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Recycling fine particles from construction and demolition wastes: characterization and effects on concrete performances

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Recycling and waste management Online Summit
November 18th, 2021

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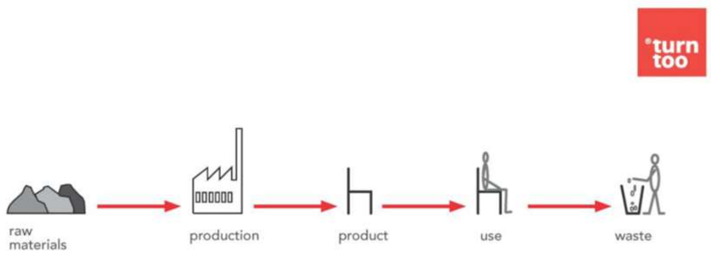
Global context

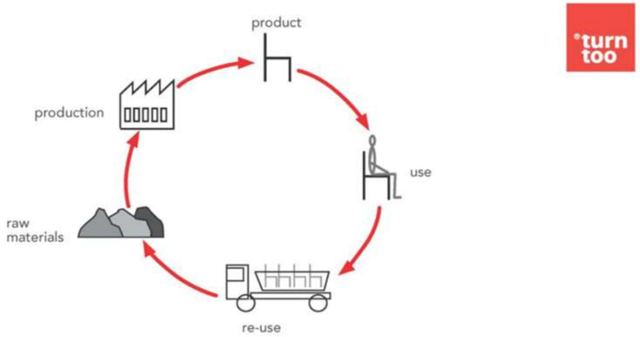
What to do?

Global context

- We are living in a **limited** world
    - ➢ Energy
    - ➢ Raw materials
    - ➢ Space
    - ➢ Maximum capacity of resilience of nature
- Ascertainment → behaviour
- **Deposit ↔ market ?**



OLD LINEAR ECONOMY - is about ownership



C2C - TECHNICAL NUTRIENT CYCLE

Global context

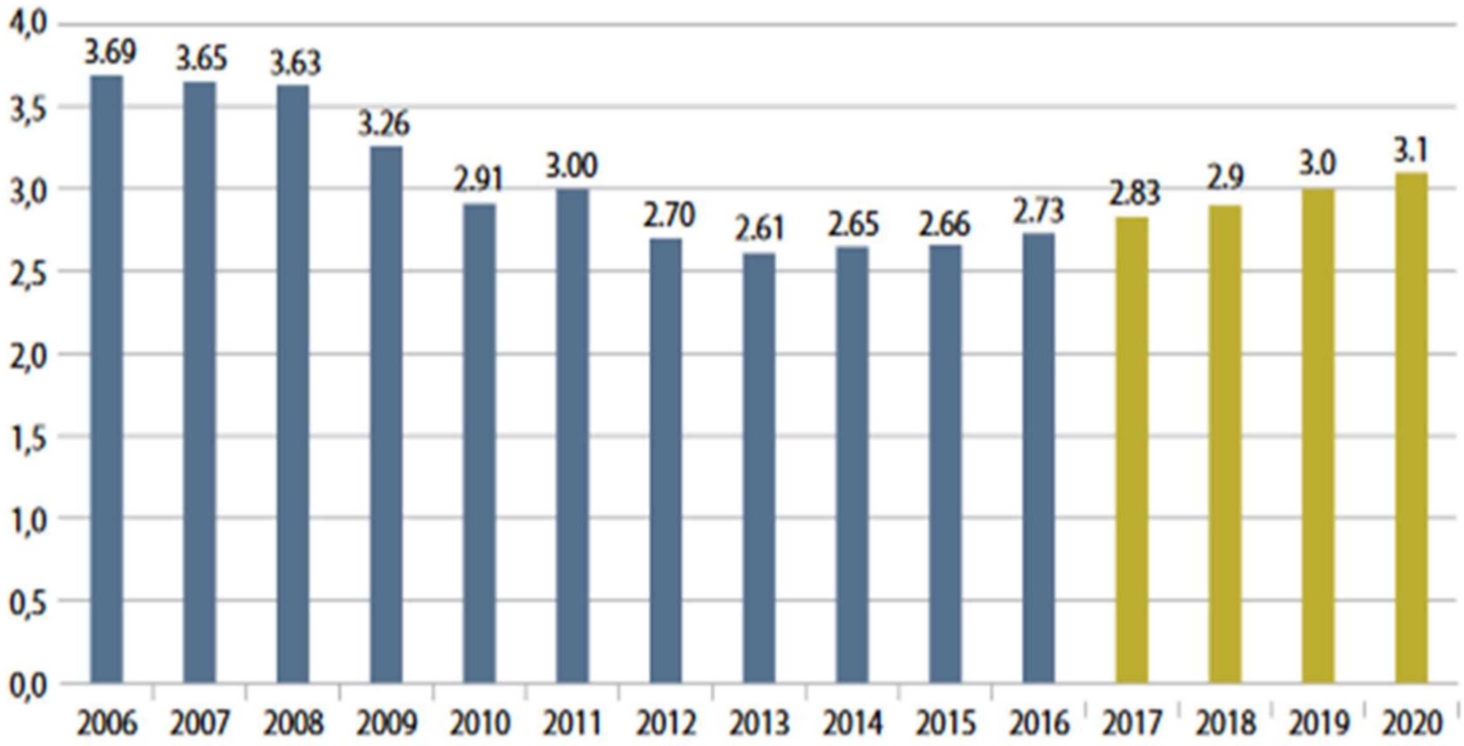
- We produce wastes
  - Between **3.4 to 4 billions tons/year** or from 80 to 126 tons/second!
  - Each day, human activity is contributing for more than 10 billions kg wastes
  - Annual production of recycled aggregates accounted for **202 million tons** in 2015
  - *Construction area is producing more or less 40% of CO_2 and 40 % of wastes*

