Beneficial Use of CO_2 in Precast Concrete Production

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Developing the Technologies and Building the Infrastructure for CO_2 Storage
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Presentation outline

- Goals and objectives
- Benefits to the program
- Project overview
- Technical status
- Accomplishment to date
- Summary

Objective

To develop a carbonation process to replace steam curing in precast concrete production for energy reduction, and carbon storage and utilization.

Masonry blocks

Fiber-cement panels

Prefabricated buildings

Hollow-core slab

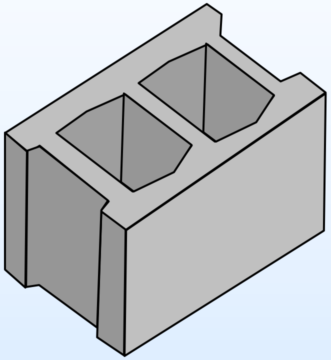
Concrete pipes

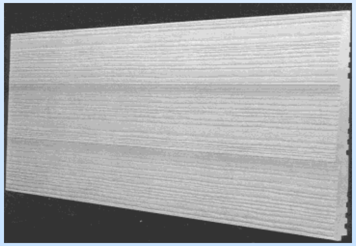
Goals

- CO_2 sequestration capacity by cement:

  $\%CO_2 = 0.78\ CaO + 1.1\ MgO + 1.4\ Na_2O + 0.9\ K_2O$

- CO_2 uptake target:
  - Each 8” concrete block shall take 0.75 lb CO_2 (25% based on dry cement)
  - Each 4’x8’ fiber-cement panel shall take 10.5 lb CO_2 (30% based on dry cement)
- Utilization process cost shall be less than \$10/tCO_2
- CO_2 capture cost shall be less than \$50/tCO_2





Benefit to the Program

- Develop technologies that will support industries' ability to capture and utilize CO_2 at the vicinity of the sources.
- Concrete blocks are produced at 4.3 billion units/year in US and fiber-cement panels are produced at 9.8 billion ft^2/year in US.
- If the uptake targets can be met, concrete block industry and fiber-cement industry alone can utilize 2.9 Mt CO_2 every year in the United States.

Project overview

- Produce commercial blocks and panels in lab
- Maximize carbonation by optimizing process parameters
- Develop CO_2 recovery process by self-concentration absorption method
- Evaluate performance of carbonated products
- Recover CO_2 from residual gas
- Perform experiment production
- Conduct cost analysis

Carbonation Mechanism

- Carbonation curing of fresh concrete (C_3S, C_2S):

$$3CaO\cdot SiO_2 + 3CO_2 + \mu H_2O \rightarrow 3CaO\cdot 2SiO_2 3H_2O + 3CaCO_3$$
$$2CaO\cdot SiO_2 + 2CO_2 + \mu H_2O \rightarrow 3CaO\cdot 2SiO_2 3H_2O + 2CaCO_3$$

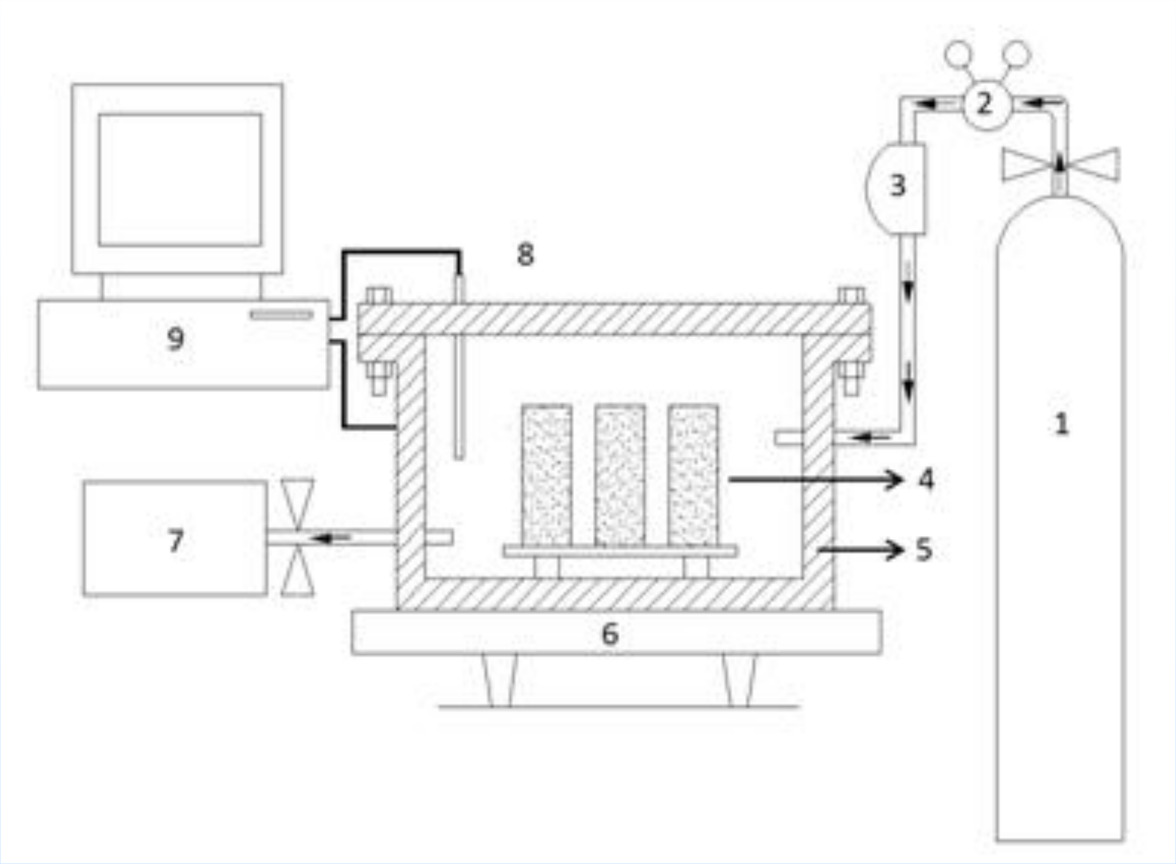
- Carbonation curing after initial hydration (CH, CSH, C_3S, C_2S):

$$Ca(OH)_2 + CO_2(aq) \rightarrow CaCO_3 + H_2O$$
$$3CaO\cdot 2SiO_2\cdot 3H_2O + 3CO_2 \rightarrow 3CaCO_3 + 2SiO_2\cdot 3H_2O$$
$$3CaO\cdot SiO_2 + 3CO_2 + \mu H_2O \rightarrow 3CaO\cdot 2SiO_2 3H_2O + 3CaCO_3$$
$$2CaO\cdot SiO_2 + 2CO_2 + \mu H_2O \rightarrow 3CaO\cdot 2SiO_2 3H_2O + 2CaCO_3$$

- CO_2 diffusion in precast products:

