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Sciences Appliquées

Efficiency of processes for the carbonation of municipal solid wastes incinerated bottom ash

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STATISTICS OVERVIEW

- Consumption
  - Sand and naturel aggregates : 3 billions tonnes *[UEPG 2024]*
- Production
  - Municipal solid waste: 230 millions tonnes *[Eurostat 2022]*

    → 18 millions tonnes MSWI BA

Piles of sand/aggregates

Piles of MSW

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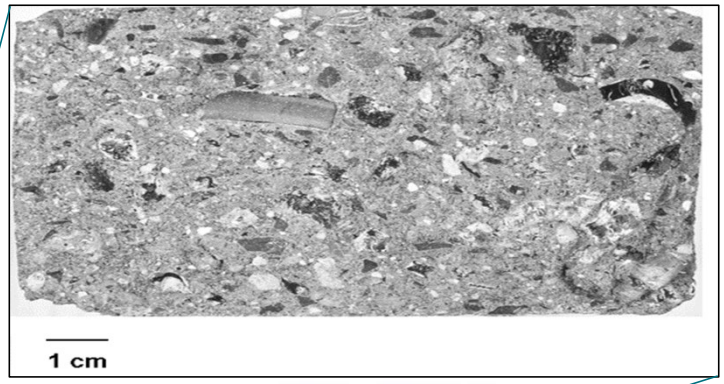
MSWI BA POTENTIAL USE

- Partial or total substitution of sand and aggregates for :
  - Road foundations
  - Concrete pavements*
  - Concrete blocks



Road foundations

*Concrete pavements**

Concrete blocks

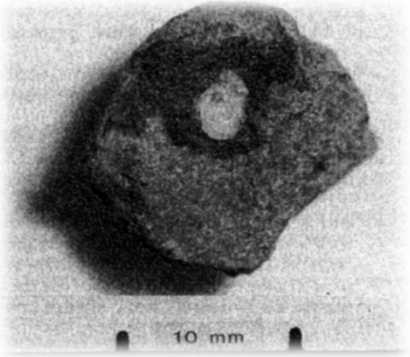
* *Courard, L., Degeimbre, R., Darimont, A., Laval, A.-L., Dupont, L., Bertrand, L. (2002). "Utilisation des mâchefers d'incinérateur d'ordures ménagères dans la fabrication des pavés en béton", Mater. Struct, 35: 365-372.*

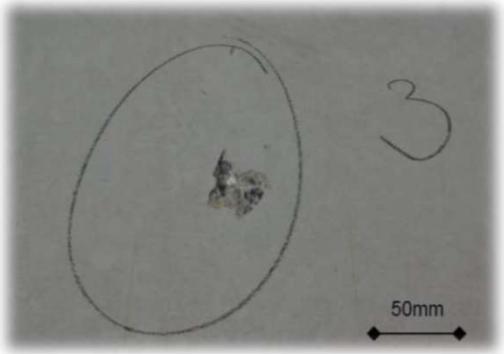
MSWI BA RISKS

- Lixiviation
- Lime nodule swelling

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15.5cal$$

Molecule	CaO	H_2O	$Ca(OH)_2$
Molecular weight	56	18	74
Real density (g/cm^3)	3.3	1	2.24
Molecular volume (cm^3/mole)	16.8		33.1





MSWI BA TREATMENT: Natural AGING

- Treatment (maturation) period: 18 weeks up to 6 months
- Chemical reaction occurring during the aging treatment*:
  1. $CaO + H_2O \rightarrow Ca(OH)_2$
  2. $Ca^{2+} + 2\,OH^- + CO_2 \rightarrow CaCO_3 + H_2O$
  3. $Ettringite + 12\,H^+ \rightarrow 2\,Al^{3+} + 3\,SO_4^{2-} + 6\,Ca^{2+} + 38\,H_2O$
  4. $Al + 4\,OH^- + 4\,H_2O \rightarrow 4\,AlO_2^- + 6\,H_2$
  5. $AlO_2^- + 2\,H_2O \rightarrow Al(OH)_3 + OH^-$
- Limitations of this treatment:
  - Long treatment period
  - Inefficient in some cases
  - Dependent on weather conditions

* *Descamps, P., Janssens, B., Dupont, L., Lefevre, L. (2011). "Memorandum technique pour l'utilisation des mâchefers de l'unité de valorisation par incinération de Thumaide".*

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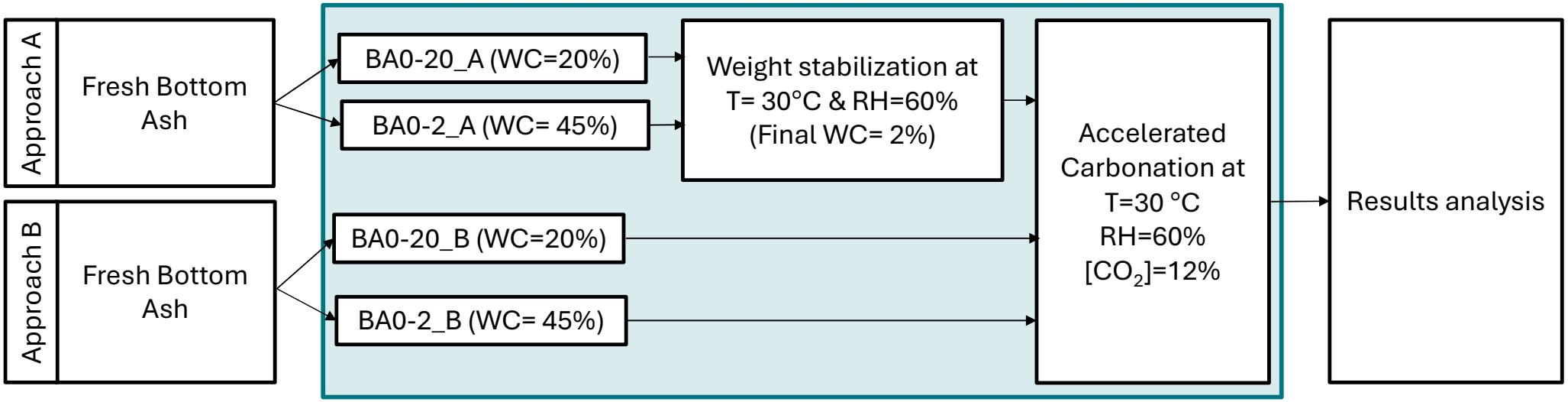
MSWI BA TREATMENT: ACCELERATED CARBONATION

