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UTILISATION DE GRANULATS RECYCLÉS ET D'AGENTS EXPANSIFS POUR LA PRODUCTION DE MATÉRIAUX CIMENTAIRES ÉCORESPONSABLES ET DURABLES

L. Courard Université de Liège, Belgique

B. Bissonnette Université Laval, Canada

23èmes journées scientifiques du Regroupement Francophone pour la Recherche et la Formation sur le Béton

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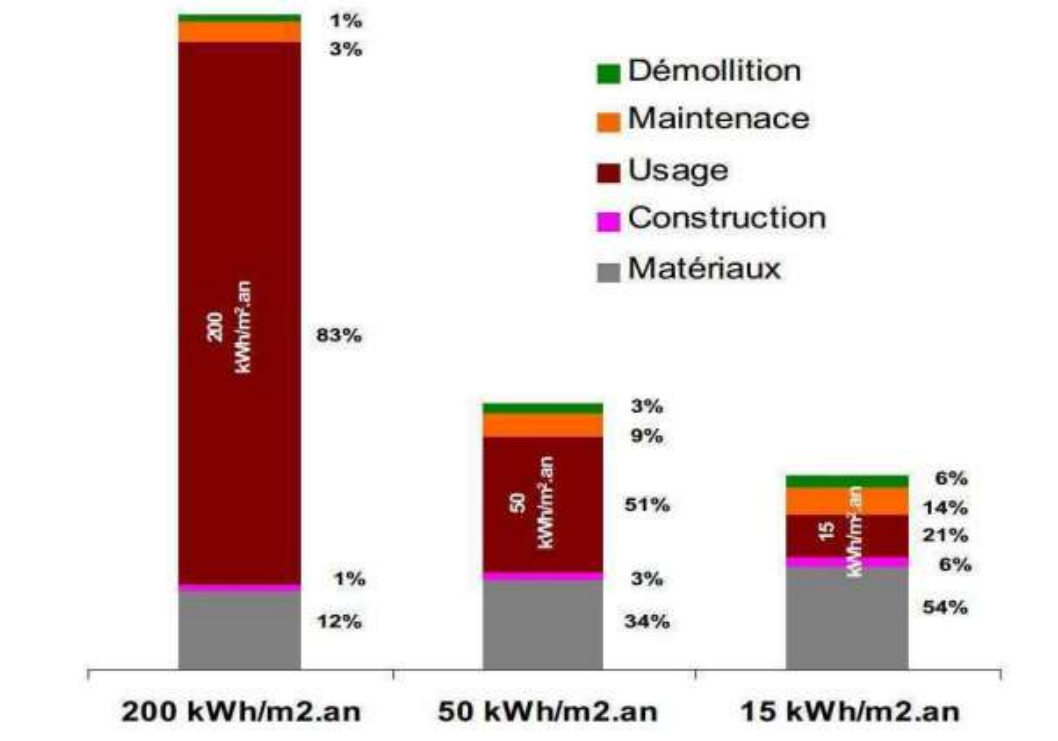
Global context

Development of materials and alternative techniques for buildings

Increasing insulation (energy) performances of housing

Breakdown of energy consumption by building item according to energy performance

Needs for developing new materials



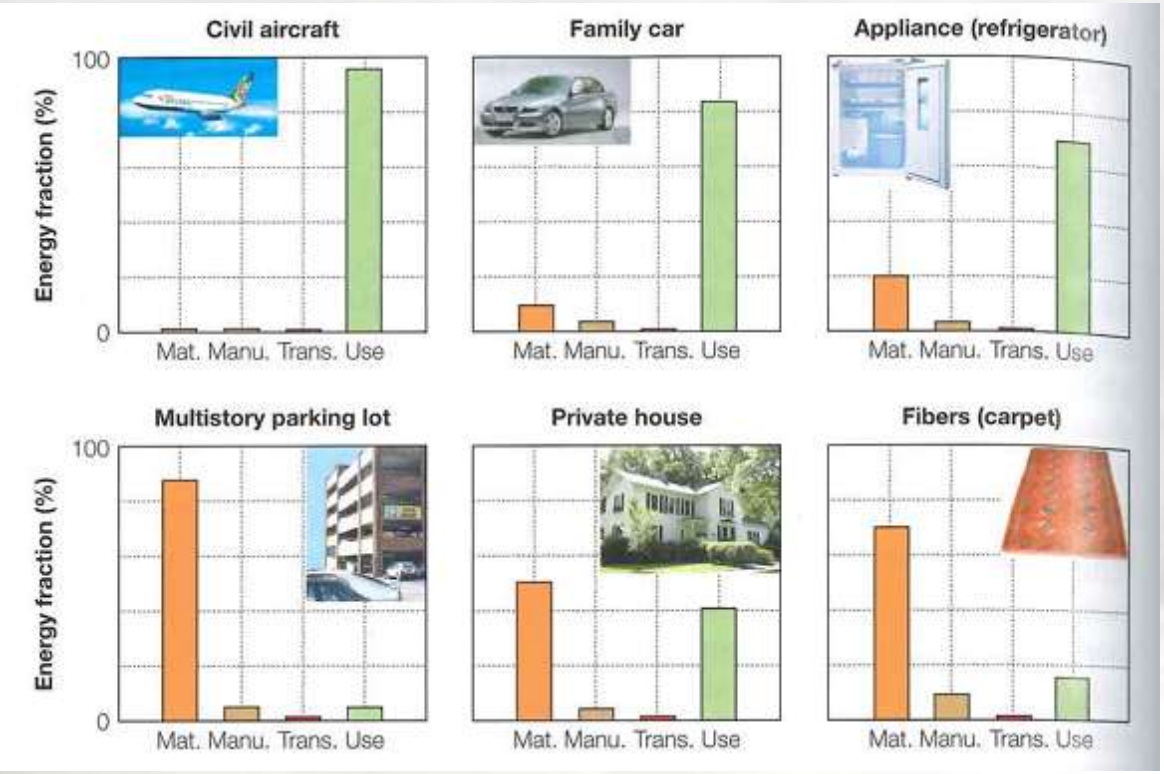
G. Escadeillas, Métamorphoses, Liège, 2011 (d'après Magniont 2010)

Global context

Approximate value of energy consumed at each phase

➡ Importance of **material selection** for infrastructures and housing

3R theory: **R**educe, **R**euse and **R**ecycle



Ashby, 2022

Natural *vs.* Recycled

Recycled aggregate production

Construction and
Demolition Waste

FRCA (d < 4 mm)