UEPG. 2018. http://www.uepg.eu/statistics/estimates-of-production-data/data-2015

Global context

- We need construction materials
  - Cement: 4 billions tons/year (56% from China)
  - Concrete: 10 billions tons/year
  - Consumption of cement in kg/inh (2018)
    - China: 1704 kg/inh
    - EU: 309 kg/inh
    - USA: 287 kg/inh
    - BE: 550 kg/inh
  - Emission of CO_2 (2018): 5-8% world production

Global context

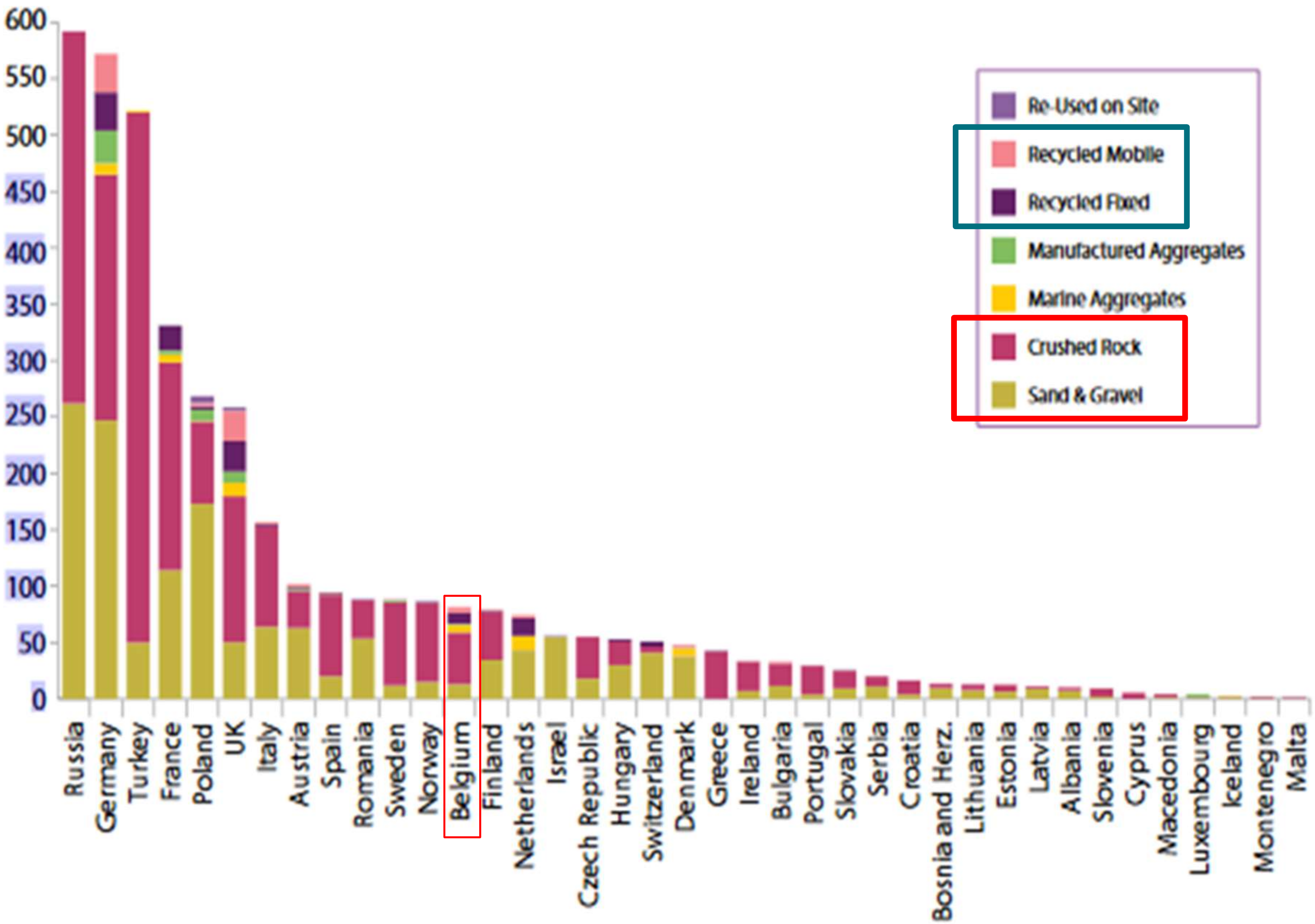


Trend in total EU + EFTA Tonnages (in billions of tonnes) for the production of aggregates

Global context

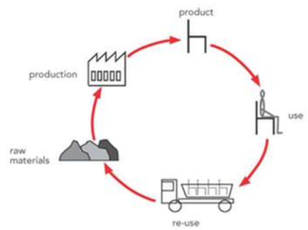
- We need construction materials
  - For the EU28 plus EFTA countries, the total 2015 **aggregates production** is estimated just on **3 billion tons**. The primary materials came from 26,000 quarries and pits, operated by 15,000 companies (UEPG 2018, http://www.uepg.eu/statistics/current-trends)