- Accelerated treatment: static carbonation
- Chemical reaction occurring during the accelerated carbonation:
  1. $CO_2 + H_2O \leftrightarrow H_2CO_3$
  2. $H_2CO_3 + OH^- \leftrightarrow H_2CO_3^{2-} + H_2O$
  3. $H_2CO_3^{2-} + OH^- \leftrightarrow CO_3^{2-} + H_2O$
  4. $Ca(OH)_2 \leftrightarrow Ca^{2+} + 2\,OH^-$
  5. $Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3$
- Advantages of this method:
  - Short treatment period
  - CO_2 sequestration
  - Circularity

Static carbonation chambers

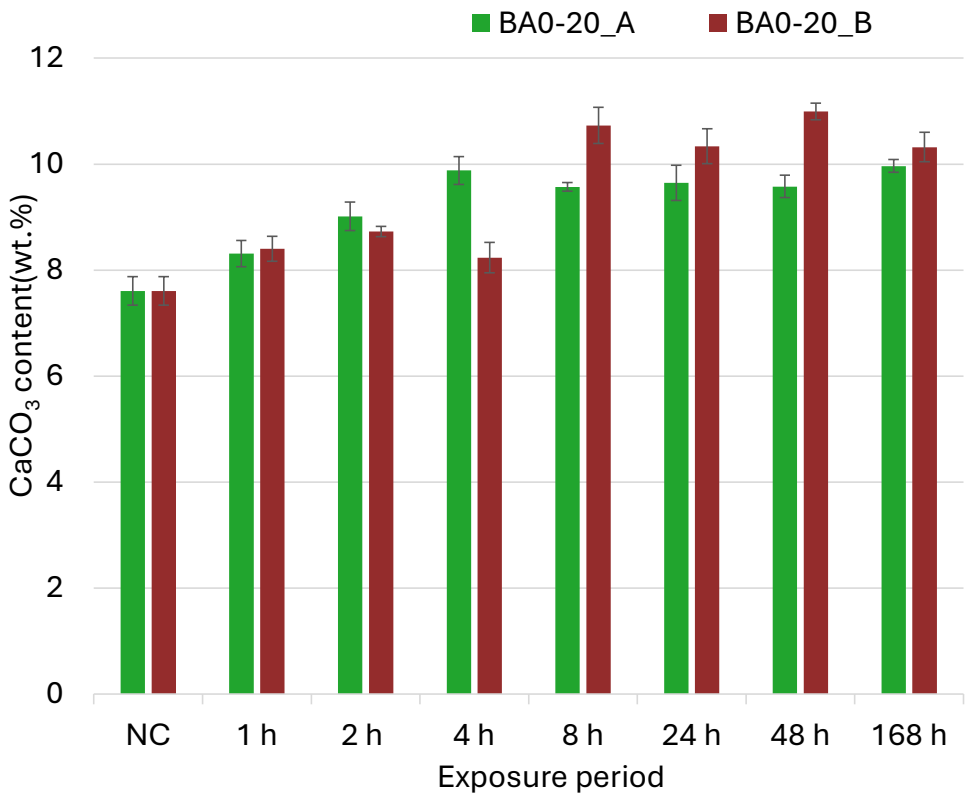
ACCELERATED CARBONATION TREATMENT

- Parameters studied:
  - Particle size: 0/2 & 0/20 mm
  - Exposure period: 1, 2, 4, 8, 24, 48 & 168 h
  - Moisture content (WC): 2, 20 & 45%
- Carbonation conditions:
  - Temperature: 30±1 °C
  - Relative humidity: 60±3%
  - CO_2 concentration: 12 %vol