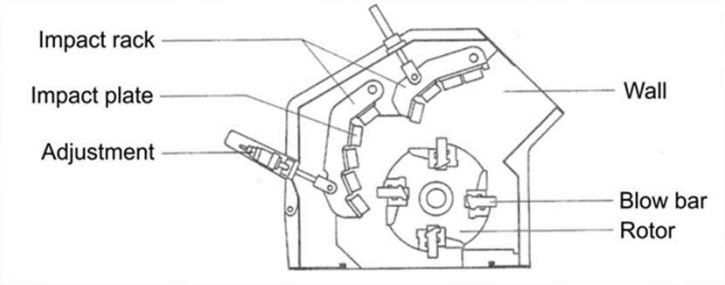
CRCA (d > 4 mm)

Sands
(0.125 mm < d < 4 mm)

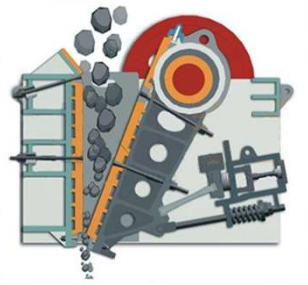
Fines
(0 mm < d < 0.125 mm)

Materials processing: washing

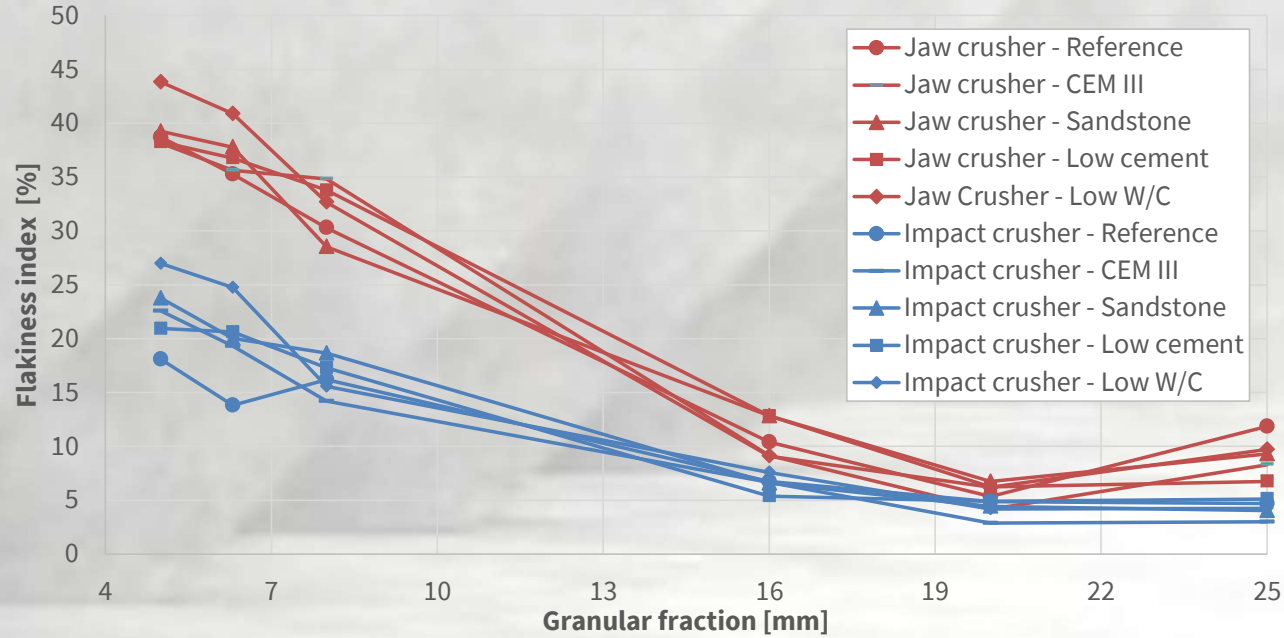
- The flakiness index decreases with increasing granular fraction
- The jaw crusher produces **flakier aggregates ➡ sand!**
- No influence of the concrete composition



Impact crusher



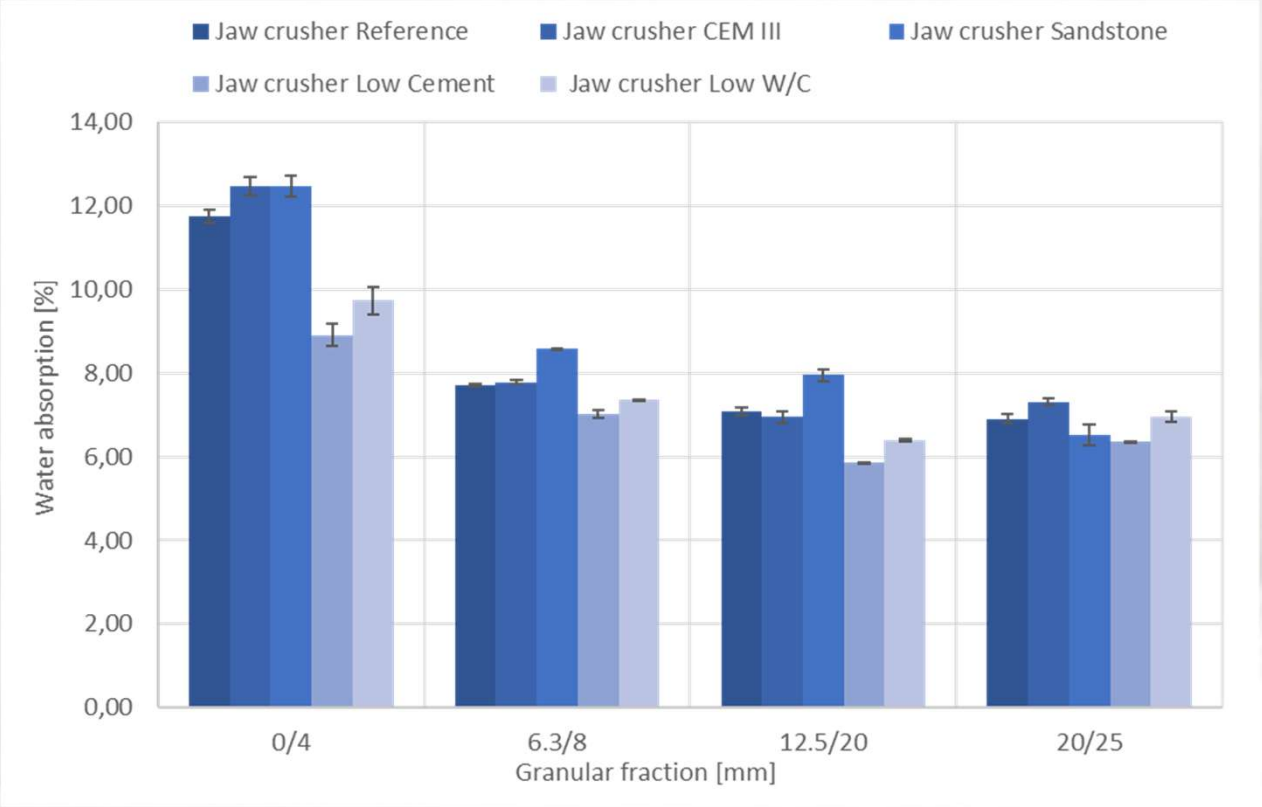
Jaw crusher



Effects of crushing method on the properties of produced recycled concrete aggregates. J. Hubert, Z. Zhao, F. Michel, L. Courard. Buildings 2023, 13(9), 2217 (https://doi.org//10.3390/buildings13092217)

