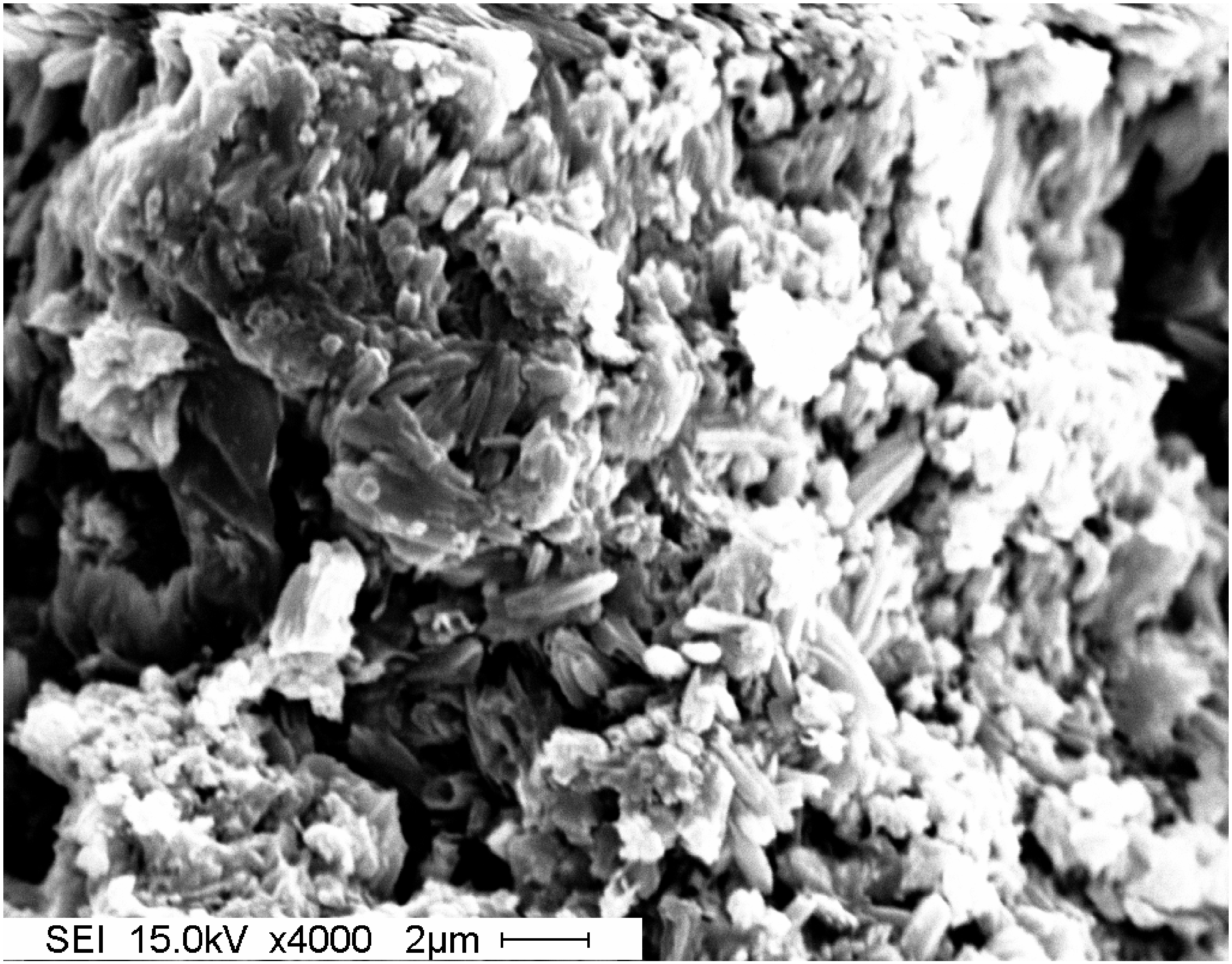
Two-hour carbonation with 99.5% CO_2

	CaO	Mass gain	IR result	Strength
Paste compacts:				
Portland cement	**63%**	**14.3%**	**12.5%**	**52.5 MPa**
EAF steel slag	**36%**	**13.4%**	**11.8%**	**17.5 MPa**
Aggregates (6mm):				
Portland cement	**63%**	**14.7%**	**12.3%**	**55.2 N**
EAF steel slag	**36%**	**11.6%**	**13.8%**	**57.2 N**
Limestone (reference)	**-**	**-**	**-**	**285 N**