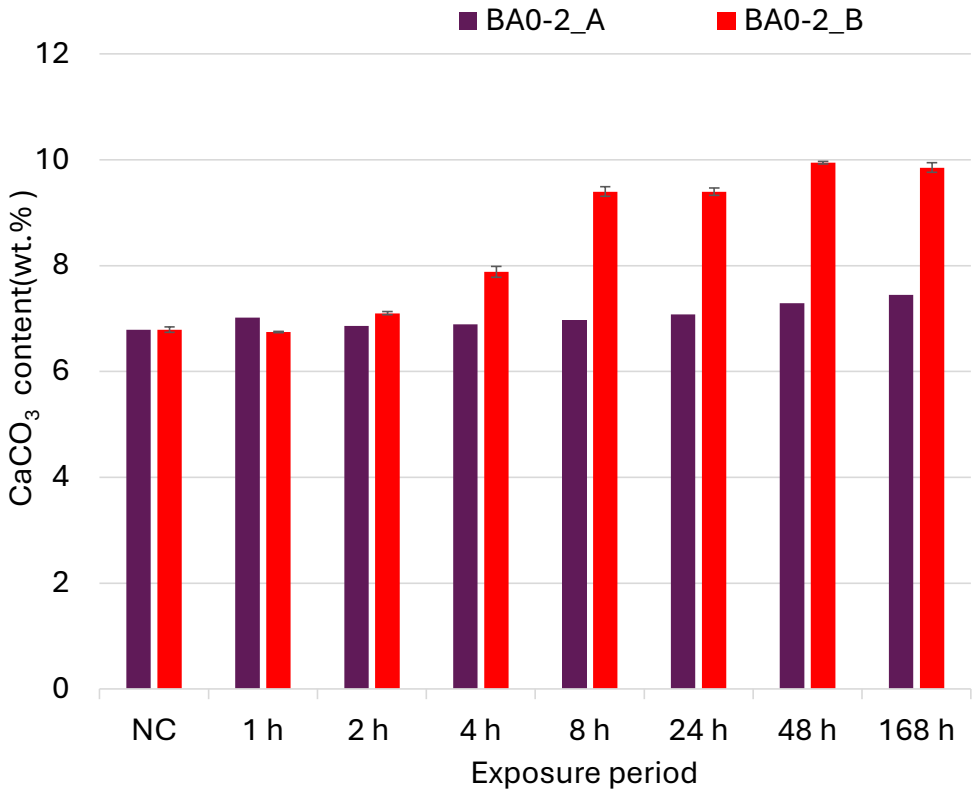


RESULTS – $CaCO_3$ content

- **BA particle size: 0/20 mm**



- **BA particle size: 0/2 mm**



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RESULTS – $CaCO_3$ content

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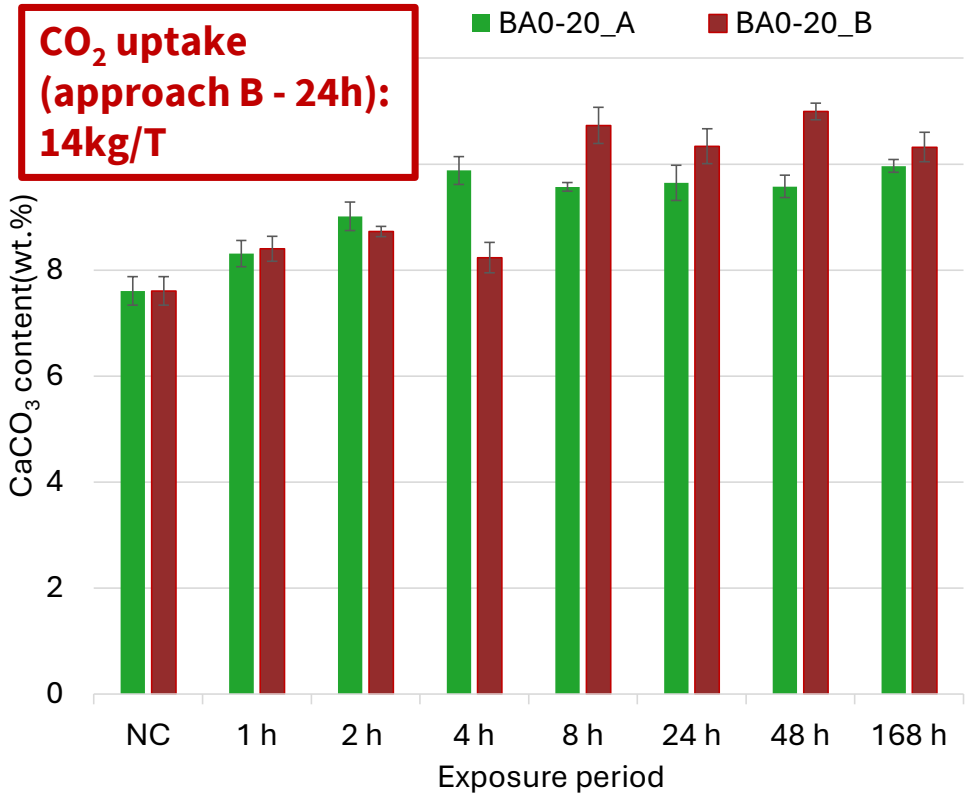

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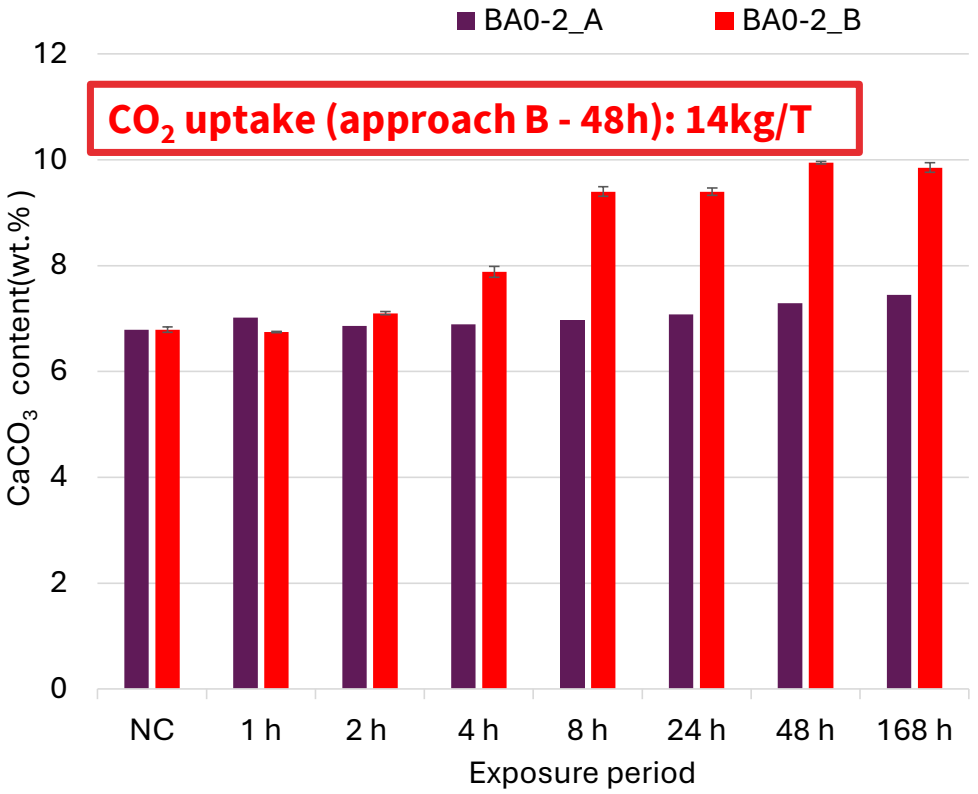
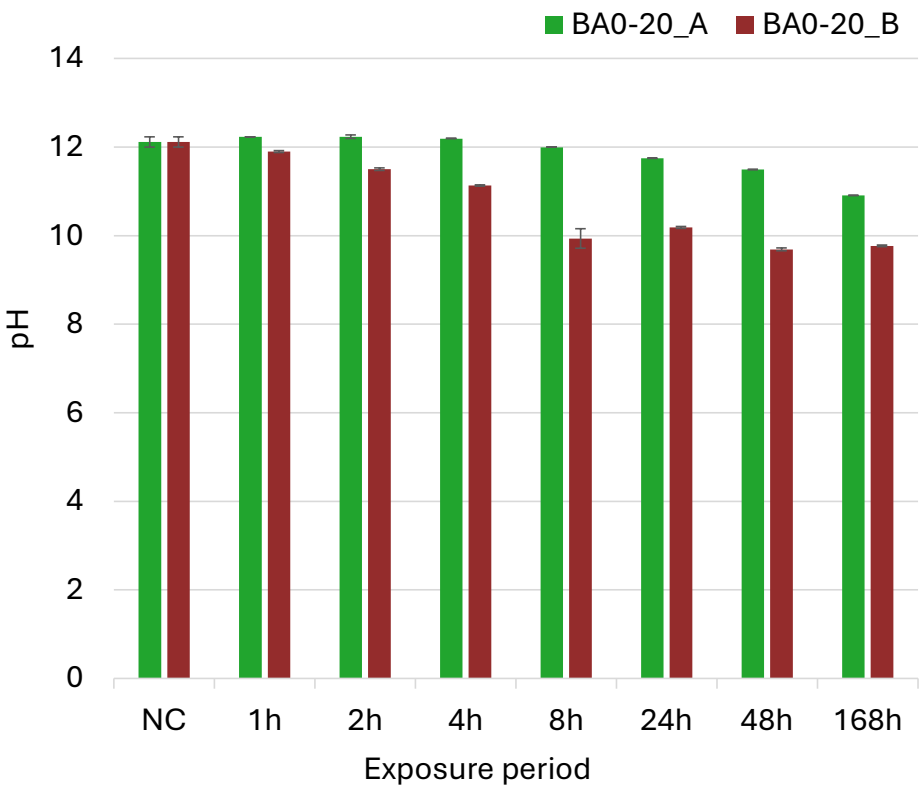
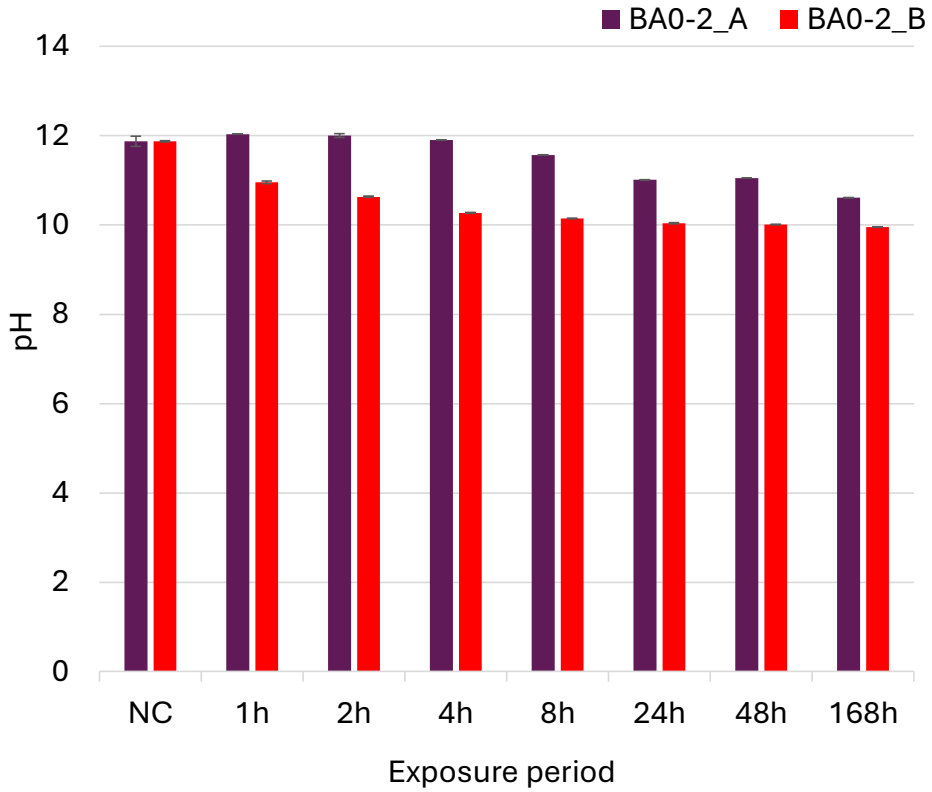