Materials processing: crushing

- **Porosity** is due to the presence of hardened cement paste and mortar
- **Water absorption** coefficient of aggregates increases as coarse particle size decreases



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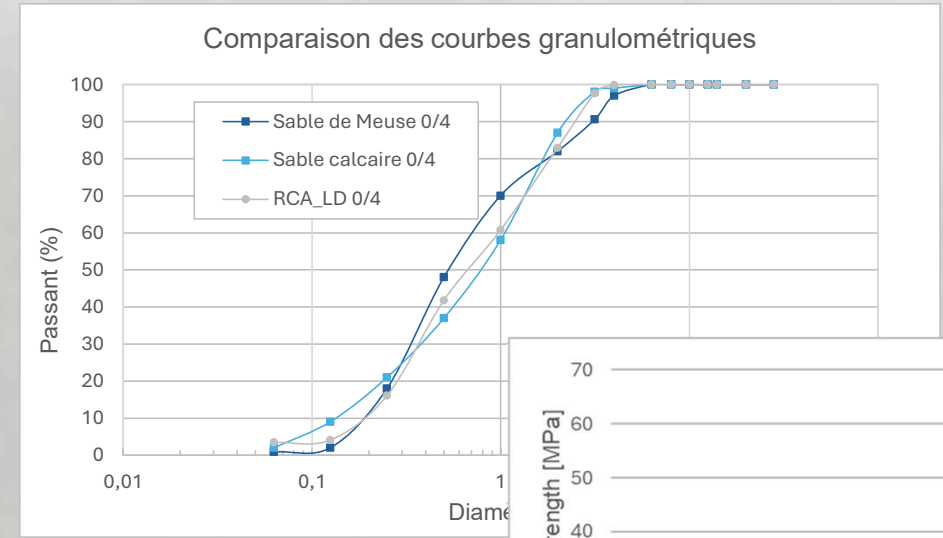
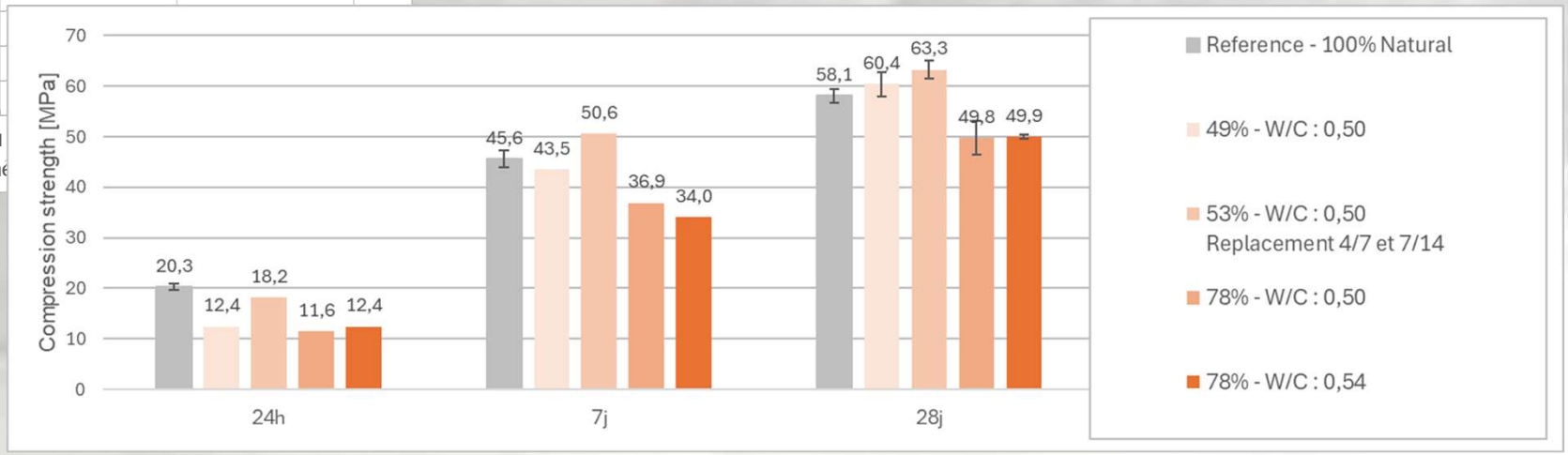
CIBER: prefabricated concrete



Aggregates	Fine content (%)	Water absorption (%)	Density (kg/m³)
Meuse sand 0/4	0.9	0.5	2750
Limestone sand 0/4	2	0.75	2700
RCA_LD 0/4	**3.44**	**5.88**	**2296**