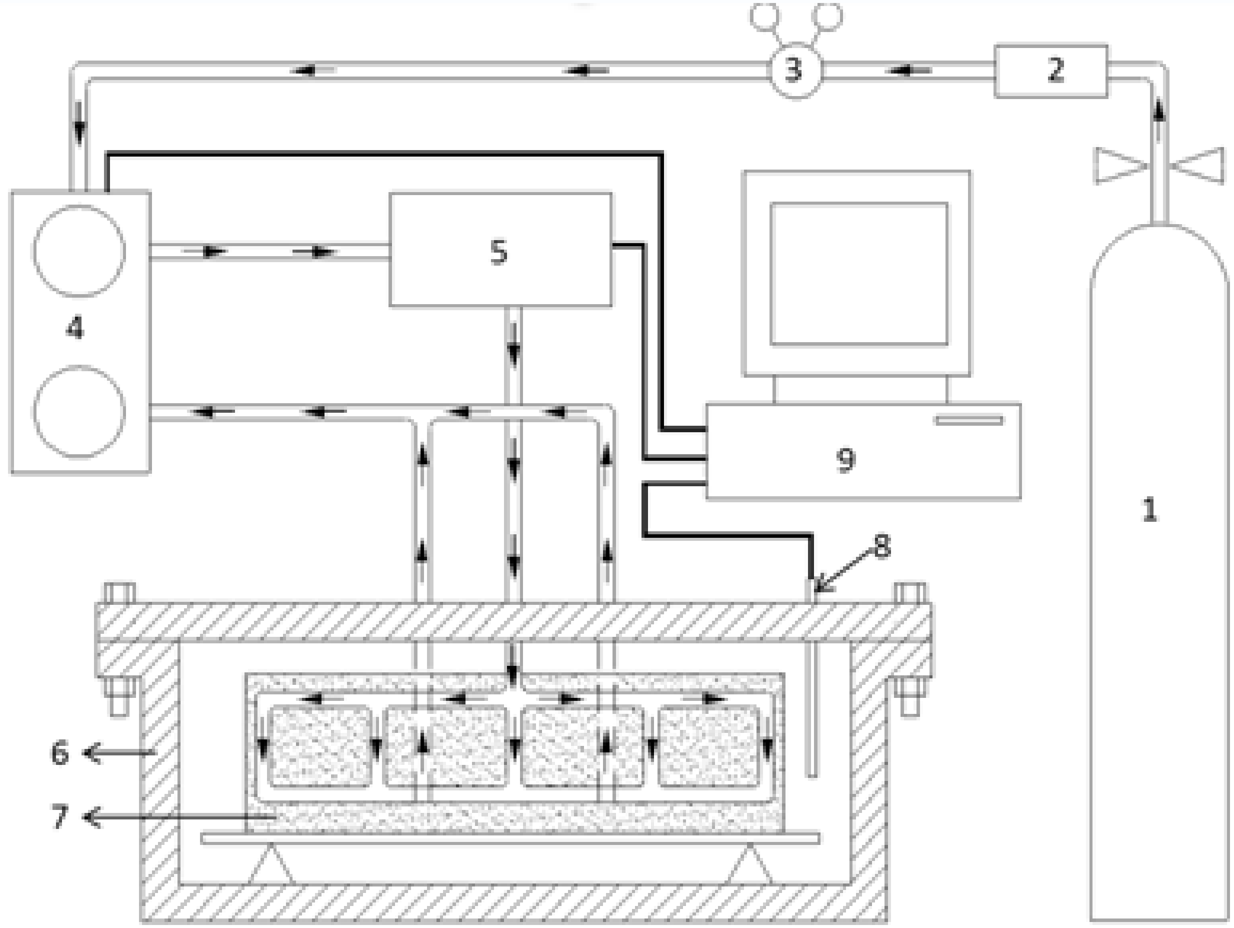
$$\frac{\partial CO_2}{\partial t} = D_{concrete}\frac{\partial^2 CO_2}{\partial x^2} \qquad D_{concrerte} = 1.64\times 10^{-6}\cdot \varepsilon_p^{1.8}(1 - DS)^{2.2}$$

Static carbonation setup



1) CO_2 tank,2) Regulator, 3)Pressure transducer, 4) Sample, 5) Carbonation chamber, 6) Digital balance, 7) Residual gas collection unit, 8) RH/ temperature meter, 9) Computer

Dynamic carbonation setup



Schematic of Dynamic System

1) CO_2 tank,2) Heater, 3)Regulator, 4)Circulation pump,5) Humidity controller, 6) Carbonation chamber, 7) Sample, 8) RH/temperature meter, 9) Computer

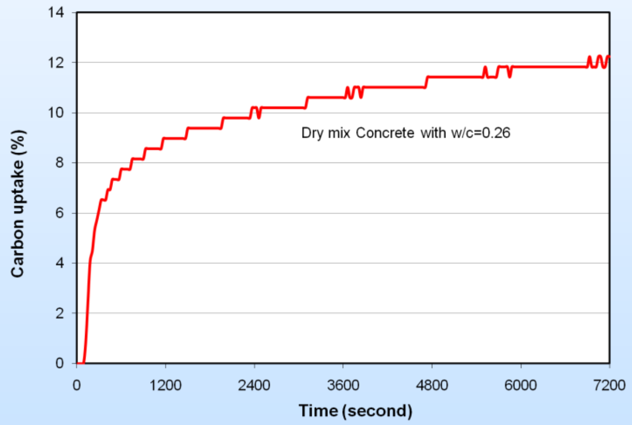
CO_2 uptake calculation

- Mass gain method (average)

$$\%CO2\ uptake = \frac{m_{CO2}}{m_{cement}} = \frac{(Mass)_{aft,CO2} - (Mass)_{bef,CO2} + (Mass)_{lost\ water}}{m_{cement}}$$

- Mass curve method (average)

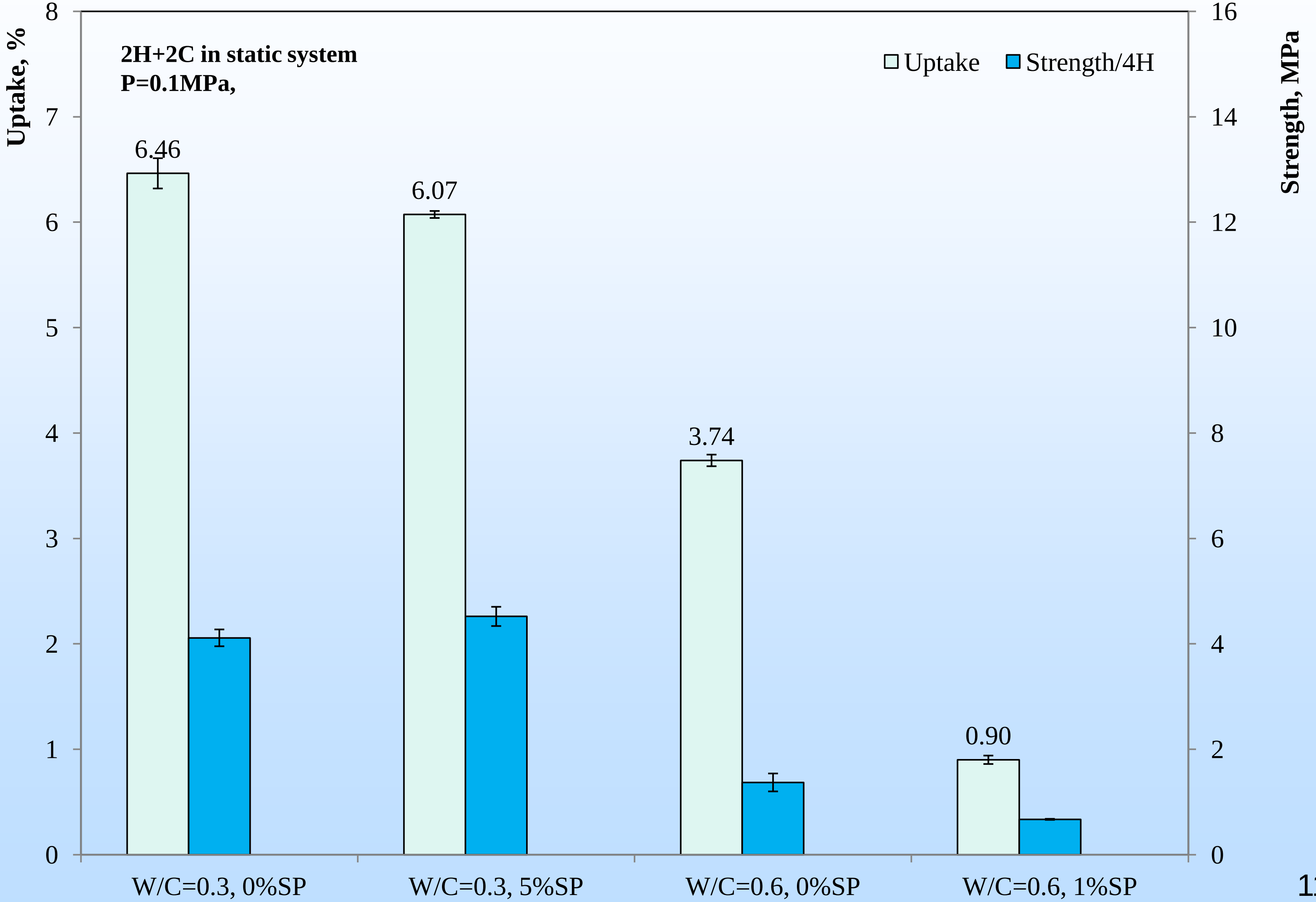
$$\%CO2\ uptake = \frac{(m_{CO2})_{masscurve}}{m_{cement}}$$