RESULTS – pH

- **BA particle size: 0/20 mm**



- **BA particle size: 0/2 mm**



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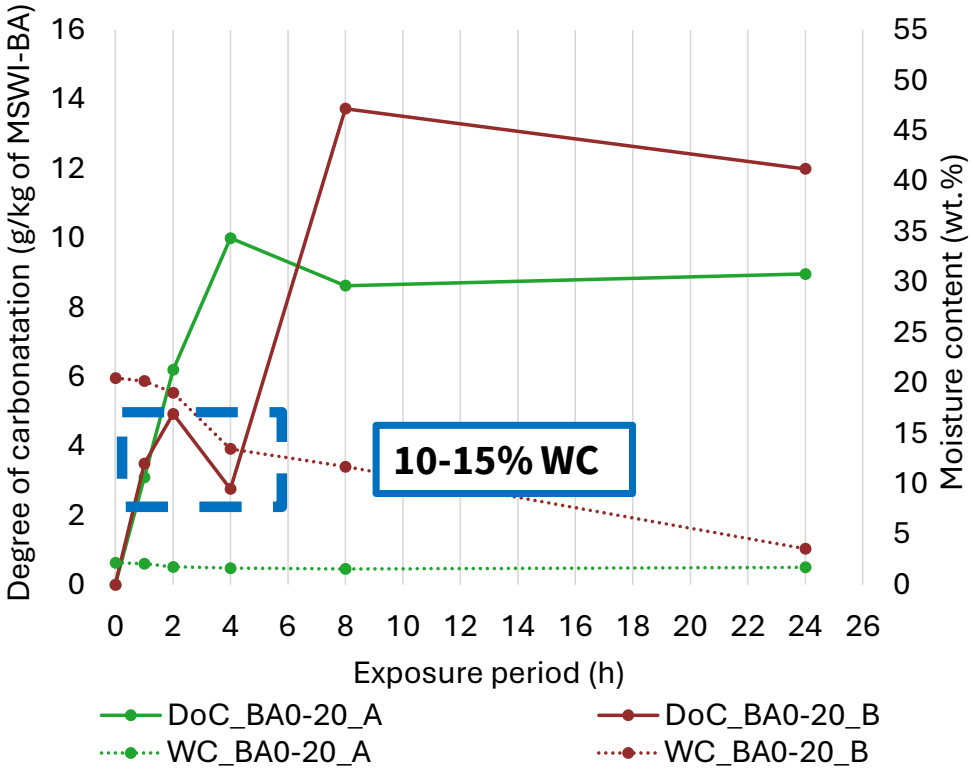
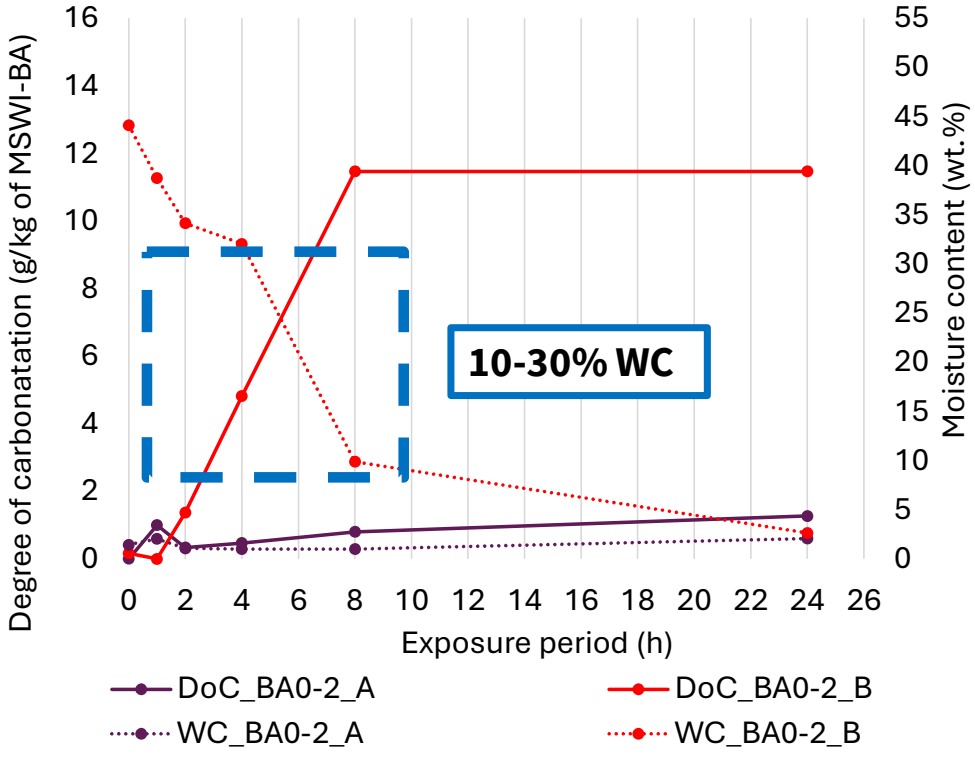
RESULTS – Influence of water content