Carbonation of Slag Aggregates: Pressure and Temperature Curves



Carbonated Slag Aggregates



Concrete with Manufactured Slag Aggregates Carbonated in Recovered CO_2

First carbonation: making of slag aggregates.

Mass gain = 11.6%, CO_2 content by IR =13.9%

Second carbonation: Making of concrete.

Mass gain = 21.1%,

CO_2 content by IR = 16%

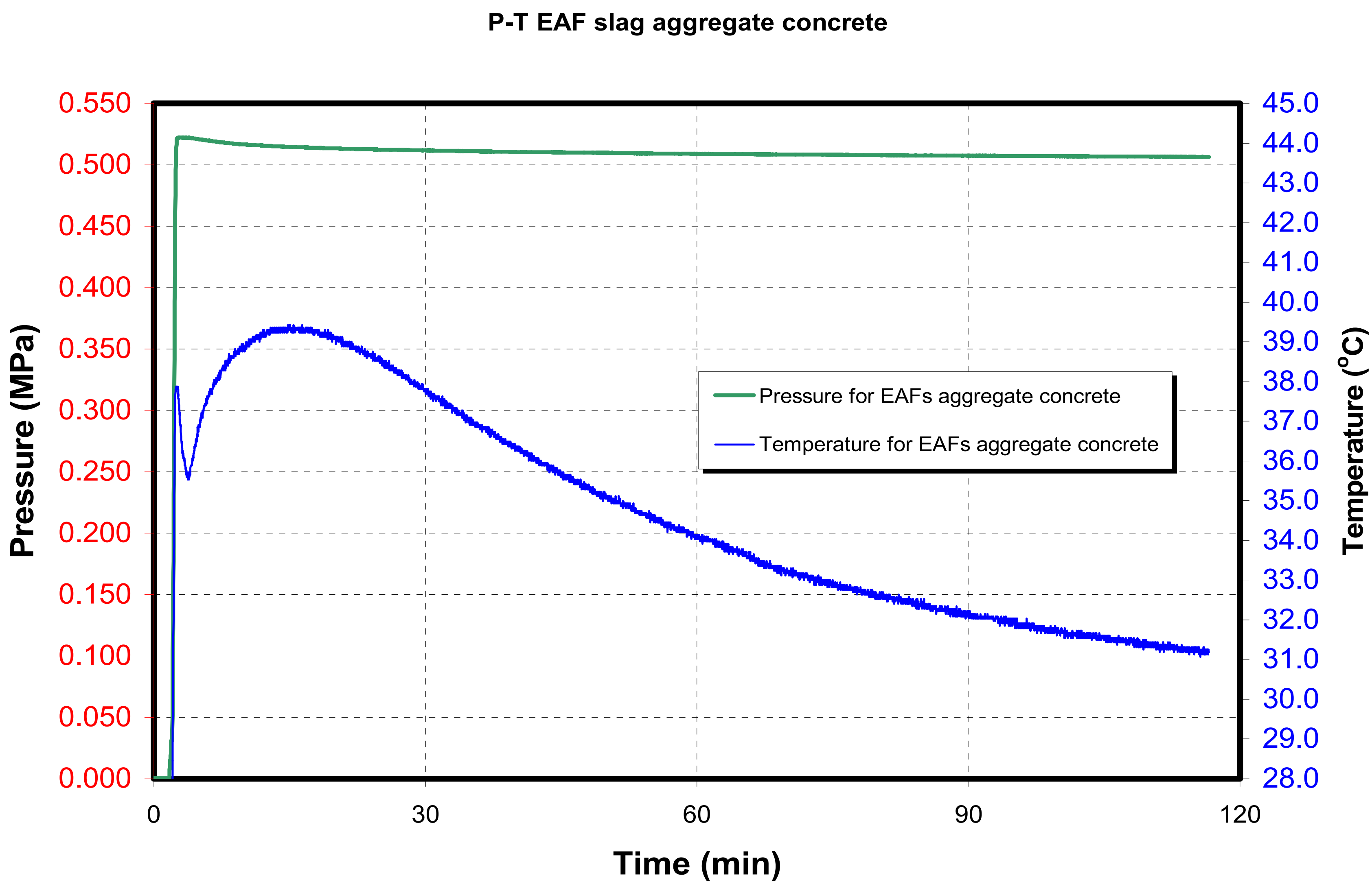
2-hr compressive strength:

slag aggregate concrete = 5.4 MPa

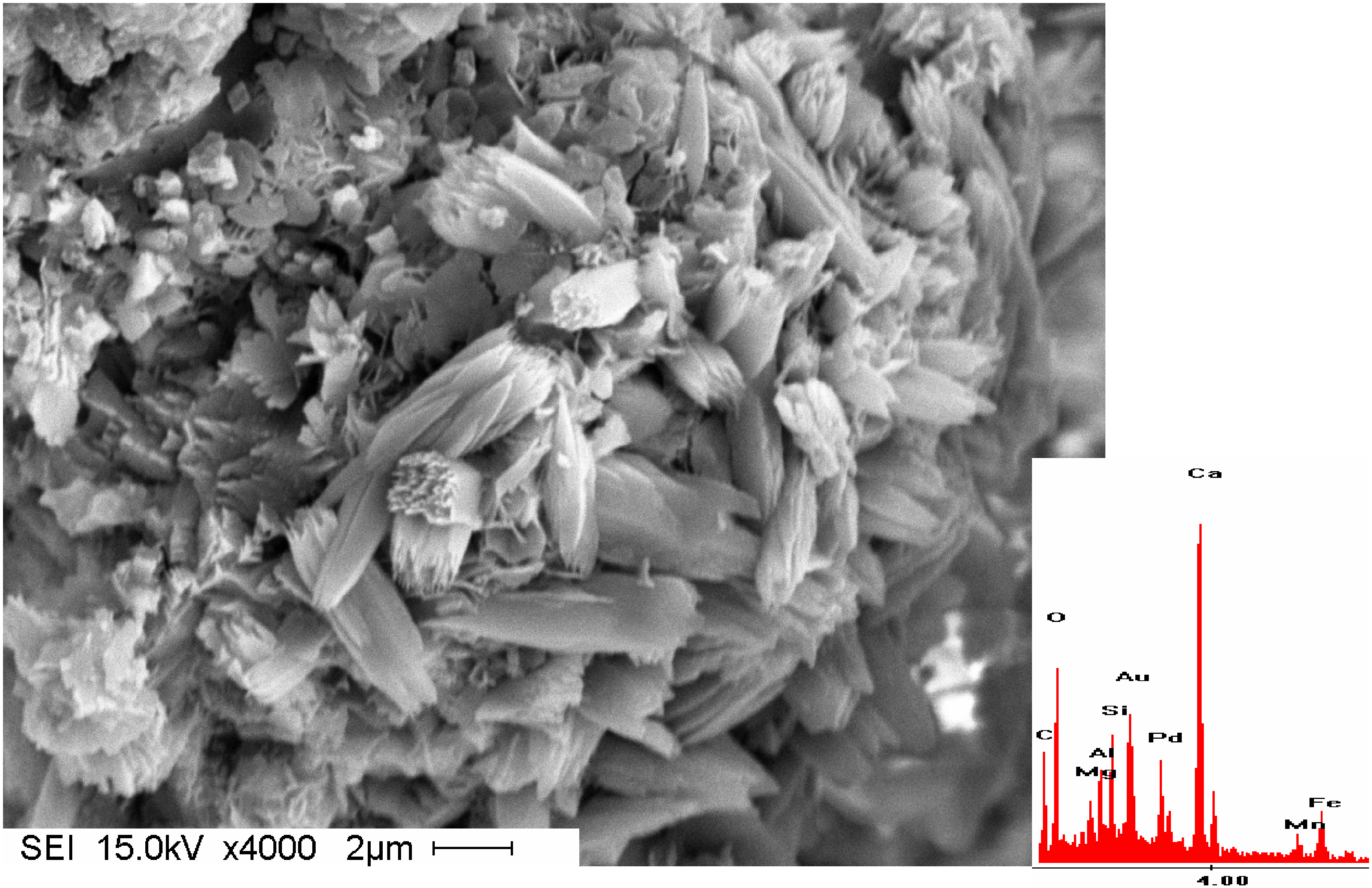
Limestone aggregate concrete = 10.3 MPa

Reference: carbonated limestone