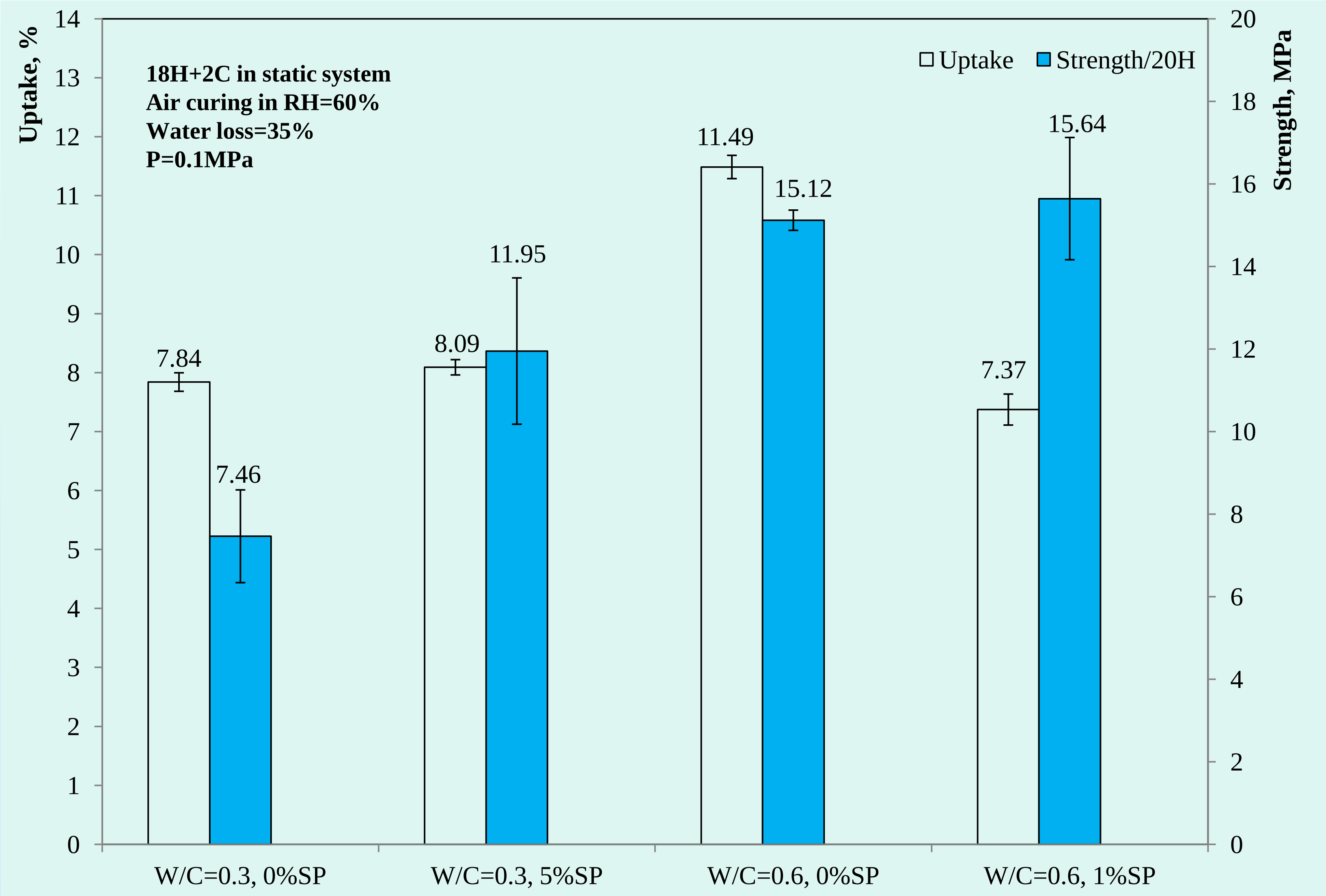
- Furnace thermal analysis (30-70g mass)