- **BA particle size: 0/20 mm**



- **BA particle size: 0/2 mm**



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RESULTS – Physical properties

- ## Real density & water absorption

		Fresh	Carbonated	Maturated	Literature*
Fines MSWI-BA aggregates	Density (kg/m^3)	1840	2145	2239	2150-2850
	Water absorption (%)	6.9	7.3	8.24	2.2-17.3
Coarse MSWI-BA aggregates	Density (kg/m^3)	2280	2360	2239	1860-2680
	Water absorption (%)	2	2.4	4	7.2-15

- ## Wear resistance (M_{DE}) & Freeze-thaw resistance (MS)

	Fresh	Carbonated	Maturated	Literature*
Wear resistance (wt.%)	21	24	21	18-31
Freeze-thaw resistance (wt.%)	21	20	19	15-25

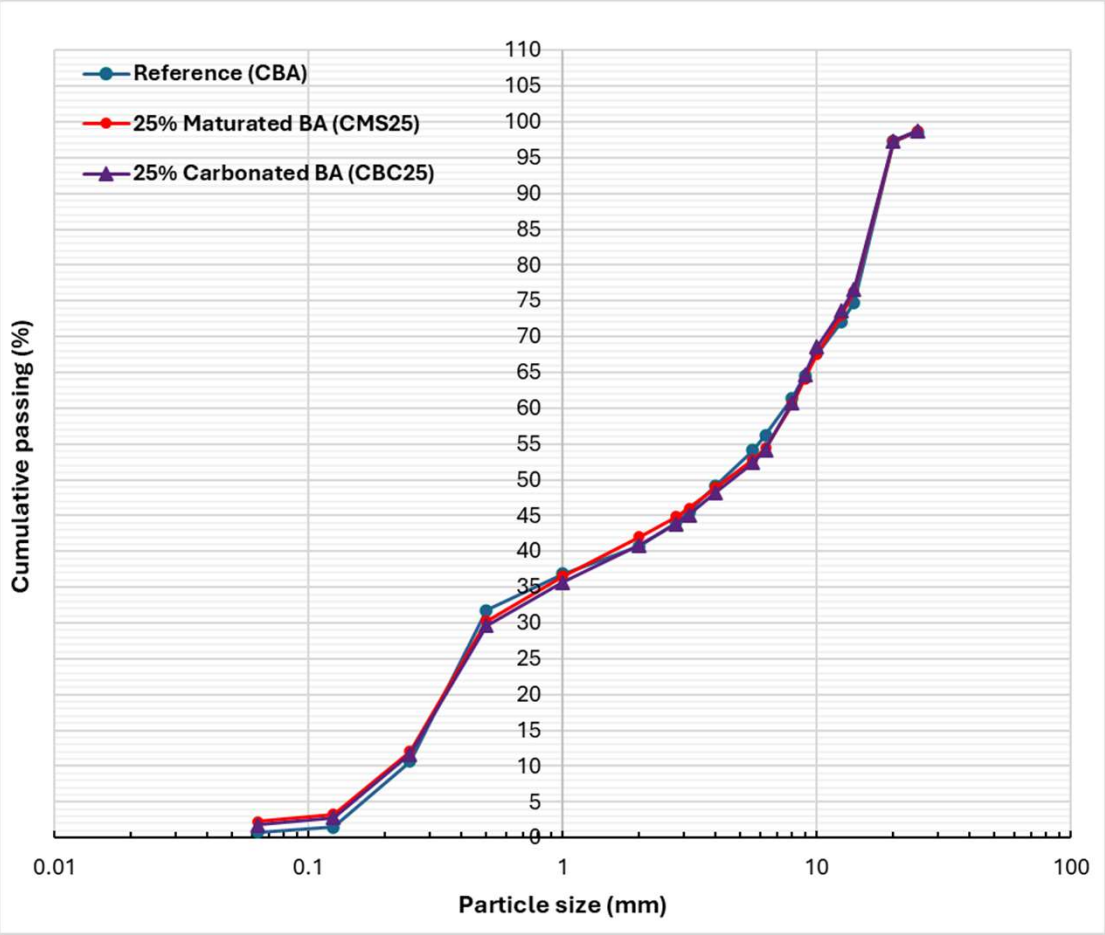
* *Descamps, P., Janssens, B., Dupont, L., Lefevre, L. (2011). "Memorandum technique pour l'utilisation des mâchefers de l'unité de valorisation par incinération de Thumaide".*

* *Dhir, R.K., Brito, J. de, Lynn, C.J., Silva, R.V., (2018a). "Municipal Incinerated Bottom Ash Characteristics", Sustainable Construction Materials: 91–138.*

* *Becquart, F., Abriak, N.E., (2013). "Experimental investigation of the Rowe's dilatancy law on an atypical granular medium from a municipal solid waste incineration bottom ash", POWDERS AND GRAINS 2013: Proceedings of the 7th International Conference on Micromechanics of Granular Media,, Sydney, Australia, 471–474.*

MSWI BA based concrete

- Two concrete formulas were produced by replacing 25% (v/v) of the **total** volume of natural sand & aggregates with maturated and carbonated MSWI BA.
- Target class of strength : ***C30/37***
- Sand and aggregates substitution rates:
  - Sand 0/2: 60%
  - Sand 0/4: 0%
  - Aggregates 2/6: 100%
  - Aggregates 6/20: 15%