Resistance : C30/37
Environment : EE3



3D printing

(+) design opportunities

(−) environmental impact

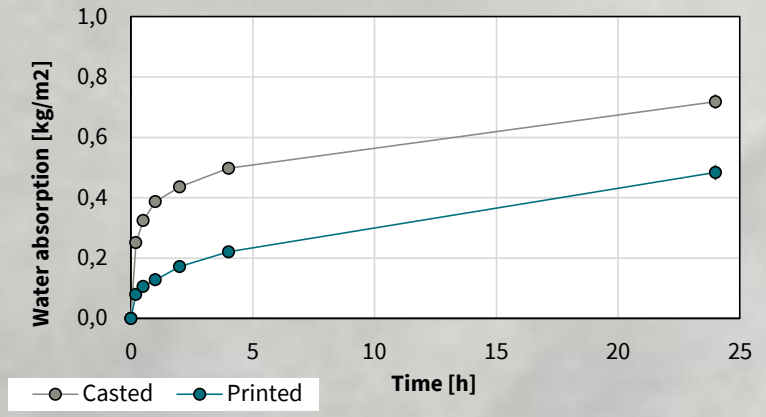
→ alternative binder

100% recycled sand

3D printing

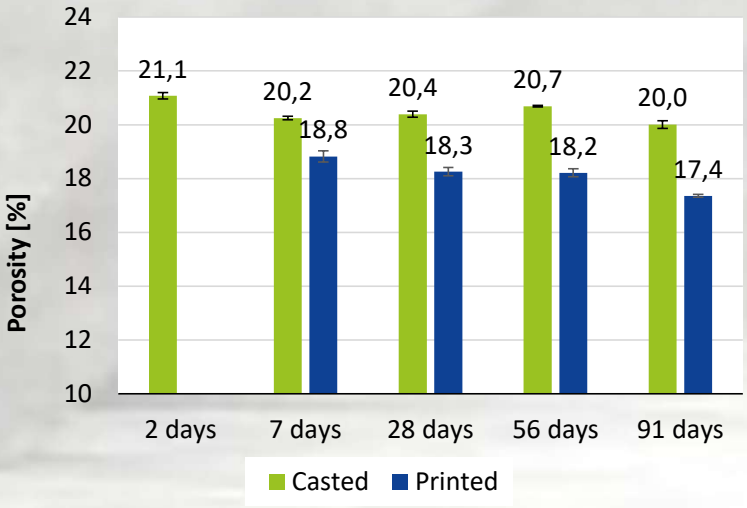
Capillary absorption tests NBN EN13057

- Influence of the ***printing process*** (casted samples vs printed samples)
- Water absorption [kg/m²] and absorption coefficient [mm/h^{0,5}]



Porosity

- Influence of the ***printing process*** (casted samples vs printed samples)



Use of recycled fine aggregates in high added value applications. J. Hubert, Y. Muy, L. Courard. International Conference on Advances in Engineering and Technology for Sustainable Development. Hanoi University of Civil Engineering, Hanoi, Vietnam, Nov 2-3, 2023 (https://hdl.handle.net/2268/308792)

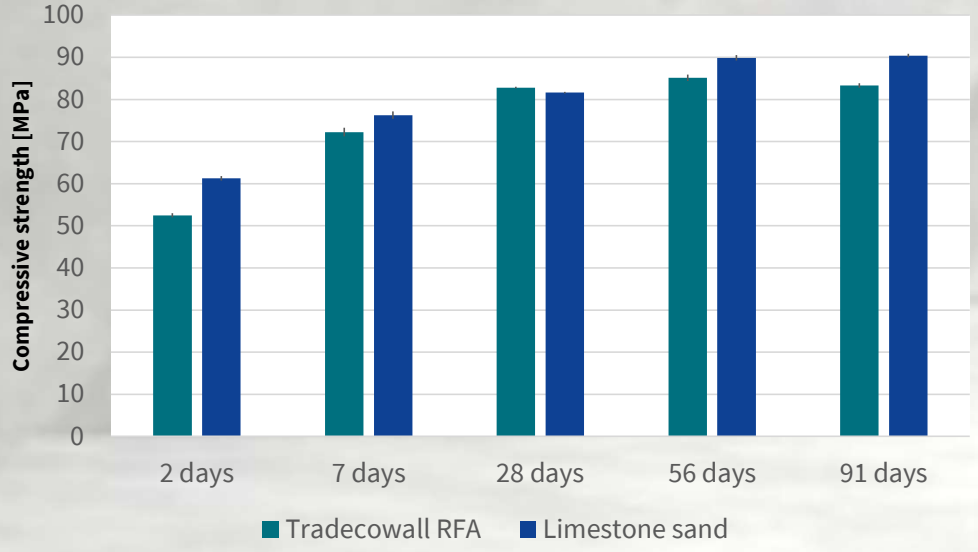
3D printing

Casted samples (4x4x16 cm prismatic samples)

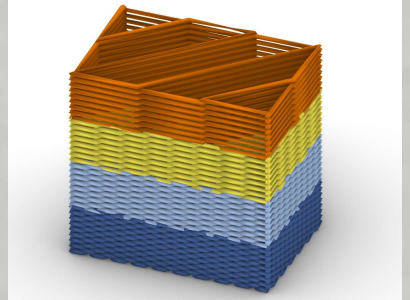
Printed samples (4x4x16 cm prismatic samples extracted from S shaped printed elements)

Three points bending and compressive strength :

- Influence of the ***type of sand*** (natural crushed limestone sand vs concrete RFA)
- Water curing (20°C and 95±5% relative humidity)



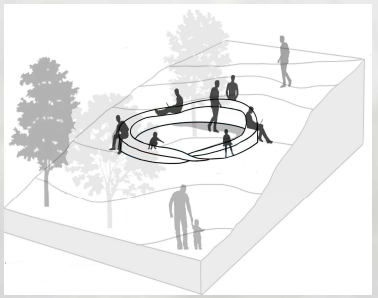
3D printing: student contest

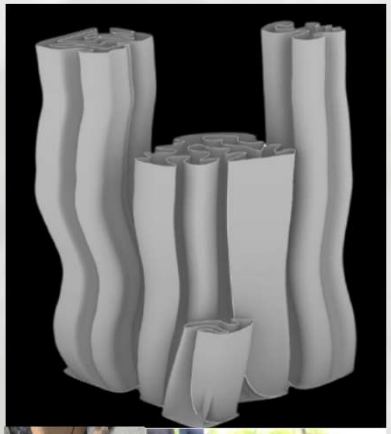





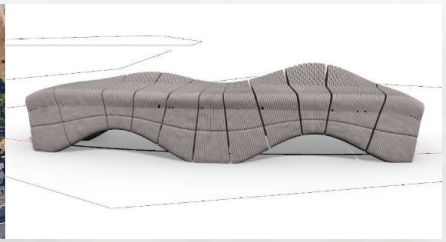









3D printing



Rammed earth (« pisé ») with recycled fine aggregates

- low maintenance, low-tech construction process and economical to build

Carbonated IMSW

Parameters:

- Particle sizes: 0/2 & 0/20 mm
- Exposure period: 1, 2, 4, 8, 24, 48 & 168 h
- Moisture content (WC): 2, 20 & 45%

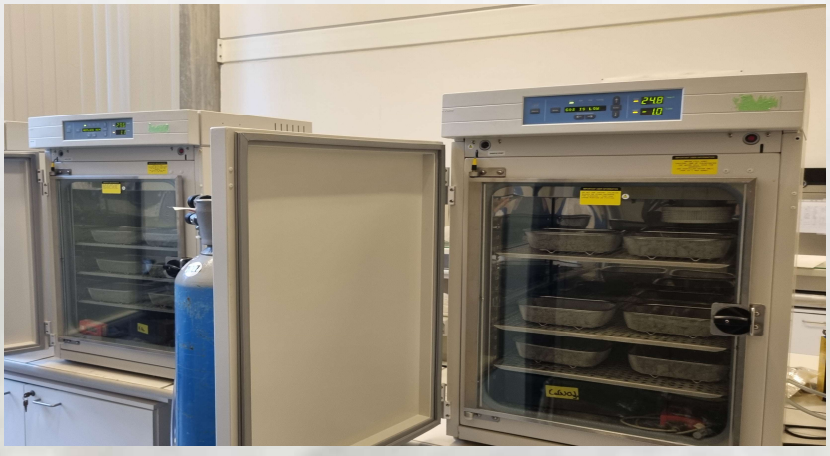
Carbonation

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

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

Carbonation conditions:

- Temperature: 30 ±1 °C
- RH: 60 ±3%
- CO_2 concentration: 12 % (vol.)