Global context



2016 aggregates production in Europe in millions of tonnes by country and type

Objectives



C2C - TECHNICAL NUTRIENT CYCLE

- 3R: Reduce, Reuse and Recycle
- Using CD&W as sub-base and base material in road construction (“less noble”)
- Meeting Sustainable Development Goals: recovery targets to 70% of construction and demolition wastes (CD&W) by 2020 in European Union (**Directive 2008/98/EC**)
- Reducing use of natural aggregates (preservation of natural resources)

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Characterization of Recycled Concrete Aggregates

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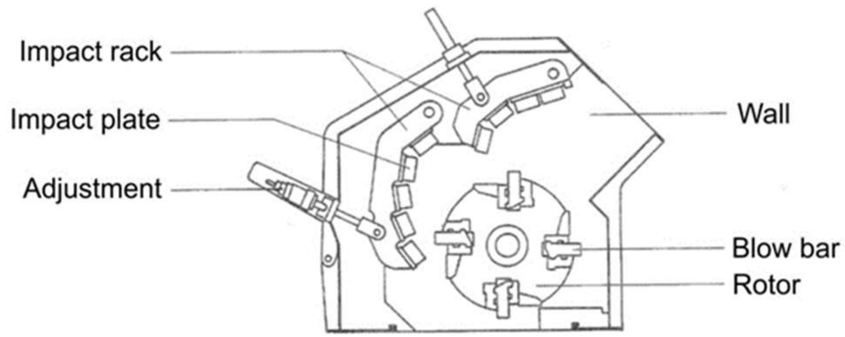
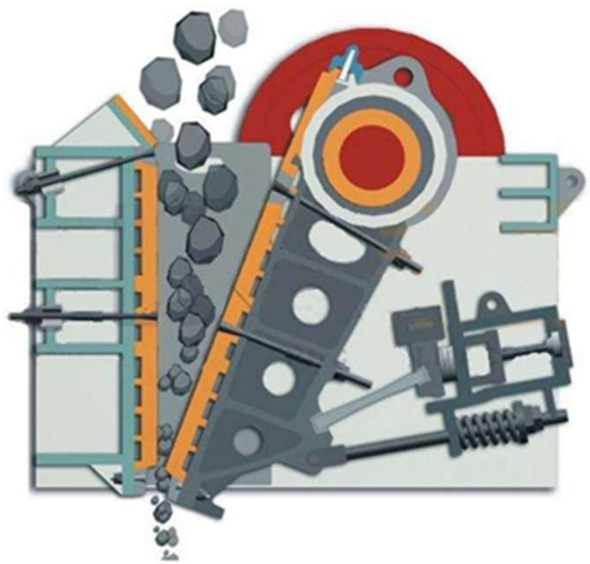
Flow sheet for material processing