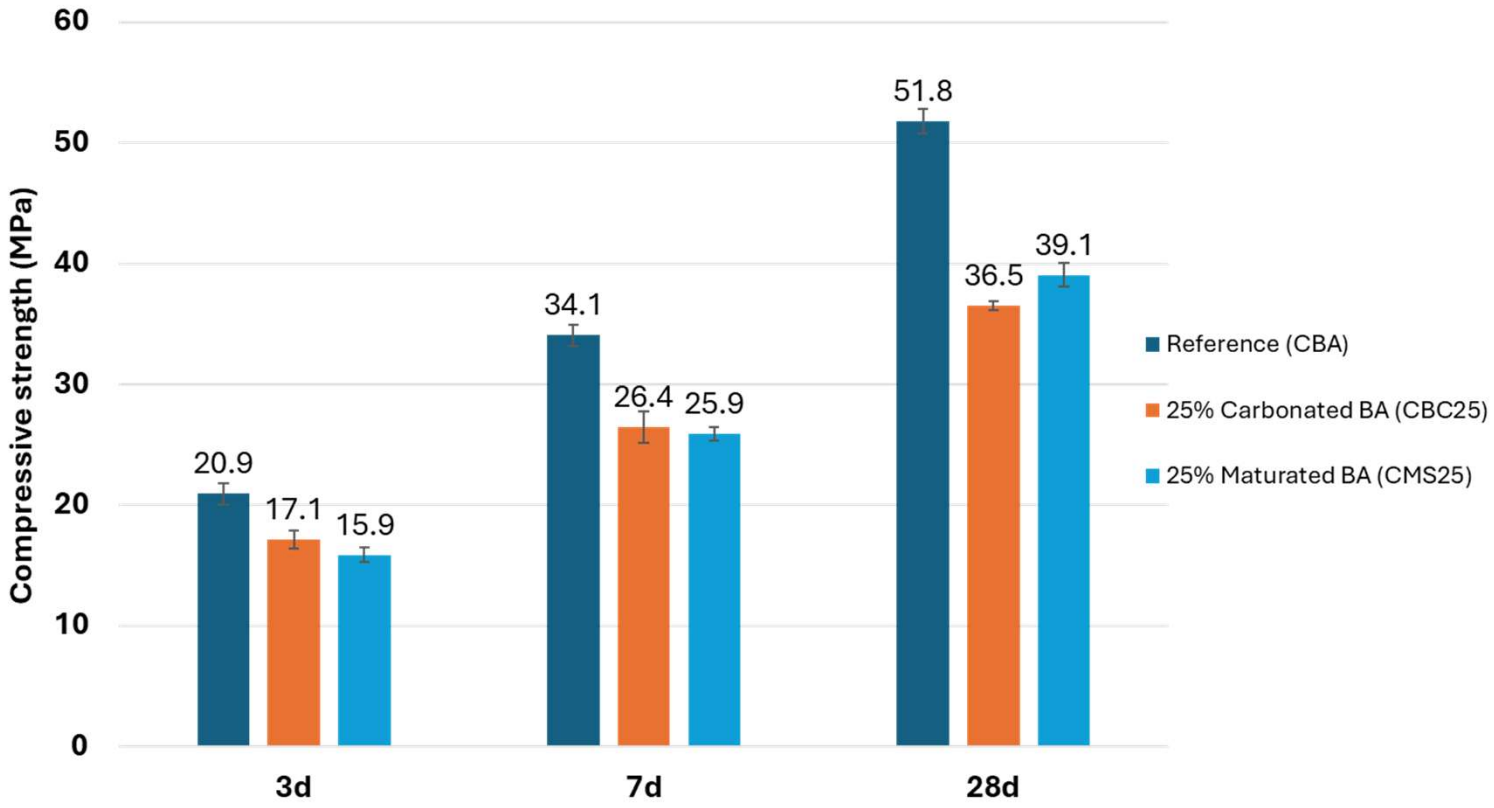
MSWI BA based concrete

Formula :	Reference (CBA)	25% Carbonated BA (CBC25)	25% Maturated BA (CMS25)
CEM III/A 42.5N	350	350	350
Scheldt sand 0/2	120	105	105
Concrete sand 0/4	685	509	509
Limestone aggregate 2/6	207	0	0
Limestone aggregate 6/20	828	708	708
BA 0/2	0	143	117
BA 2/6	0	126	109
BA 6/20	0	118	109
Superplastifier	2.48	2.95	2.77
Water	179	194	194
W_{eff}/C	0.49	0.49	0.49

RESULTS – Fresh state properties

Tests results				
Composition	**Density (kg/m^3)**	**Slump (mm)**	**Flow spread (mm)**	**Air content (%)**
Reference (CBA)	2367	175	535	3
25% Carbonated BA (CBC25)	2272	207	470	4.7
25% Maturated BA (CMS25)	2200	170	490	5.8

RESULTS – Compressive strength



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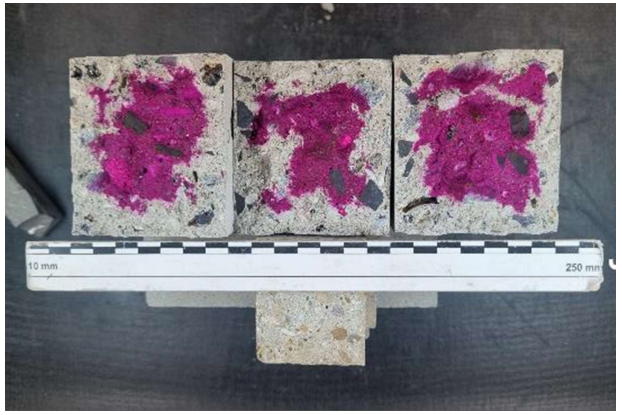
RESULTS – Durability

Tests results				
Composition	Water absorption (%)	Carbonation depth (mm)		
		7d	28d	70d
Reference (CBA)	5.97	1.89	3.58	6.00
25% Carbonated BA (CBC25)	7.11	3.44	6.89	14.40
25% Maturated BA (CMS25)	7.44	5.26	9.53	16.35

CBA (70d)

CBC25 (28d)



CMS25 (28d)