$$CO_2\ Content(\%) = \frac{M_{550} - M_{1000}}{M_{Cement}}$$

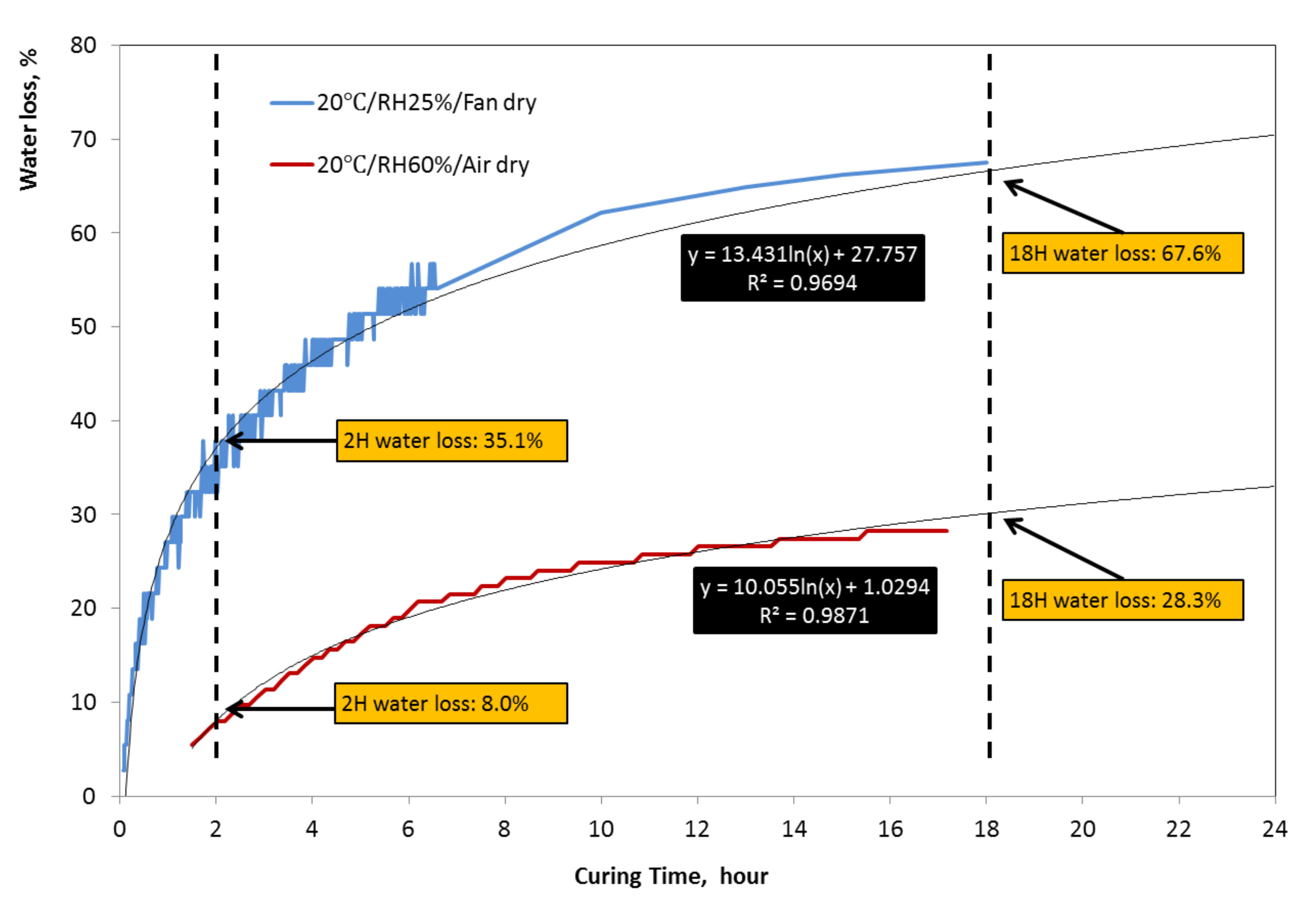
Fresh concrete carbonation



Carbonation after 18 hr hydration

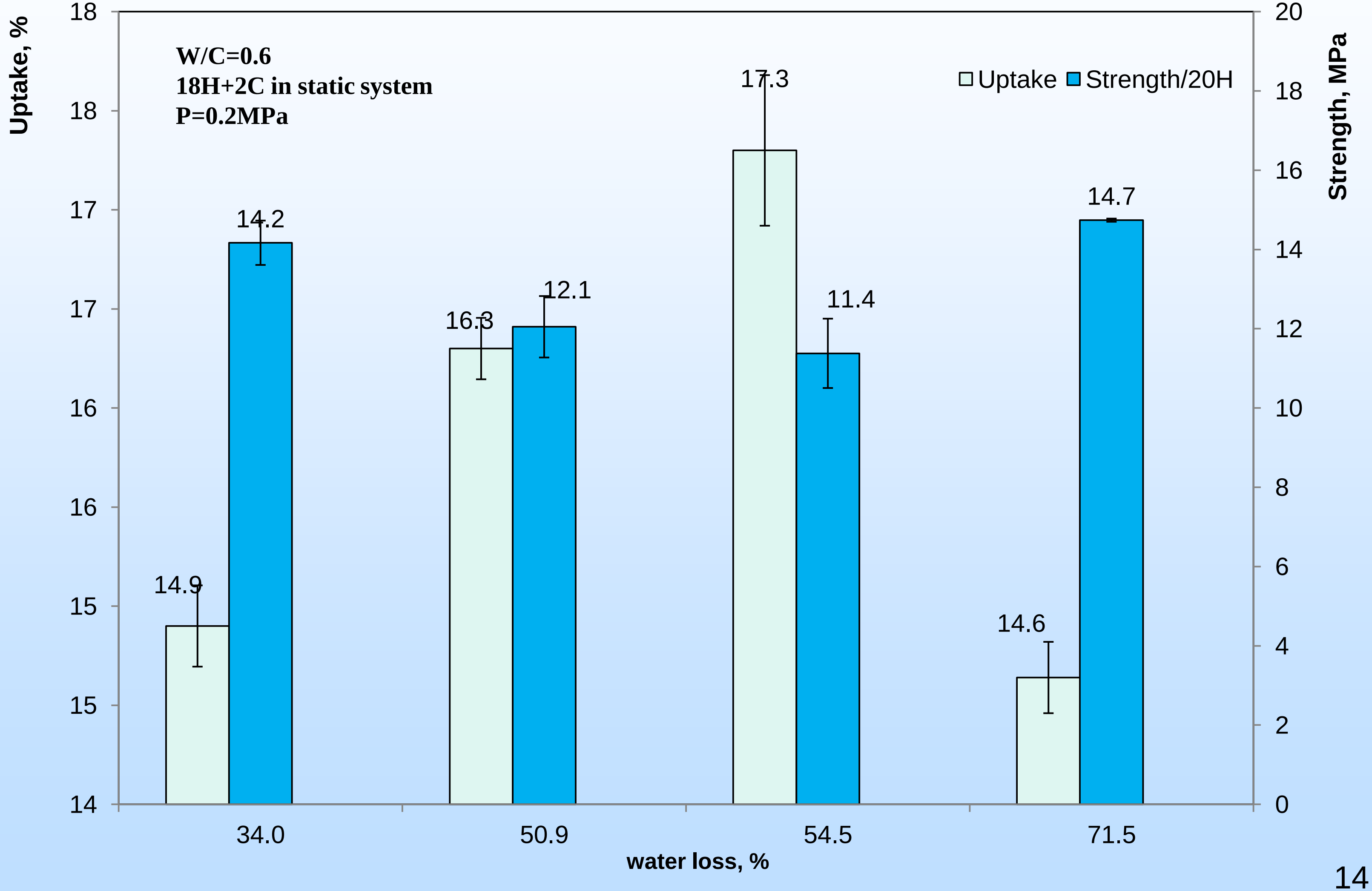


Water loss in initial open air hydration

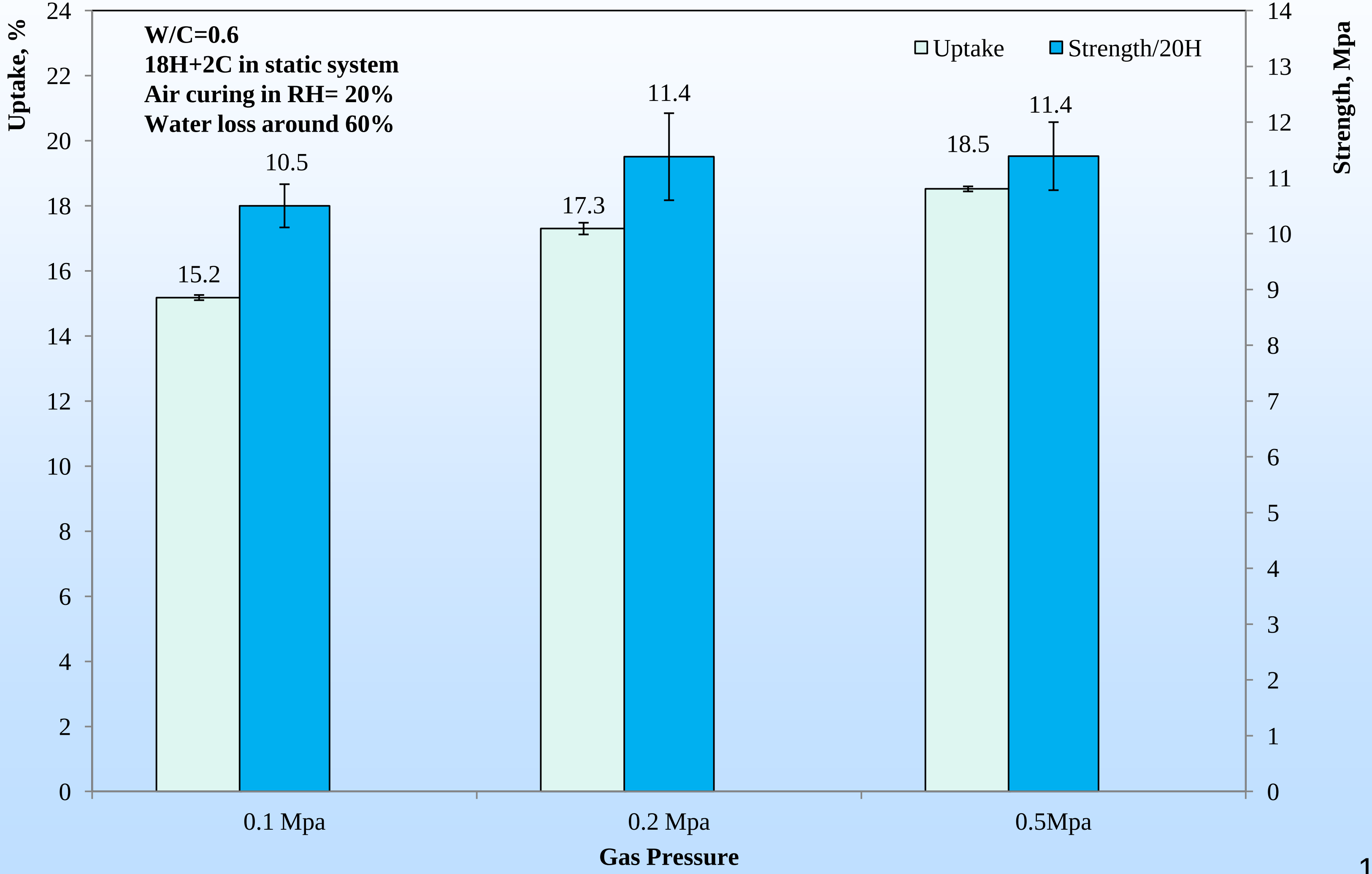


Water loss due to initial hydration at different RH condition (W/C=0.6)