Flow sheet for material processing

Material processing

- Impact crusher
  - allows producing very fine fractions
  - induces the biggest wear
  - limited by the primary size of waste to be treated
- Jaw crusher
  - to treat bulky waste like concrete slabs
  - does not allow to produce very fine particles
  - generally, requires a secondary crushing





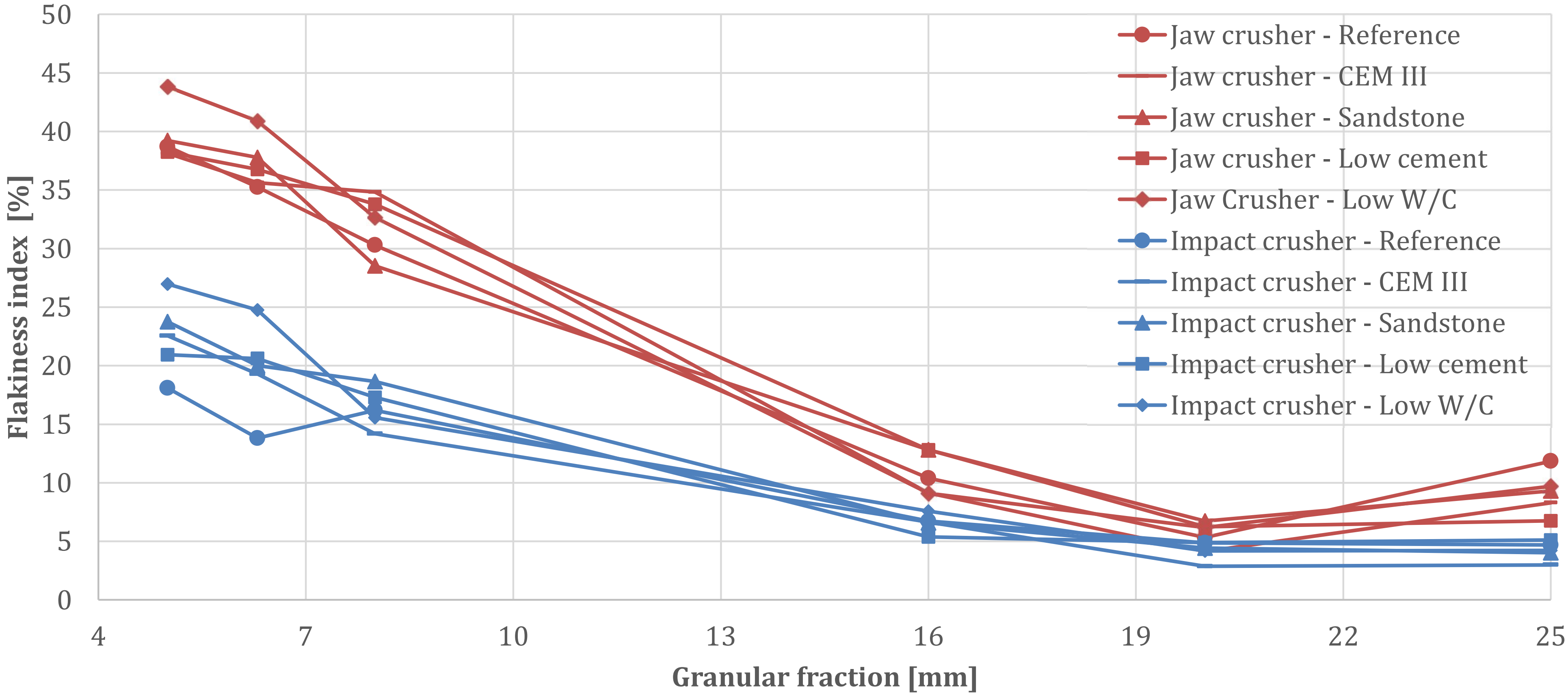
Material processing

- Experimental mixes

Name	Reference	CEM III	Sandstone	Low cement	Low W/C
Aggregates nature	Limestone	Limestone	**Sandstone**	Limestone	Limestone
Aggregates 2/7 mm (kg/m^3)	368.8	368.8	368.8	405.1	367.1
Aggregates 7/14 mm (kg/m^3)	345	345	345	379	343.4
Aggregates 14/20 mm (kg/m^3)	433.5	433.5	433.5	476.2	431.5
Sand 0/4 mm (kg/m^3)	604.9	604.9	604.9	664.4	602.1
Cement type	CEM I 52.5	**CEM III 52.5**	CEM I 52.5	CEM I 52.5	CEM I 52.5
Cement quantity (kg/m^3)	400	400	400	**320**	452
Cement paste volume (dm^3/m^3)	351	358	351	282	351
Efficient water (kg)	224.2	224.2	224.2	180.6	207.1
W/C ratio	0.56	0.56	0.56	0.56	**0.46**
Superplasticizer (g/kg cement)	0	0	0	6.8	3.3