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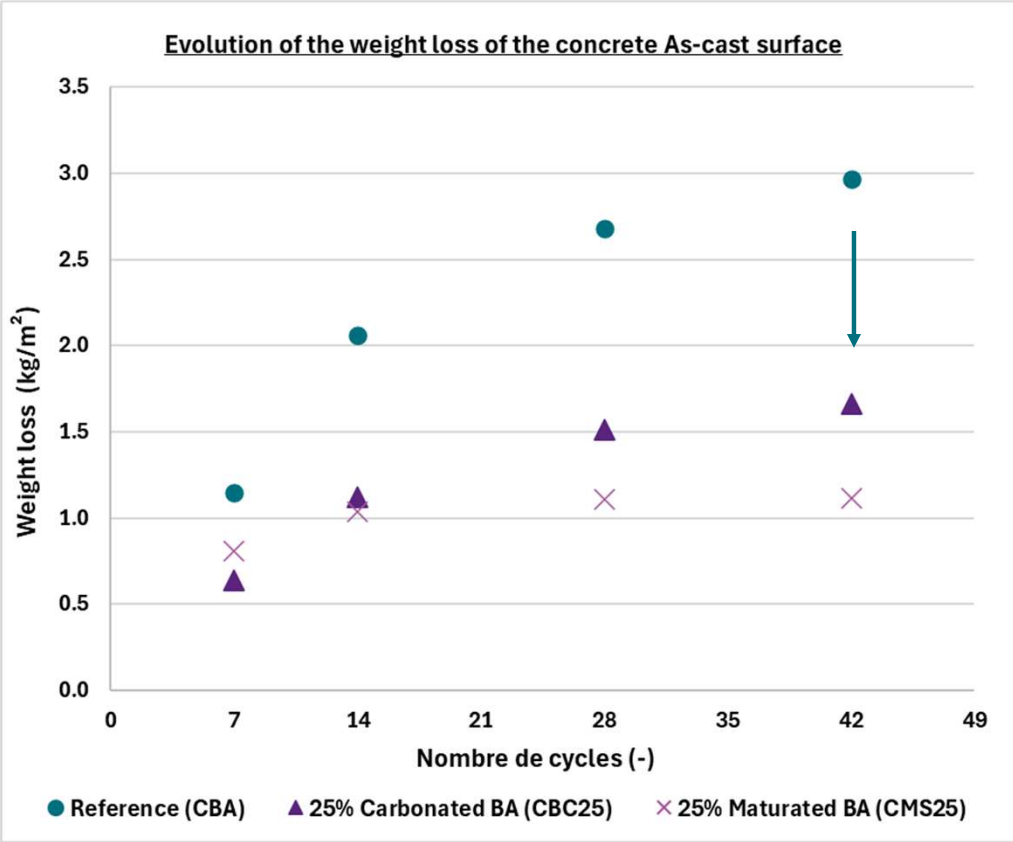
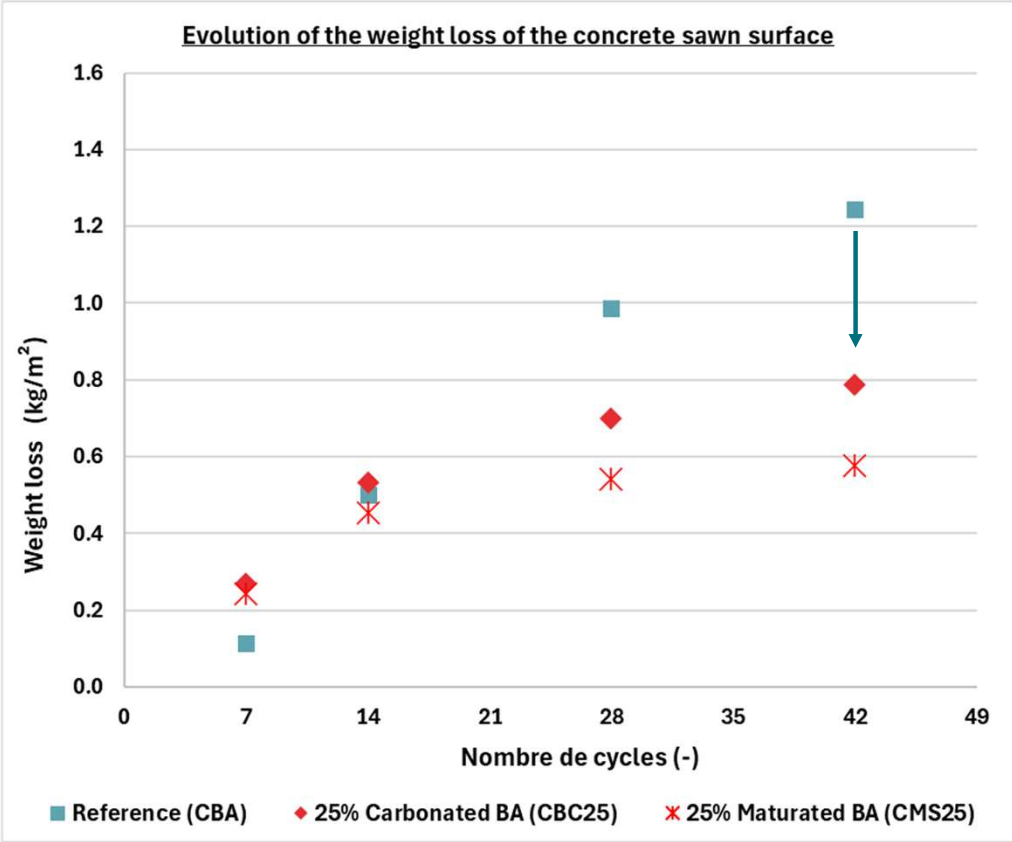
RESULTS – Freeze thaw resistance

- As-cast surface



- Sawn surface



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CONCLUSION

- **Moisty carbonation** (approach B) is more effective regarding carbon capture and pH stabilization.
- There is **no significant improvement** in the **physical properties** of MSWI-BA regarding the type of treatment used.
- Both **carbonated** and **maturated BA** used for concrete have similar effects.
- Replacing **25%** of natural sand and aggregates with BA lightly reduces the **compression strength** and **carbonation resistance** while enhancing the **freeze-thaw resistance**.