aggregate concrete: Mass gain = 10.6%

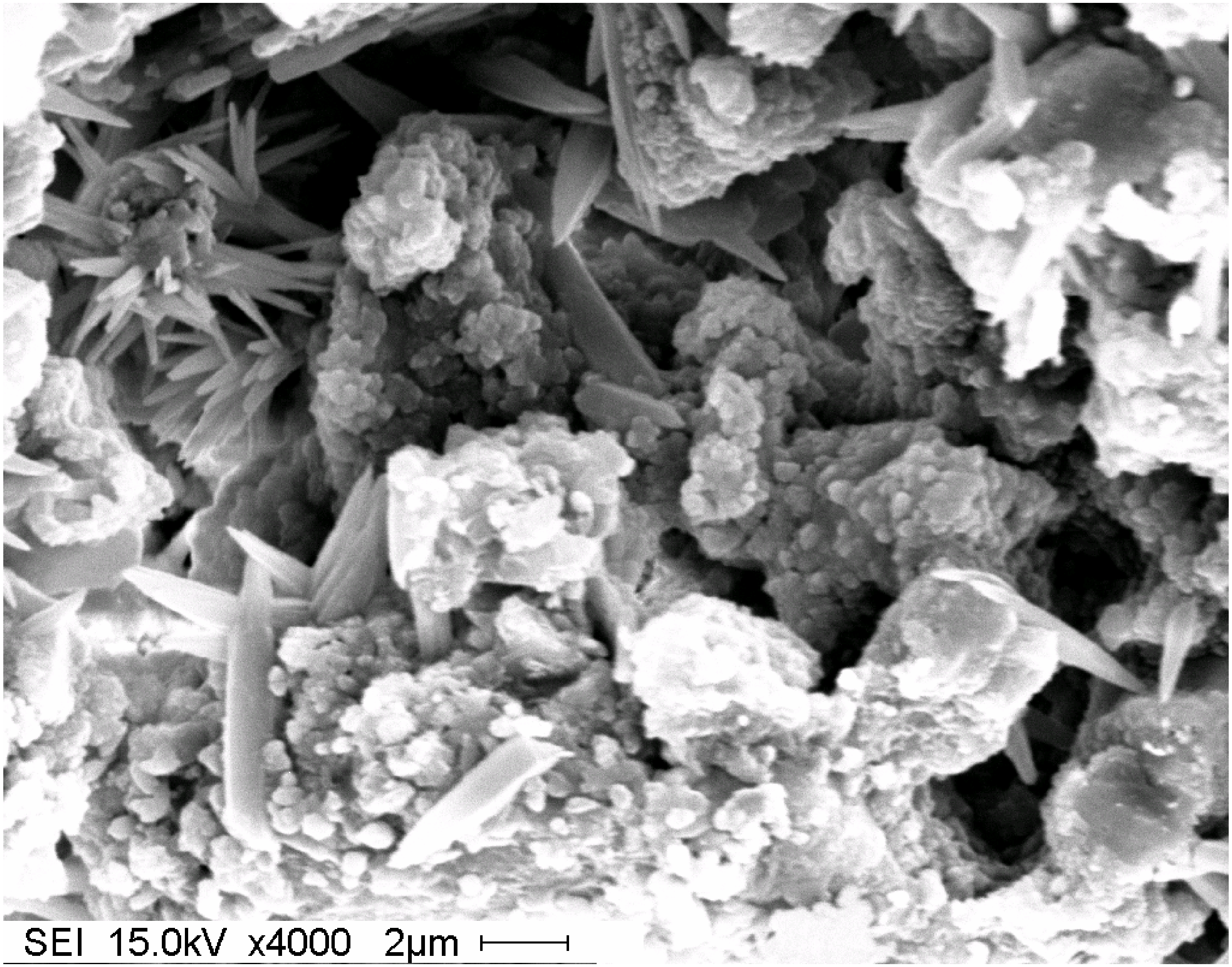
Carbonation of Slag Aggregate Concrete: Pressure and Temperature Curves