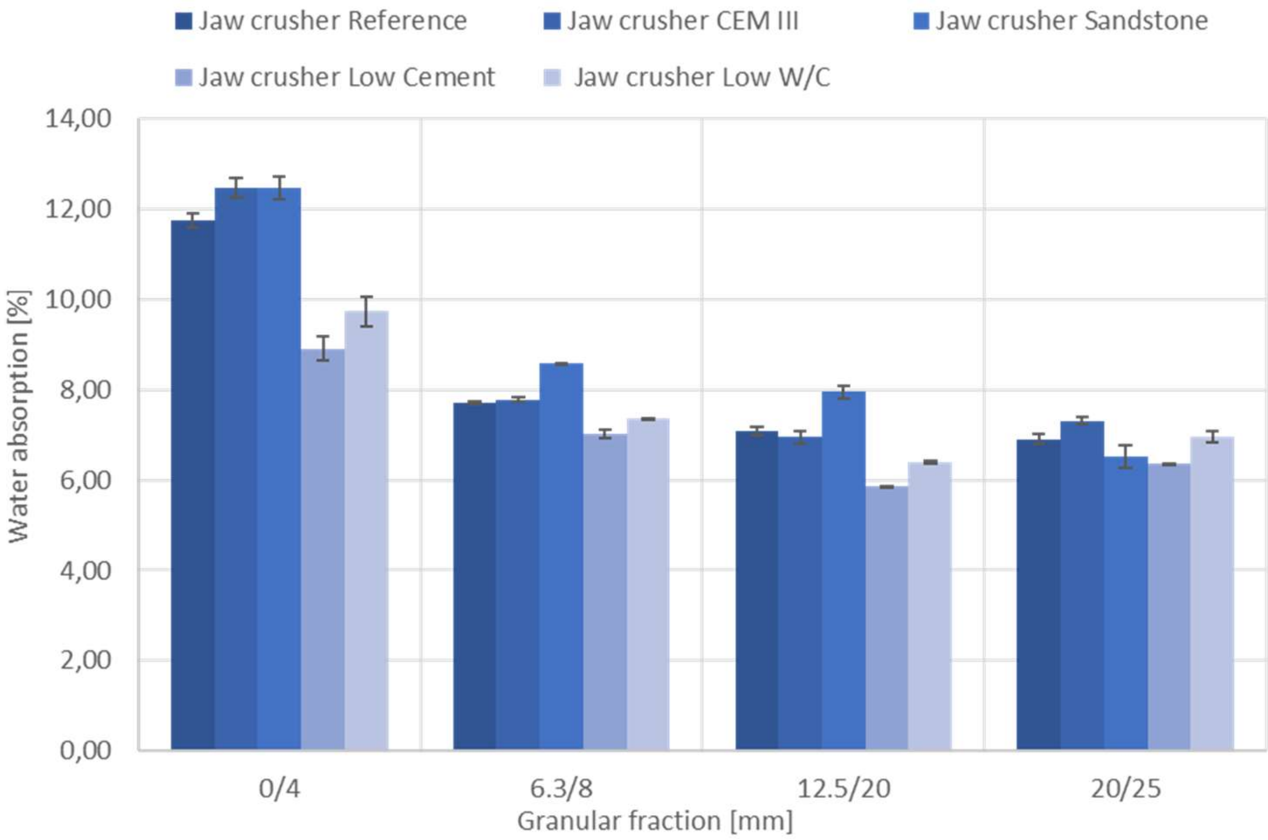
Material processing

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



Water absorption

- Water absorption for the recycled aggregates (jaw crusher) *versus* granular fraction



Recycling FRA

- Mohamed El Karim Bouarroudj. Use of reference natural materials for the design of mortars with sand and fine recycled concrete. PhD thesis (Université de Liège and Université de Lille (IMT Lille Douai)) http://www.theses.fr/2019MTLD0016

- Charlotte Colman. Gypsum residues in fine recycled aggregates: effects on mechanical and microstructural properties of cementitious composites. PhD thesis (Université de Liège and Université de Lille (IMT Lille Douai)) http://hdl.handle.net/2268/251515