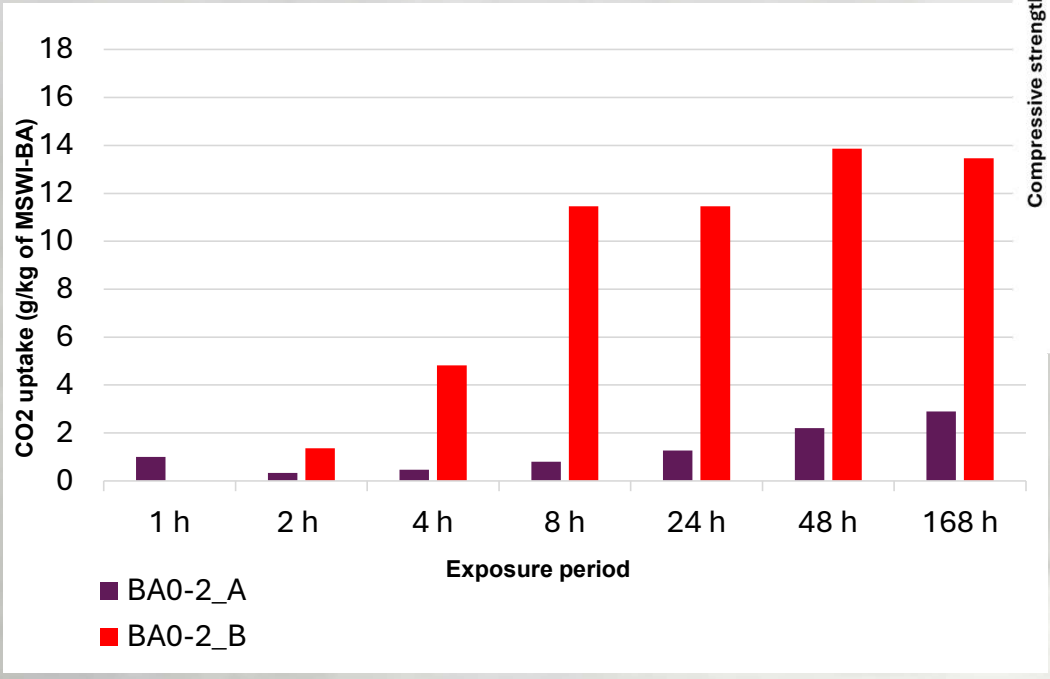
Accelerated carbonation of municipal solid waste incineration bottom ash for alternative aggregate production. I.E. Kanjo, J. Hubert, J.T. Tchuindjang, S. Marquis, Ph. Descamps, L. Dupont, L. Courard. 10th International Conference on CONcrete under SEvere Conditions – Environment and Loading 2024, Chennai, India

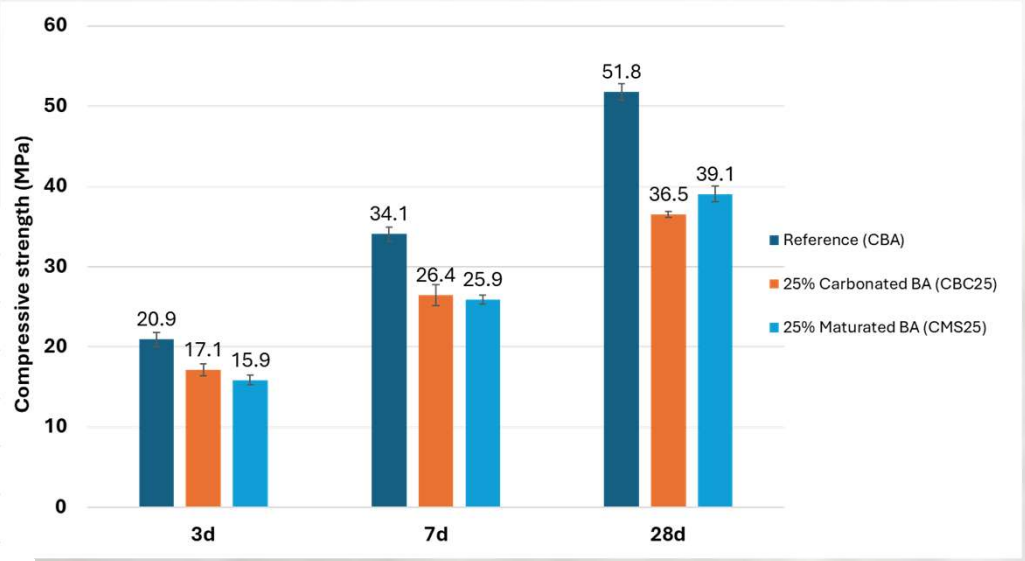
REMIND Wallonia

CARBOC

Carbonated IMSW

- CO_2 uptake - 0/2 particle size





24h CO_2 uptake = 18 weeks natural maturation

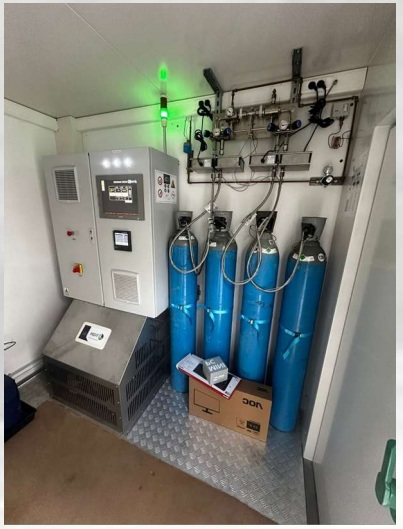
CARBOC

Efficiency of processes for the carbonation of municipal solid wastes bottom ash. I. J. Kando, L. Courard, J. Hubert. 1st International Conference on Research and Application of Carbonation Technology for Wastes and Concrete (ReACT2024), Hong-Kong, 11-13 Dec 2024