Slag Aggregates
in Carbonated Slag Concrete



Cement Paste in Carbonated Slag Concrete

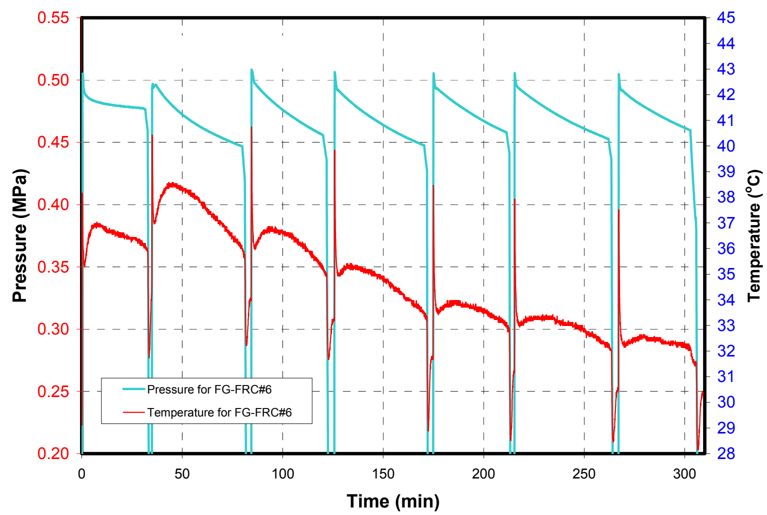


The Projected CO_2 Uptake by Masonry Blocks

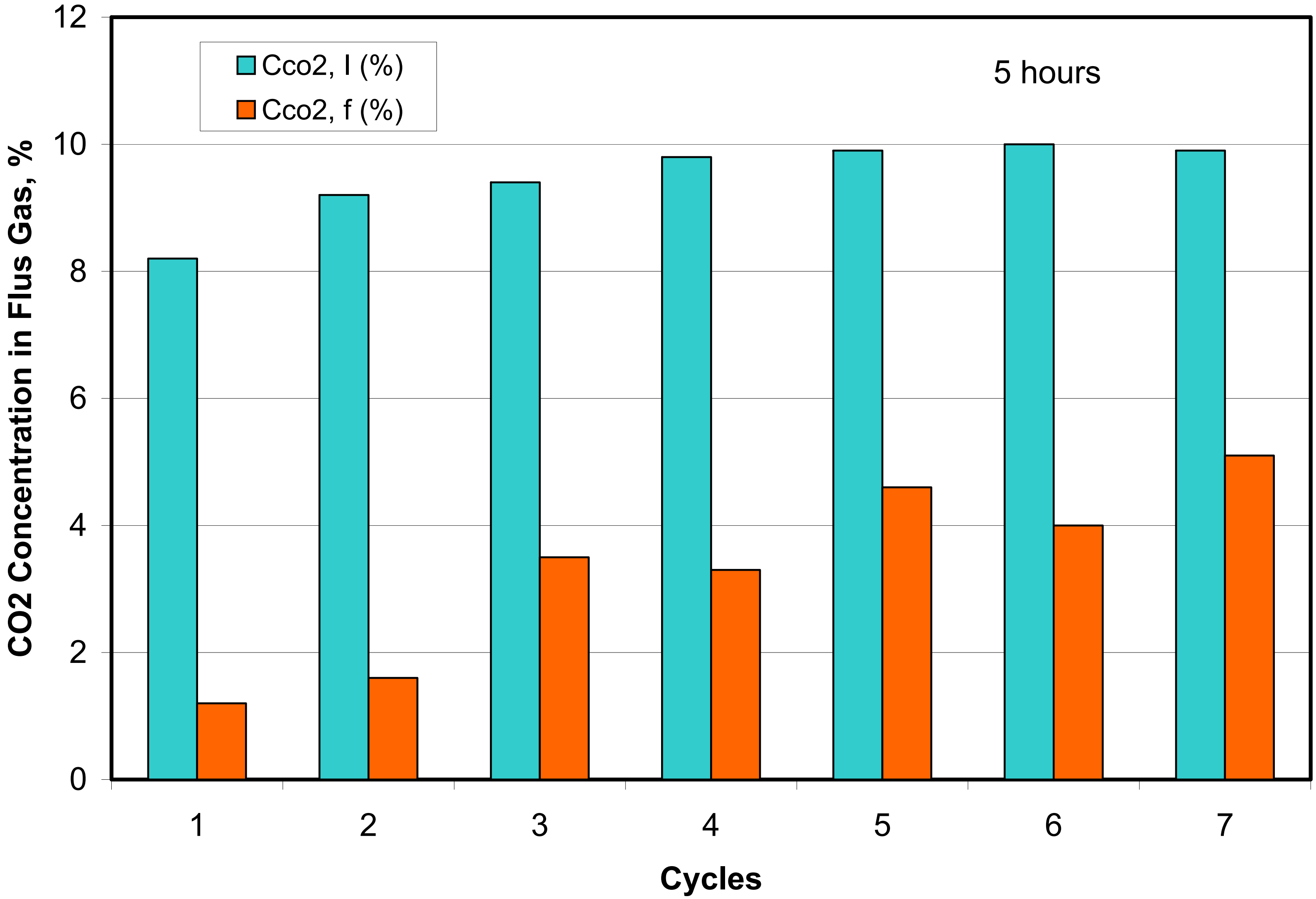
- *If Portland cement binder is capable of taking 20% of CO_2 and aggregates taking 10% of CO_2 by mass;*
- *For a standard concrete masonry block containing 10% cement, 12% water and 78% aggregates by mass;*
- *One production line can produce 51,000 units/day and consume CO_2 at 69 tons/day (14 tons by cement & 55 tons by aggregates).*
- *For a two-line production set next to a typical cement kiln with a capacity of 3000 tons/day, the reduction in CO_2 emission from cement production can reach 5.8% every work day.*