ON GOING RESEARCH

- **Accelerated carbonation of municipal solid waste incineration bottom ash for alternative aggregate production.** I.E. Kanjo, J. Hubert, J.T. Tchuindjang, S. Marquis, Ph. Descamps, L. Dupont, L. Courard. Proceedings of 10th International Conference on CONcrete under SEvere Conditions – Environment and Loading CONSEC 2024, 25-27 September 2024, Chennai (India), pp145-150 (https://hdl.handle.net/2268/324160)
- **Mitigation of Alkali-Silica Reaction Through Carbonation of Recycled Concrete**. S. Grigoletto, J. Hubert, J. Duchesne, B. Bissonnette, F. Michel, L. Courard. Proceedings of the 17th International Conference on Alkali Aggregate Reaction in Concrete ICCAR 2024, 18-24 May 2024, Ottawa (Canada), pp626-634 (https://hdl.handle.net/2268/320679)
- **Numerical FE2 Study of Chloride Ingress in Unsaturated Recycled Aggregates Concrete**. A. Fanara, L. Courard, F. Collin. Cement and Concrete Research 2024 (1873-3948) (https://doi.org/10.1016/j.cemconres.2024.107703)
- **Development and properties of recycled biomass fly ashes modified mortars**. J. Hubert., S. Grigoletto, F. Michel, Z. Zhao, L. Courard. Recycling 2024, 9, 46 (https://doi.org//10.3390/recycling9030046)

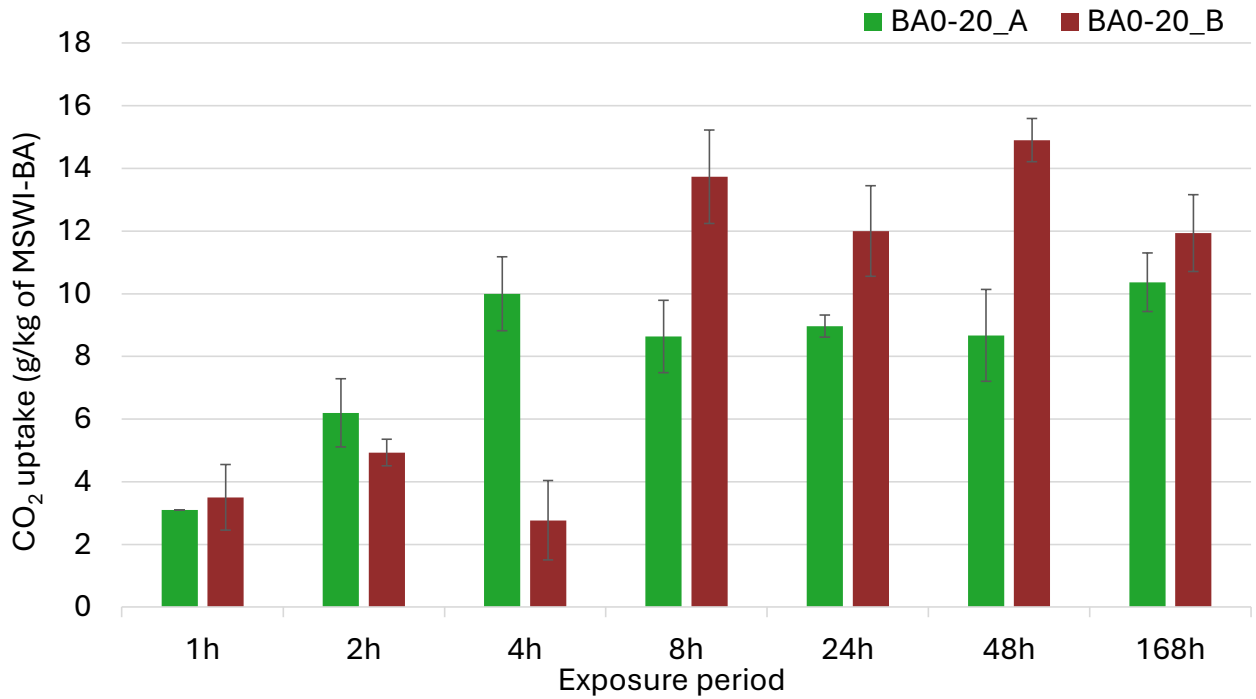
THANK YOU

for your attention !

The work conducted here is part of the research project **PNRR Remind CARBOC** titled:
« Captage et stockage du CO_2 par carbonatation de mâchefers et de béton à teneur réduite en ciment »

RESULTS – CO_2 uptake

- **BA particle size:** 0/20 mm



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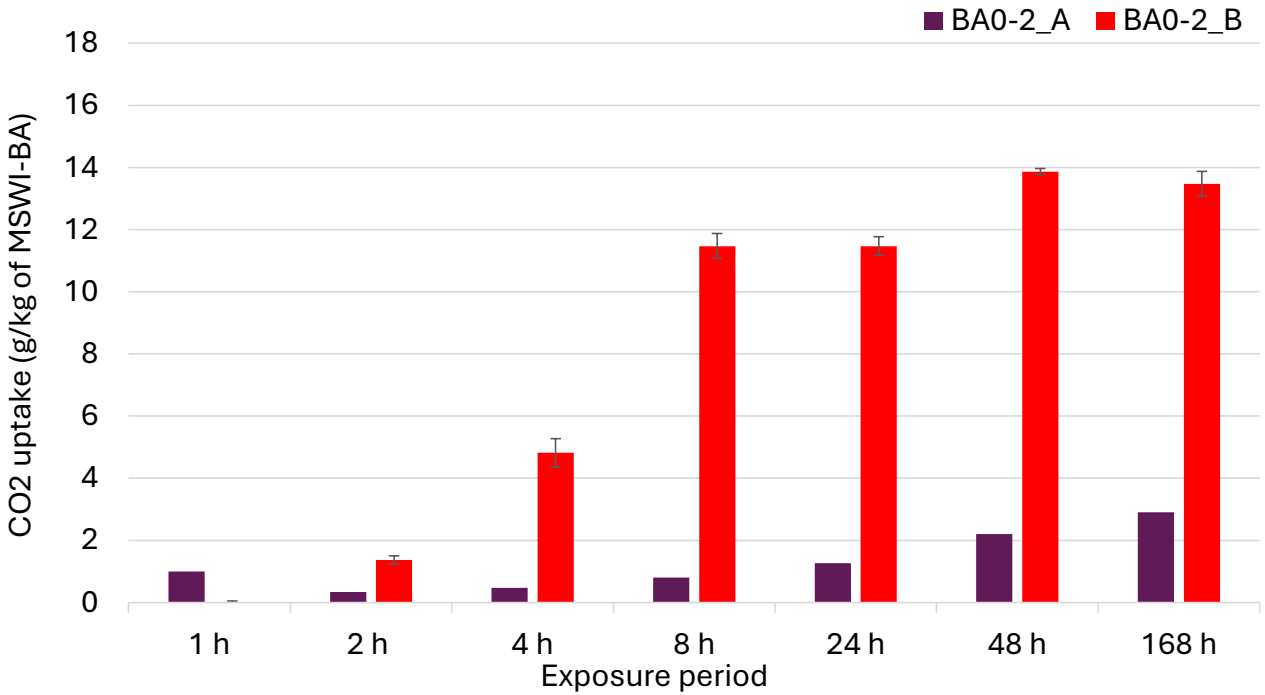
RESULTS – CO_2 uptake

- **BA particle size:** 0/2 mm



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