CarboNEX

- Experimental room for accelerated carbonation (temperature, humidity and CO_2 concentration)



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Use of Shrinkage-Compensating Agent for Mortars

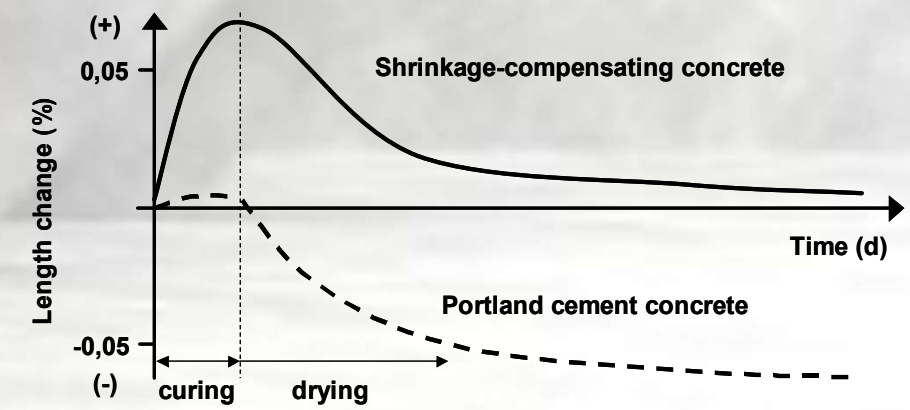
Shrinkage cracking

- Moisture loss in cement-based materials inevitable below 100% RH
- Causes drying shrinkage and volume changes
- Chemical shrinkage from hydration reactions also occurs
- Shrinkage leads to tensile stresses and cracking risks

(carrollsbuildingmaterials.com)

Mechanism of shrinkage compensation

- Chemical expansive agents added to cement or mortar/concrete (*expansive cement* or *expansive component*)
- During curing, reaction produces expansive compounds
- Expansion is offset by subsequent shrinkage
- Proper dosage critical to achieve the desired strain balance



Types of expansive agents

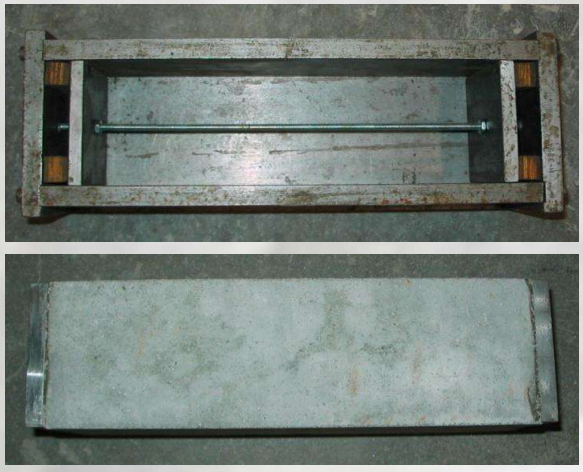
- Three main categories for mortar/concrete
  - CSA-based expansive cements (*type K*, *type M*)
  - Lime-based agents (*type G*)
  - Magnesium oxide-based agents (MgO)
- Specialty additives: gas-liberating agents (N_2, H_2, O_2), diols
- Dual-action agents for plastic and hardened state expansion phases

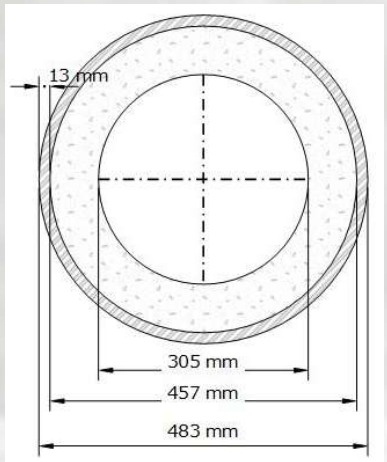
Dimensional balance and restraint

- Expansion and shrinkage are asynchronous processes
- Restraint essential to produce compressive prestress
- In new constructions: minimal reinforcement provides restraint
- Repairs rely on substrate bond and edge abutment for restraint
  - Adequate surface preparation improves chemical prestress development

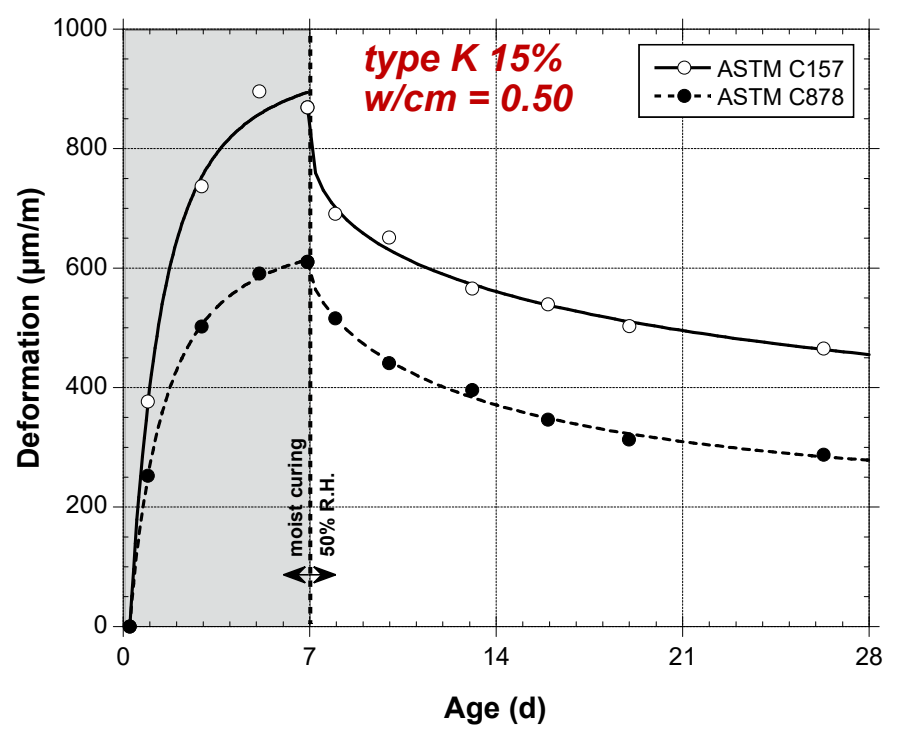
Research on dimensional balance

- Variables studied
  - agent type (*type K*, *type G*, MgO)
  - dosage
  - binder composition
  - w/cm ratio
  - curing
- Testing
  - ASTM C157 mod. (free length change)
  - ASTM C878 (restrained length change)
  - AASHTO T334 mod. (inverted ring tests)