- Adèle Grellier. Valorization of recycled silicate fines for designing concrete. PhD thesis (Université de Liège and Université de Lille (IMT Lille Douai)) http://hdl.handle.net/2268/252184

- Makara Long. Rammed Concrete with Recycled Fine Aggregates. Mst thesis. University of Liège, 2021

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Effect of gypsum residues in fine recycled aggregates

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Research context

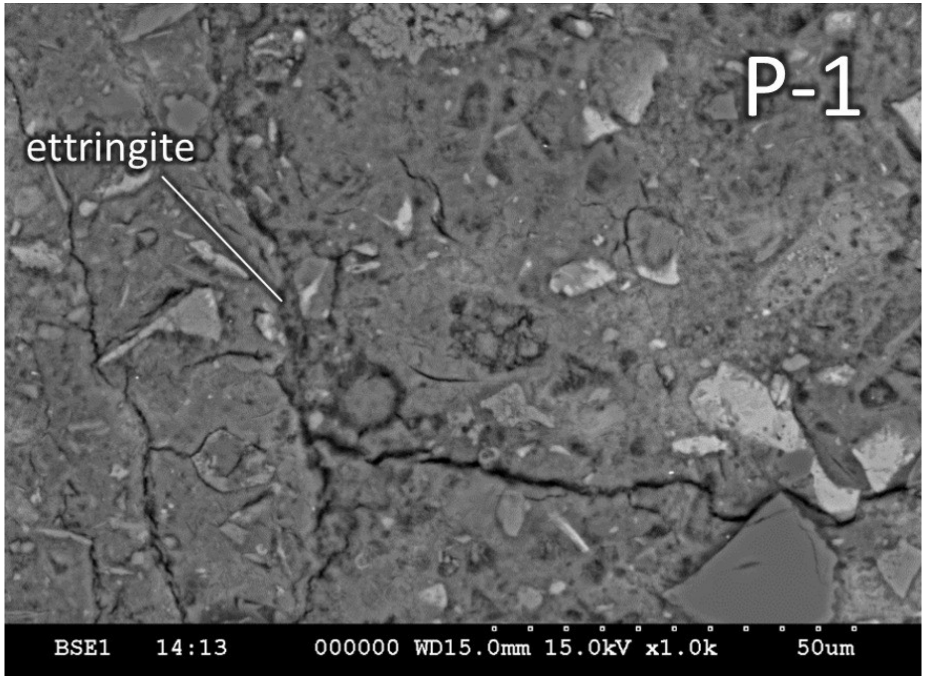
Recycled aggregates, and especially the finer fraction (0/4 mm) are often not valorized because of their residual gypsum ($CaSO_4.2H_2O$) content.