Carbonation with As-Captured Flue Gas

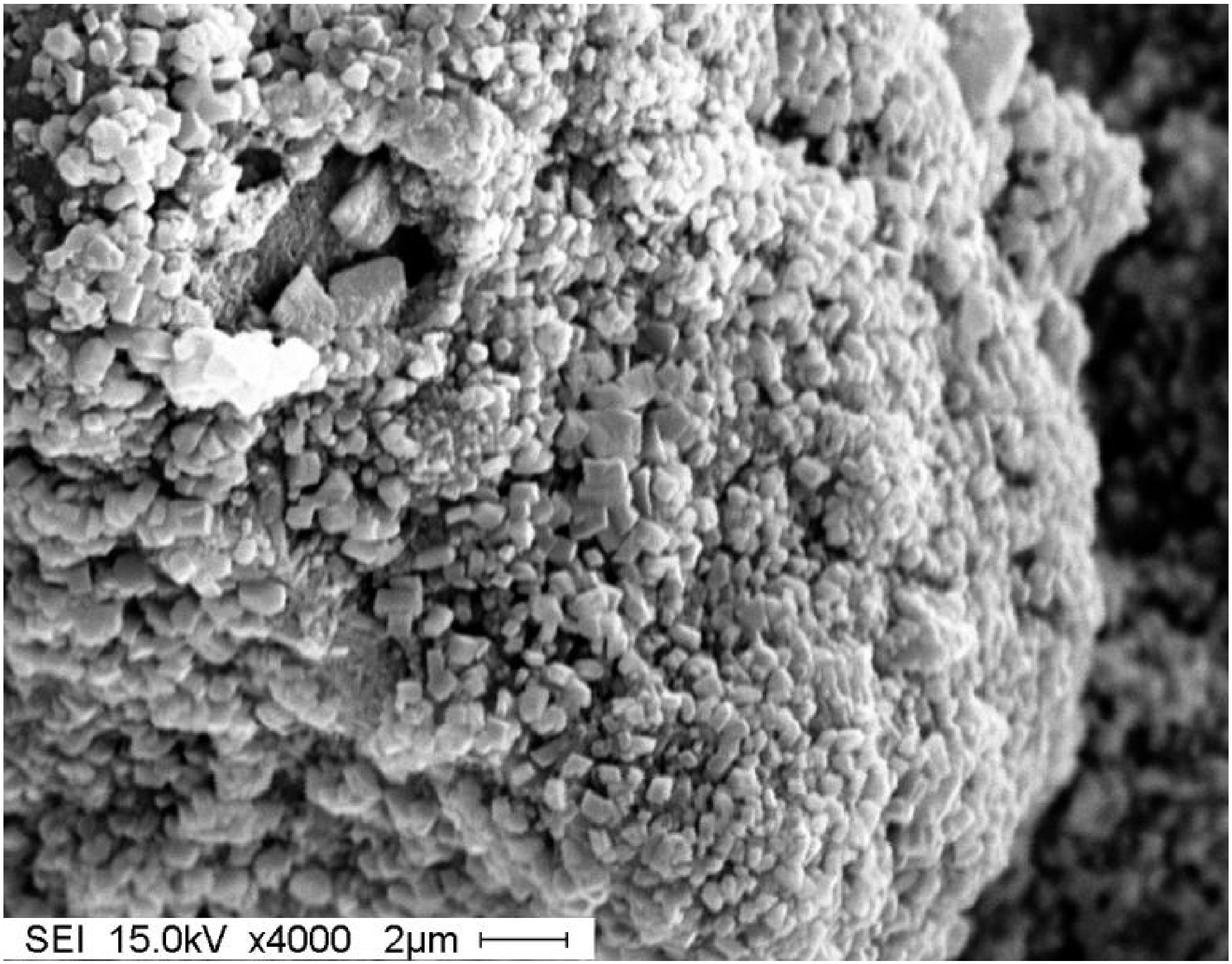
	Time	CO2,%	Period (min)	cycle	Strength (MPa)	Mass gain (%)
Cement	5 hr	11.3	35/ 45/ 35/ 45/ 35/ 45/ 35	7	7.4	6.8
Cement	2 hr	100	120	1	52.5	14.3
Limestone Concrete	5 hr	11.3	35/ 45/ 35/ 45/ 35/ 45/ 35	7	9.3	6.4
Limestone Concrete	2 hr	100	120	1	10.3	11.6



Carbonation of Limestone Concrete in Flue Gas



Microstructure of Carbonated Limestone Concrete in flue gas



Conclusions

- ***Reduction in CO2 emission by 5-6% can be achieved in a profit-oriented concrete production.***
- ***Further reduction is possible if the reaction efficiency can be improved.***
- ***The production can be set next to a cement plant or a thermal power station to uptake flue gas CO_2 while making building products.***
- ***The energy required for carbonation curing is less than that for steam curing or autoclave curing.***
- ***Both recovered CO_2 and as-capture flue gas can be used as curing agents.***
- ***The challenge: The incentive for business.***