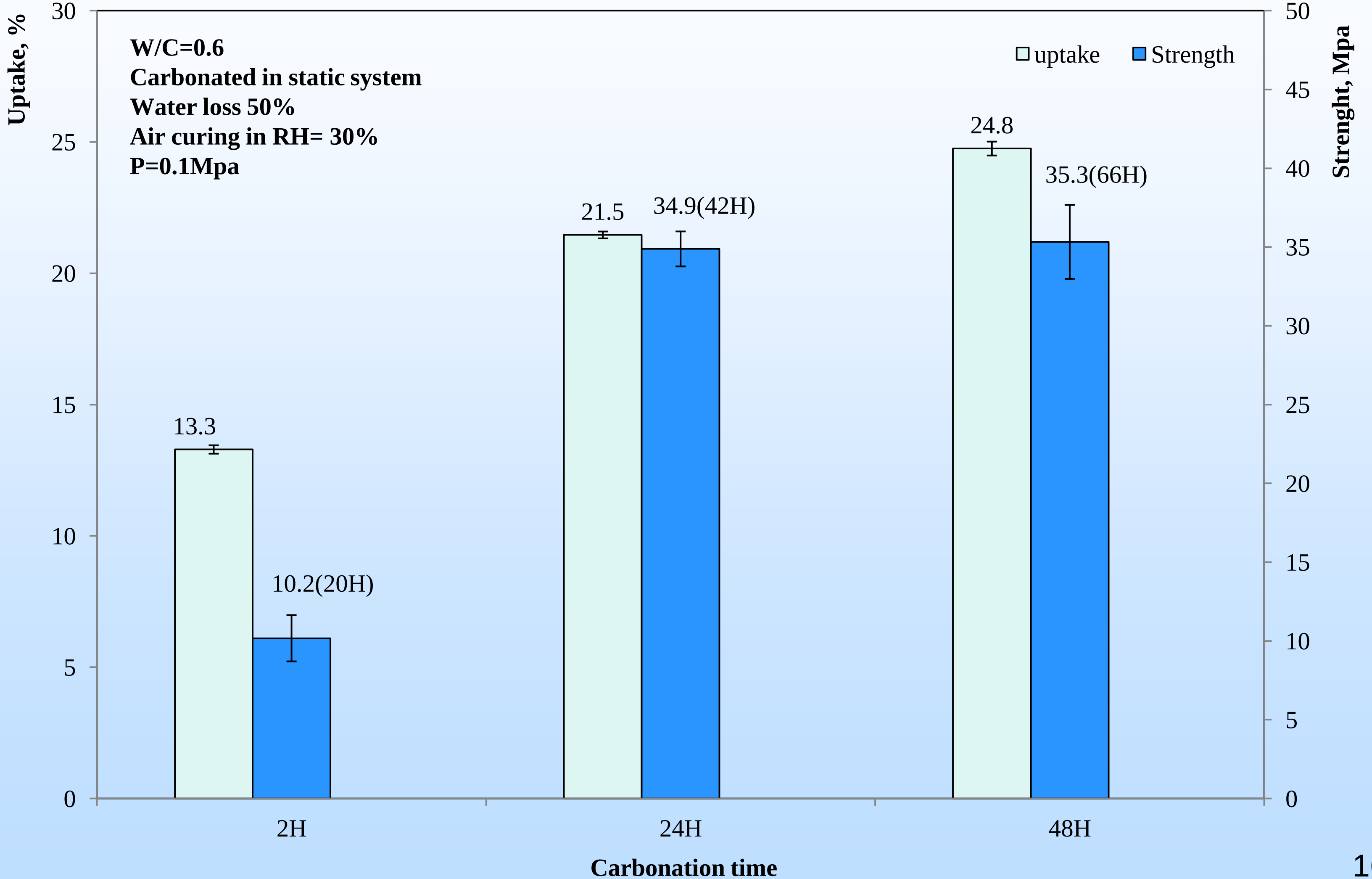
Effect of water removal on carbon uptake