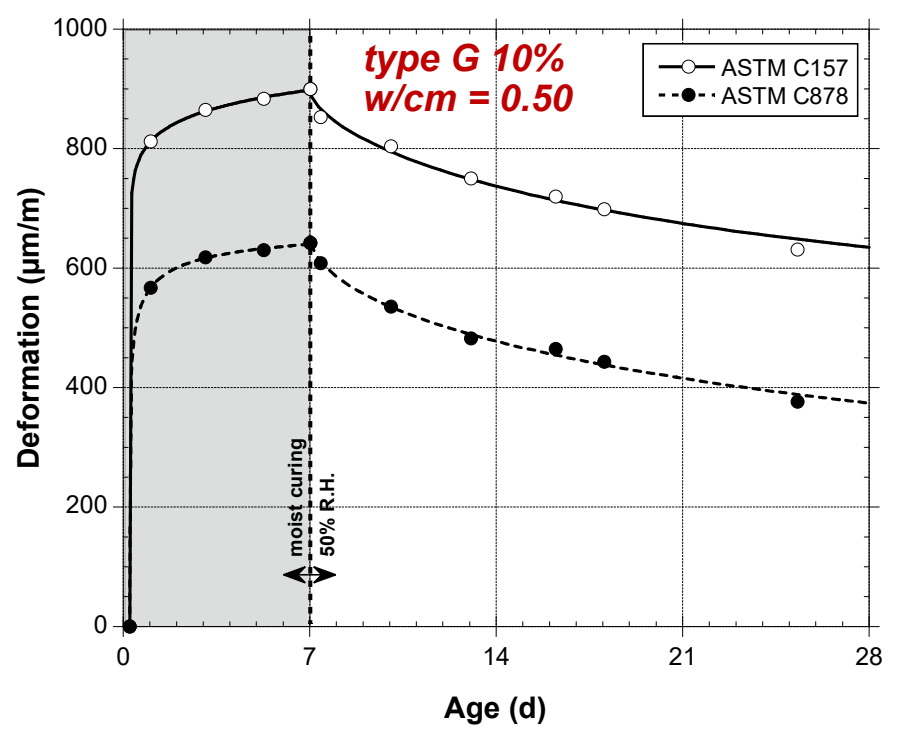




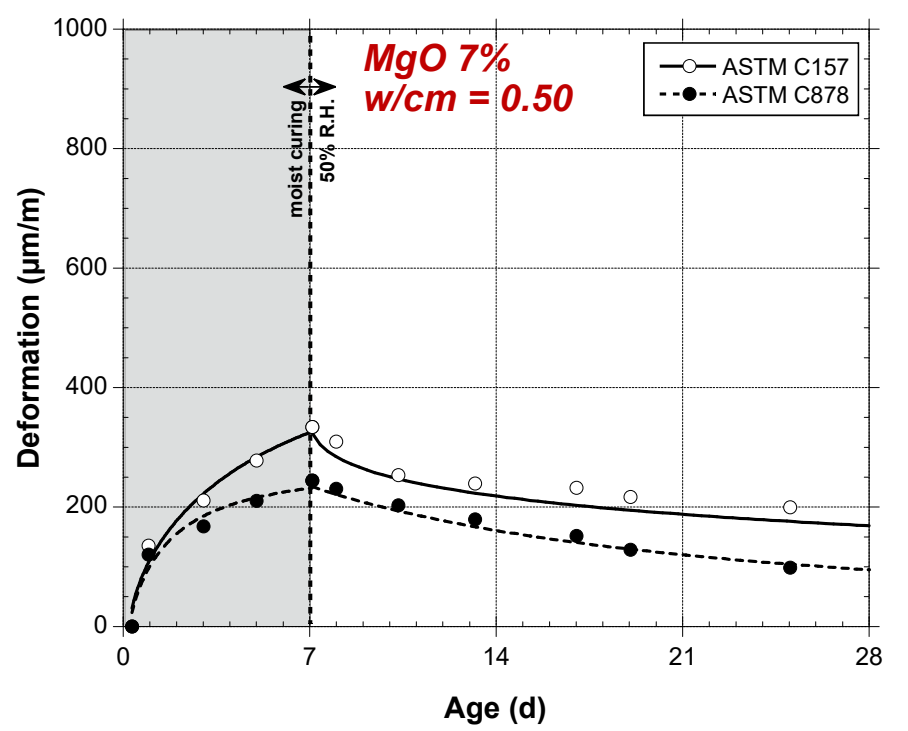
CSA-based agent (*type K*)



Lime-based agent (*type G*)