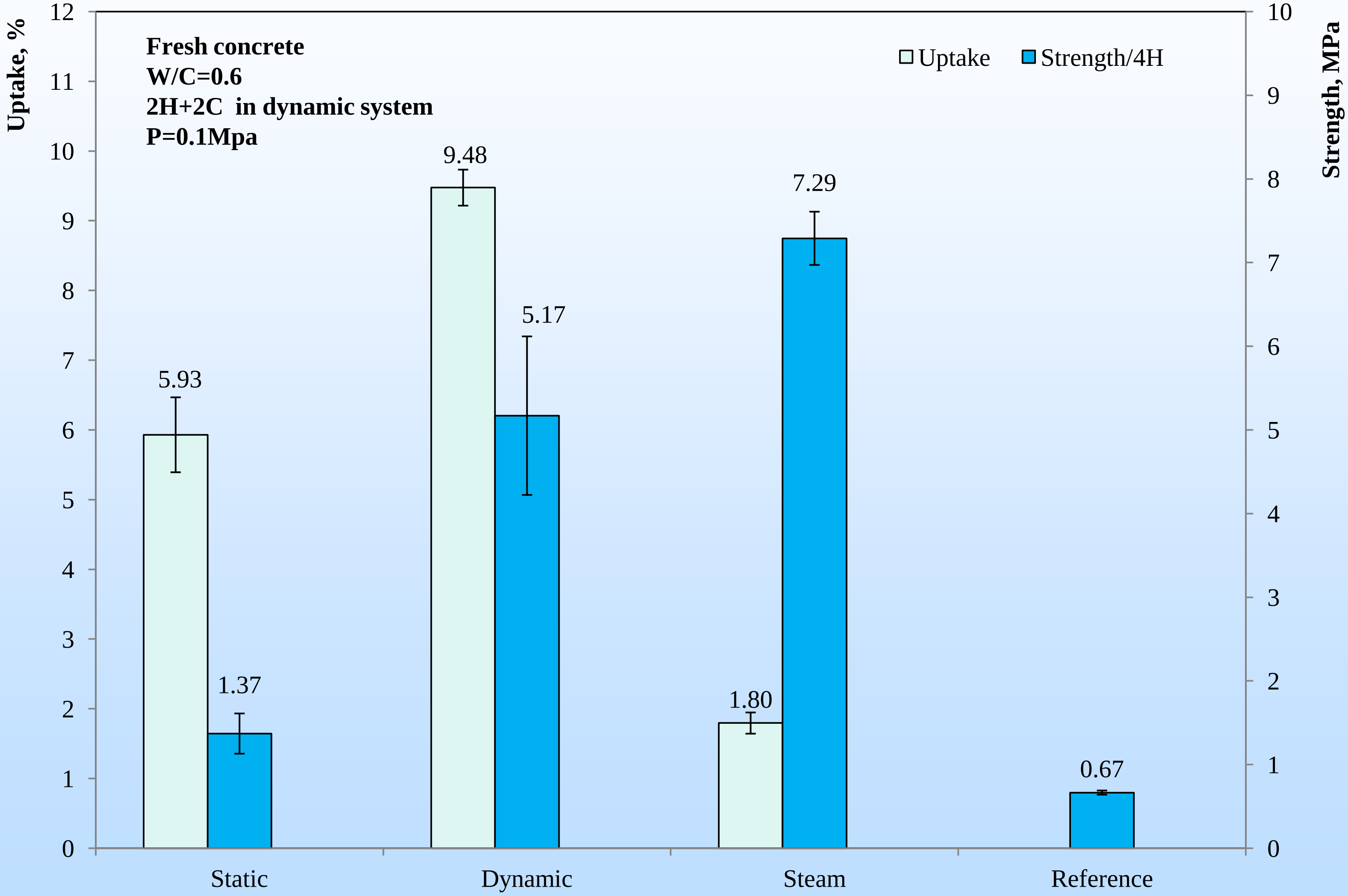
Effect of gas pressure



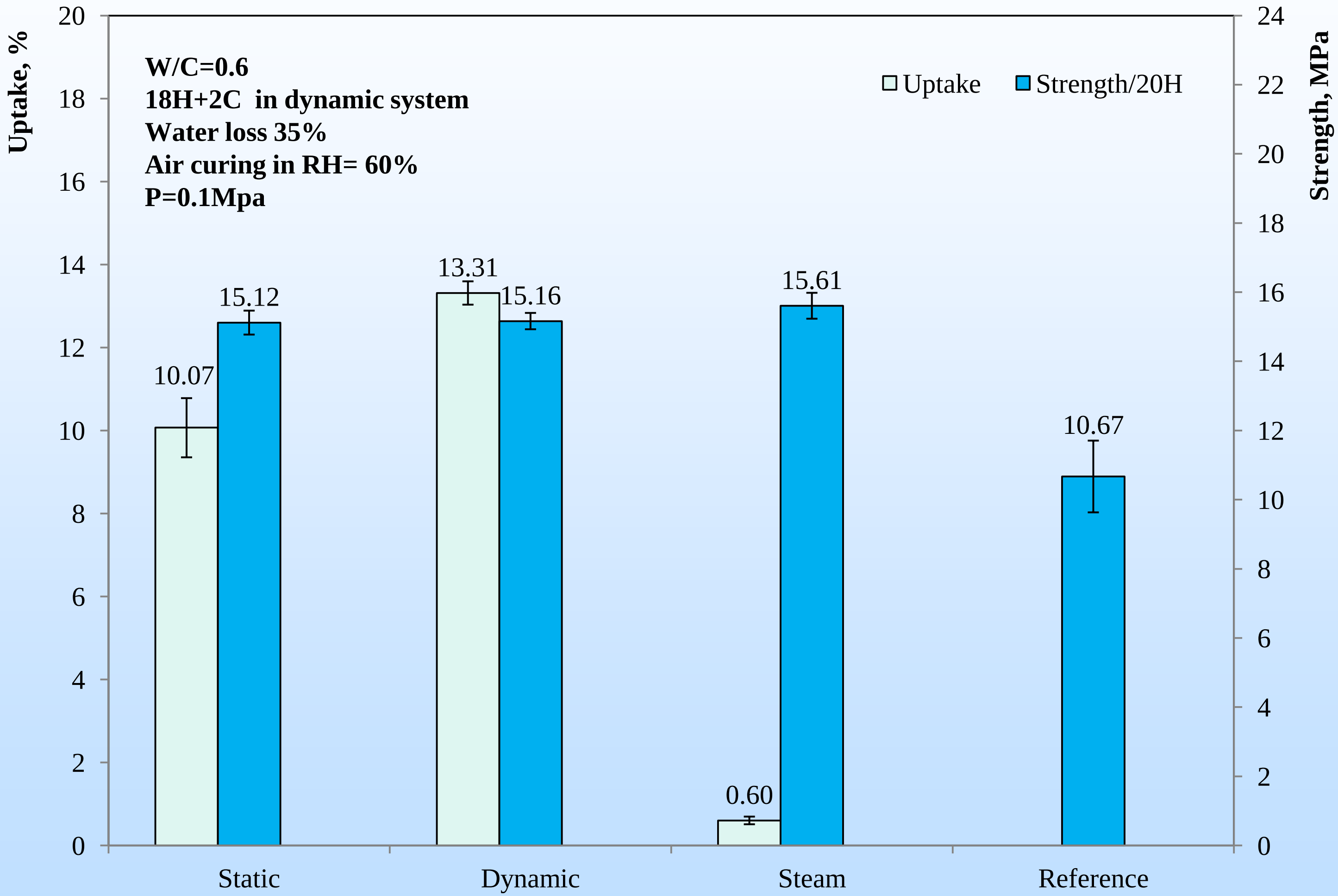
Effect of carbonation duration



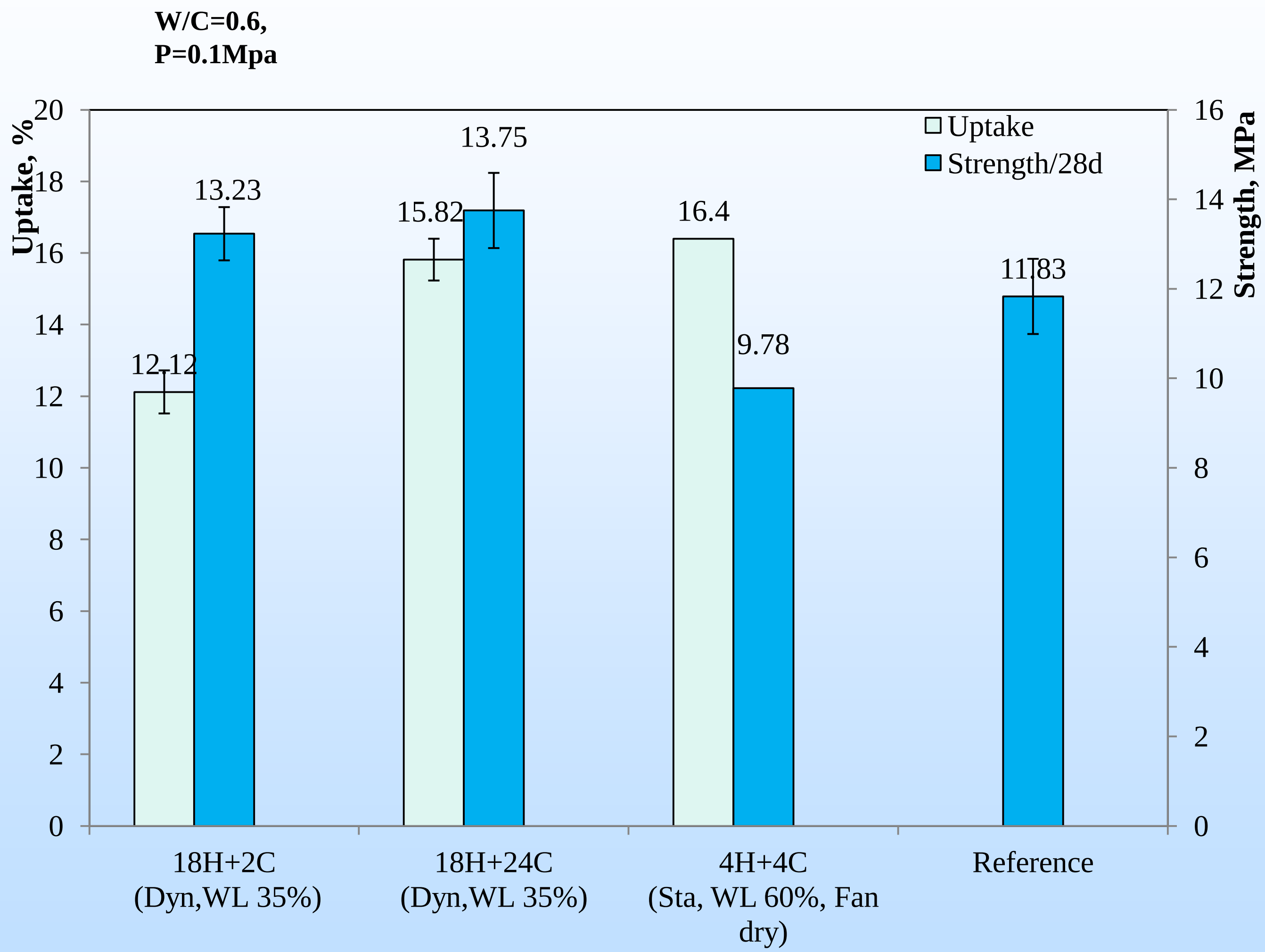
Dynamic for fresh carbonation



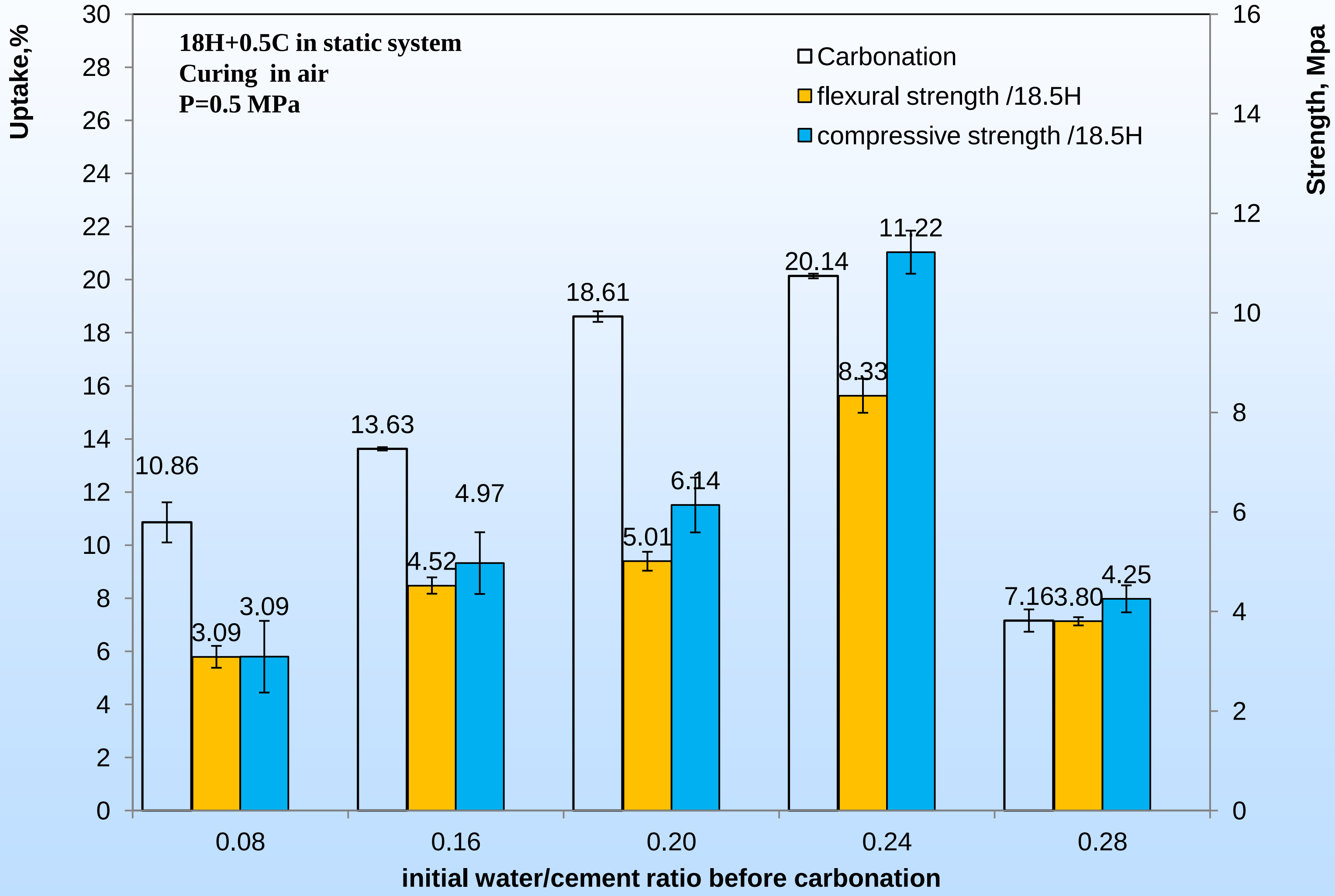
Dynamic for hardened carbonation



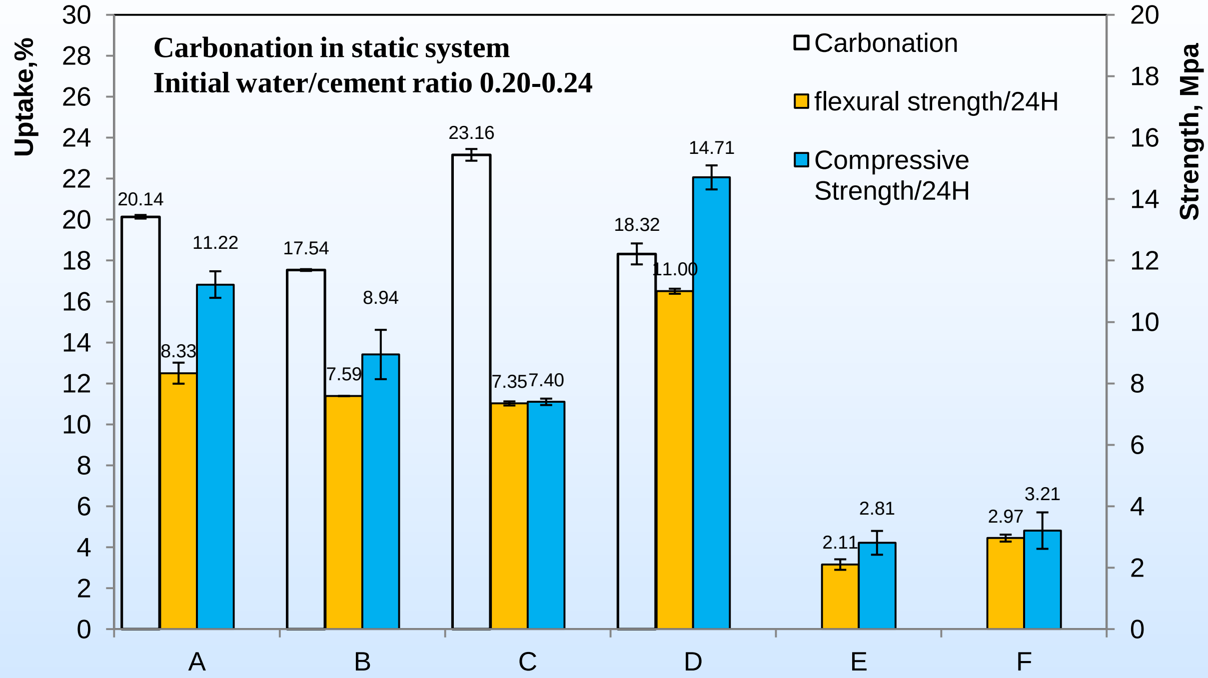
Full size concrete blocks



Carbonation of fiber-cement panels



Effect of pressure and duration

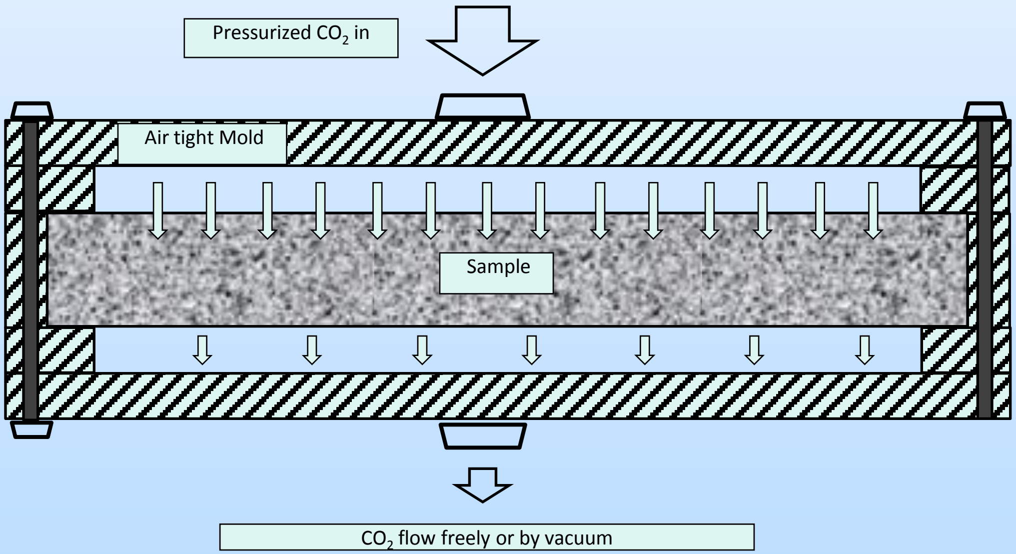


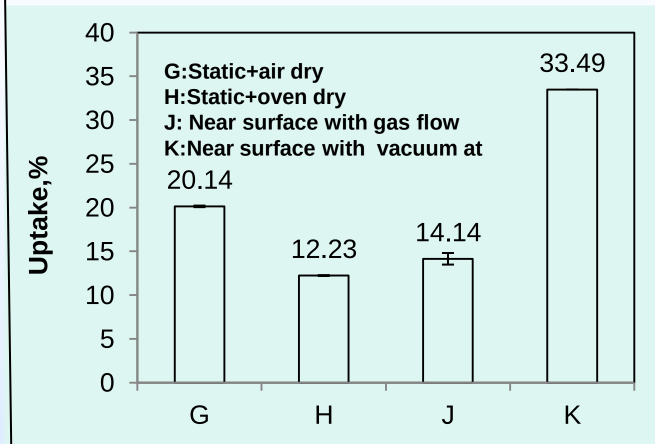
NO.	Process parameters	Molding pressure	Air curing time	Carbonation time	Carbonation pressure
A	Reference	0.7 Mpa	18H	0.5 H	5 bar
B	Gas pressure	0.7 Mpa	18H	0.5 H	2 bar