MgO-based agent



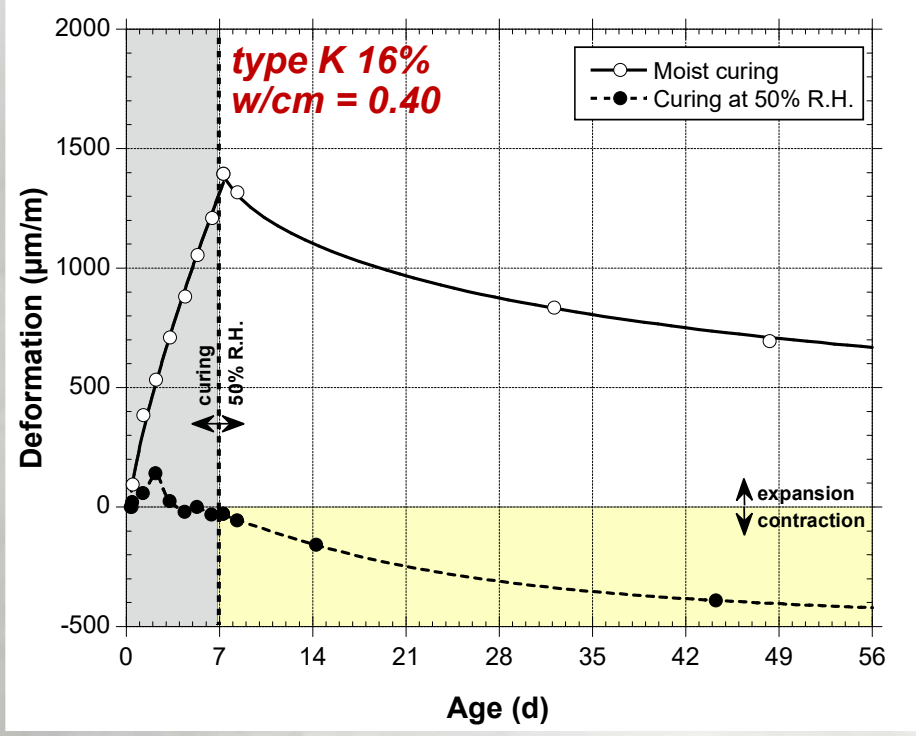
Long-term dimensional behavior

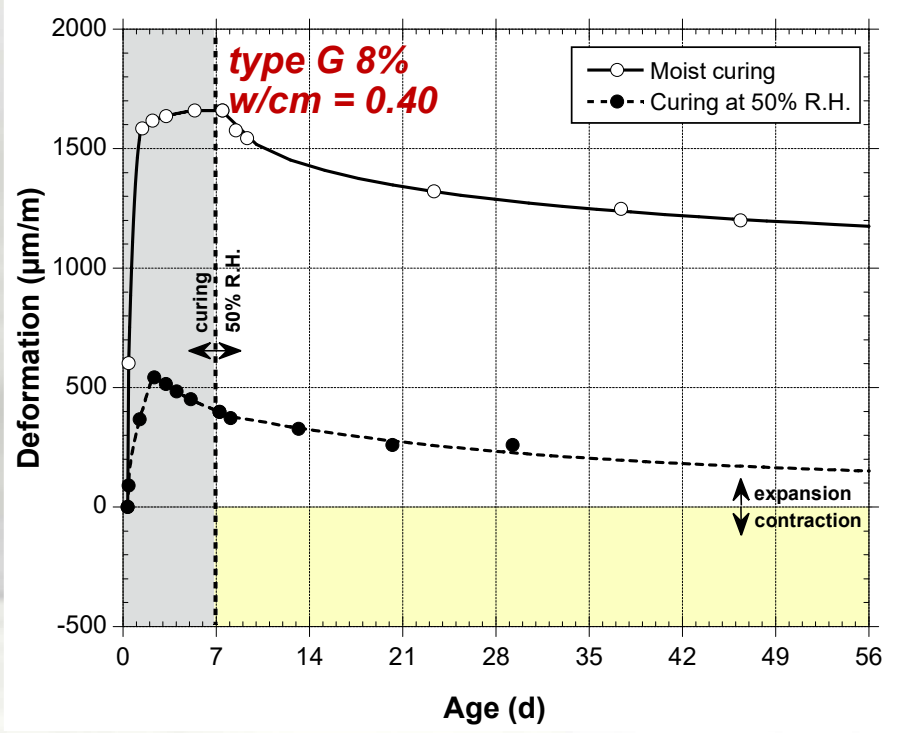
Component (% / wgt. of binder)	Average net deformation (µm/m)					
	free ASTM C157 mod.			restrained ASTM C878 mod.		
	7 d	28 d	500 d	7 d	28 d	500 d
type K (15%)	+870	+465	+120	+610	+285	-95
type G (10%)	+900	+630	+285	+640	+375	+70
MgO_2 (7%)	+335	+200	-85	+245	+100	-135

Curing conditions

- Curing conditions significantly influences expansion

Curing conditions





Curing conditions

- Early drying = minimal expansion
- Can lead to **net shrinkage**, in some case worse than plain mortar
- Prevents full chemical reaction of expansion agent
- Highlights importance of curing planning

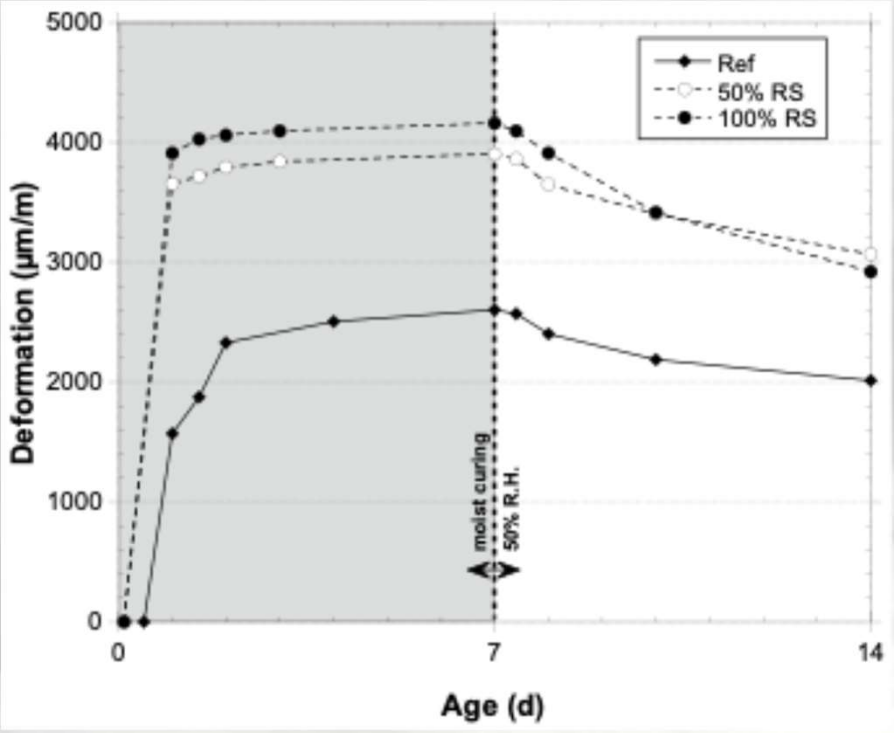
(gharpedia.com)

More eco-friendly concrete materials

- Low-CO_2 binders
- Recycled aggregates
  - RCA
  - CWA

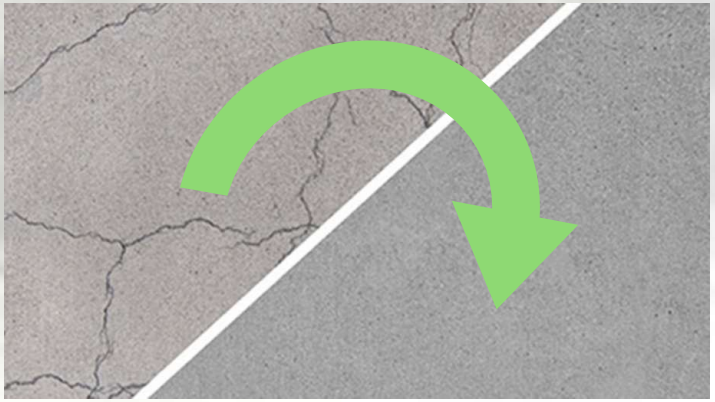
- Use of shrinkage compensation to make the materials both more durable and sustainable

On-going study



Sustainability benefits

- Crack-free surfaces prevent water ingress and corrosion
- Improved durability
- Life-cycle cost reduction
- Compatible with green building standards



(ctscement.com)

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