C	Time	0.7 Mpa	18H	4 H	5 bar
D	Molding pressure	7 Mpa	18H	4H	5 bar
E	Air curing(Hydration only reference)				
F	Sealed in bag(Hydration only reference)				

Near surface dynamic carbonation

Table 2 influencing factor of carbonation

No.	Molding pressure	Air curing time	Oven curing time	Carbonation time	Carbonation pressure	Carbonation method
G	0.7 Mpa	18H	/	0.5 H	5 bar	static
H	0.7 Mpa	/	0.5H	0.5 H	5 bar	static
J	0.7 Mpa	18H	/	0.5 H	2bar	Near surface with gas flow
K	0.7Mpa	18H	/	0.5 H	2 bar	Near surface with vacuum at bottom



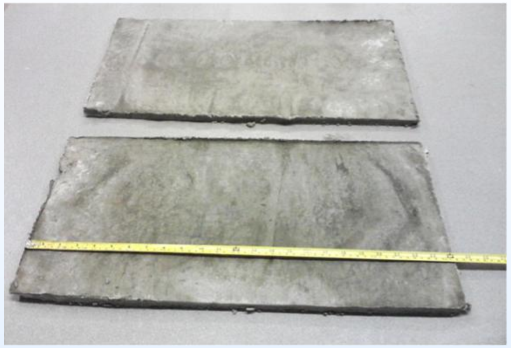


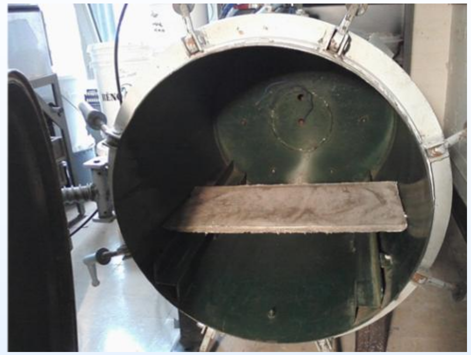
Observation:

1) In static system, air dry method is superior to oven dry.

2) Near surface carbonation method with vacuum at bottom has the potential to improve the carbonation reaction.

Large fiber cement panel (1'x2') tests





1'×2' panel sample and test chamber

Table 3: Results of 1'×2' panels (static carbonation)

NO.	Pressure	Carb. Time	Air curing time*	Oven dry time**	CO_2 uptake	28d Strength, Mpa***	
						Flexural	Compressive
Slab 1		1 H	18 H		16.06%	6.03±1.07	10.05±2.97
Slab 2	2 bar	1 H	18 H	2H	16.52%	5.91±1.17	7.86±2.21
Slab 3		12 H	18 H		20.46%	6.57±0.52	8.97±3.00

Observation:

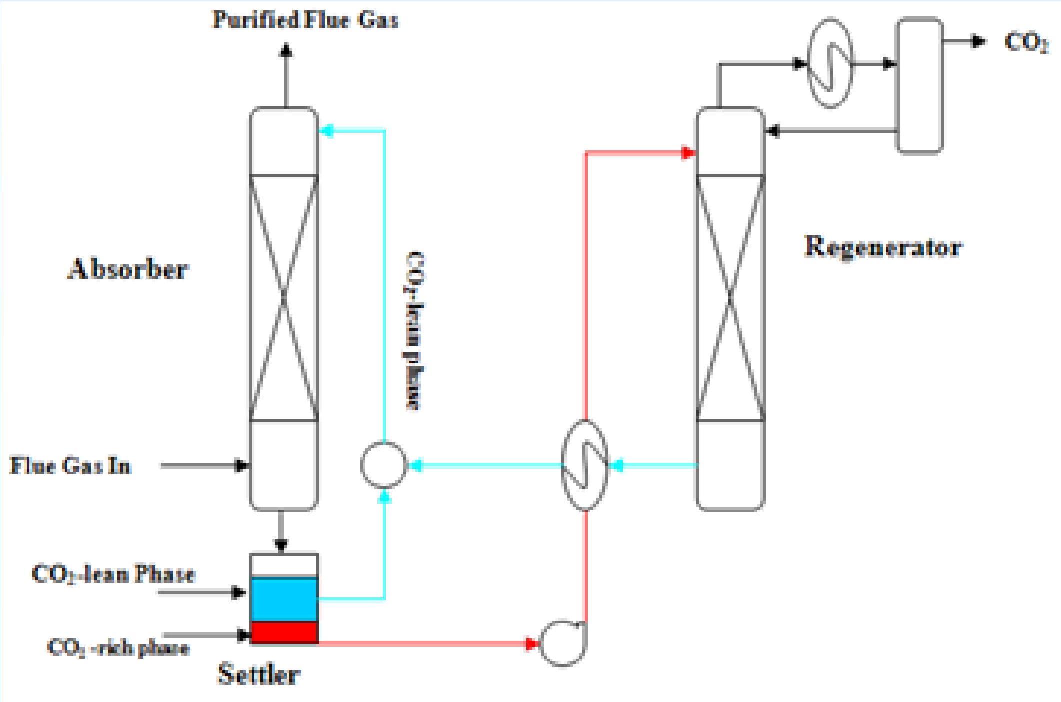
1) The process is possible to be scaled up.
2) Carbon uptake reaches to 16-20%.
3) Flexural and compressive strengths are comparable to commercial products.

Flue gas capture and CO_2 recovery

- Flue gas was collected from cement plant
- The flue gas contains 13% CO_2 at 2000 psi.

CO_2 recovery by Self-Concentration Absorption Method

- Developed and patented by 3H Company.
- Increased height of absorber enables capture efficiency to 90% and recovered CO_2 purity to 99%.



Accomplishments to Date

- Static and dynamic carbonation systems are developed for concrete block and fiber-cement panel production.
- Carbonation chambers are designed and fabricated for laboratory investigation and can be scaled up for commercial production.
- Carbon uptake of 16-25% for concrete blocks and 16-30% for fiber-cement panels are reached at laboratory optimized conditions.
- CO_2 recovery system using self-concentrating absorption method is modified to reach a capture efficiency of 90%.

Project Summary

- Carbonation of hydration products is more efficient than carbonation of calcium silicates.
- Longer reaction time and higher gas pressure lead to higher reactivity.
- Water content in precast products plays critical role in promoting the degree of carbonation.
- The cost limit by \$10/tCO_2 is challenging.
- Carbon uptake and cost limit are conflicting.

Future work

- The system will be further optimized to reduce energy use in every step.
- Cost analysis will be performed together with technology development.
- Self-concentration absorption method will be used to recover CO_2 from residual gas after process.
- Experiment production will be carried out to link CO_2 capture to CO_2 utilization.
- Large scale network operation will be established to implement CO_2 capture, compression, transport and utilization.

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

- Describe project team, organization, and participants.
  - McGill University (Materials development, carbonation systems, performance assessment, cost analysis.)
  - 3H Company (Self-concentrating absorption system, cost analysis, carbonation systems.)

Gantt Chart

Table 1, Organizational chart (corrected in Q7 with no-cost extension)

Quarter	Date	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7
Q1	10/1-12/30, 2010	Mc+3H, 1.0						
Q2	1/1-3/30, 2011		Mc+3H, 2.1, 2.2	Mc+3H, 3.1,3.2				
Q3	4/1-6/30, 2011		Mc, 2.2	Mc, 3.1,3.2,3.3,3.4			Mc+3H, 6.1	
Q4	7/1-9/30, 2011	Mc+3H, 1.0, agreement	Mc, 2.2	Mc, 3.2,3.3,3.4	Mc, 4.1, 4.3			
Q5	10/1-12/30, 2011	Mc+3H, 1.0, agreement		Mc,3.4	Mc 4.1,4.3		1.0	
Q6	1/1-3/30, 2012		Mc, 2.2	Mc, 3.3, 3.4	Mc, 4.3		3H, 6.2	
Q7	4/1-6/30, 2012			Mc, 3.3	Mc, 4.3		3H, 6.2	Mc 7.1
Q8	7/1-9/30, 2012		Mc, 2.2		Mc, 4.3		3H, 6.2	Mc 7.1
Q9	10/1-12/30, 2012					Mc, 4.2, 5.1, 5.2	3H, 6.3, Mc, 6.1	
Q10	1/1-3/30, 2013				Mc, 4.2		3H, 6.4	
Q11	4/1-6/30, 2013						Mc+3H, 6.4, 6.5	
Q12	7/1-9/30, 2013							Mc+3H, 7.1,7.2

Q5 to Q8 are granted for no-cost extension in Budget Period 1.

The following tasks are accomplished in Budget Period 1: *Task 1.0 – Project Management and Planning; Task 2.1 Fabricate Block CO_2clave; Task 2.2 Fabricate Panel CO_2clave; Task 3.1 Prepare Cement Mixes; Task 3.2 Prepare Blocks; Task 3.3 Prepare Panels; Task 3.4 Use Seeding Technology; Task 4.1 Conduct Single Block Tests; Task 4.3 Conduct Panel Tests; Task 6.1 Capture of Flue Gas from Power Plant or Cement Plant for CO_2 Recovery; Task 6.2 Production of CO_2 Using Self-Concentrating Absorption Technology. Task 7.1 Determine Utilization Cost.*

Bibliography

Not available yet.