Standard EN206 species a maximum of 0.2 mass% of water soluble sulfates in recycled aggregates.

Sulphate attack

$$3(CaSO_4 \cdot 2H_2O) + 3CaO \cdot Al_2O_3 + 26H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3(CaSO_4) \cdot 32H_2O$$

Secondary ettringite fills up pores, cracks and causes internal pressure.



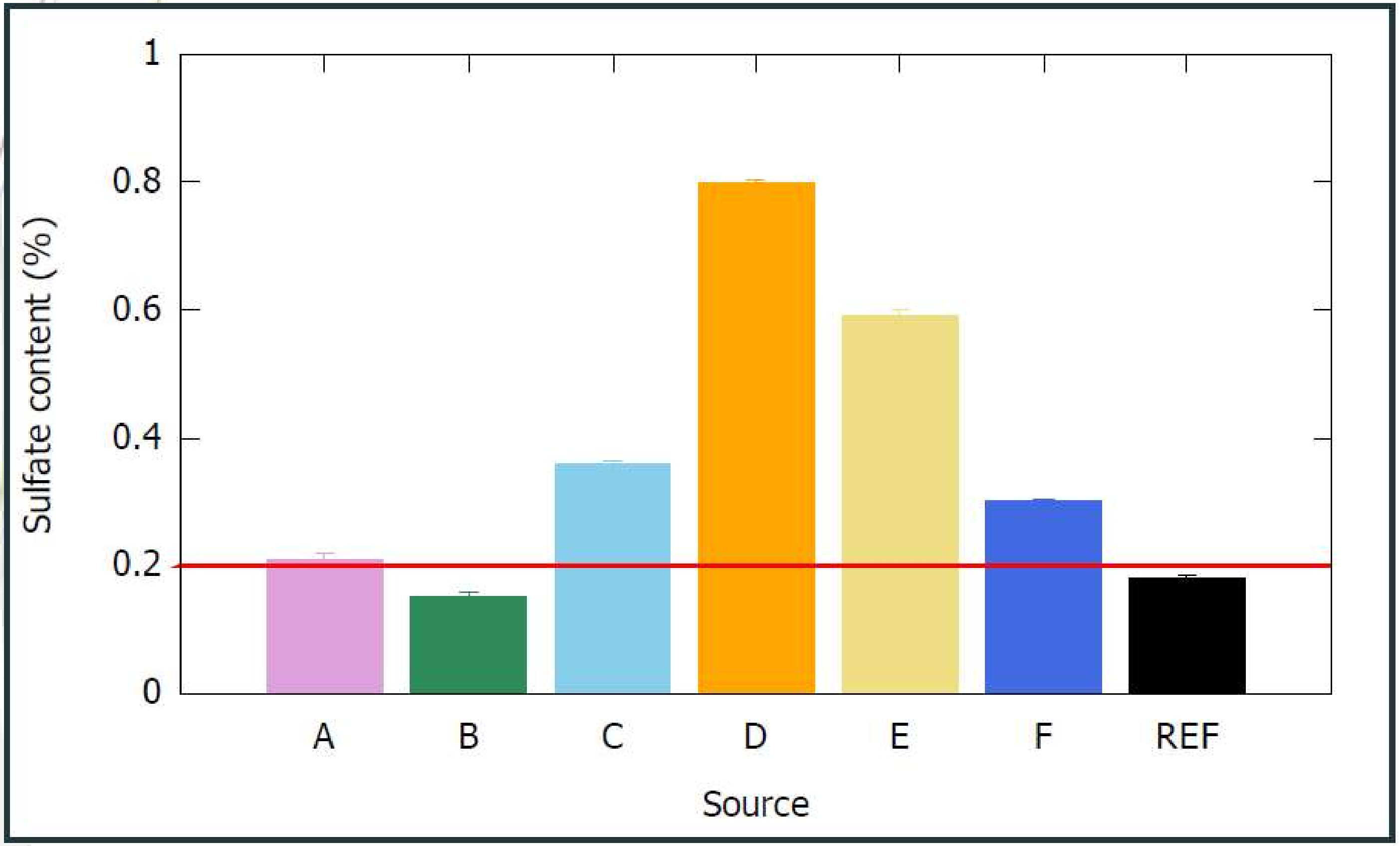
Sulphate attack

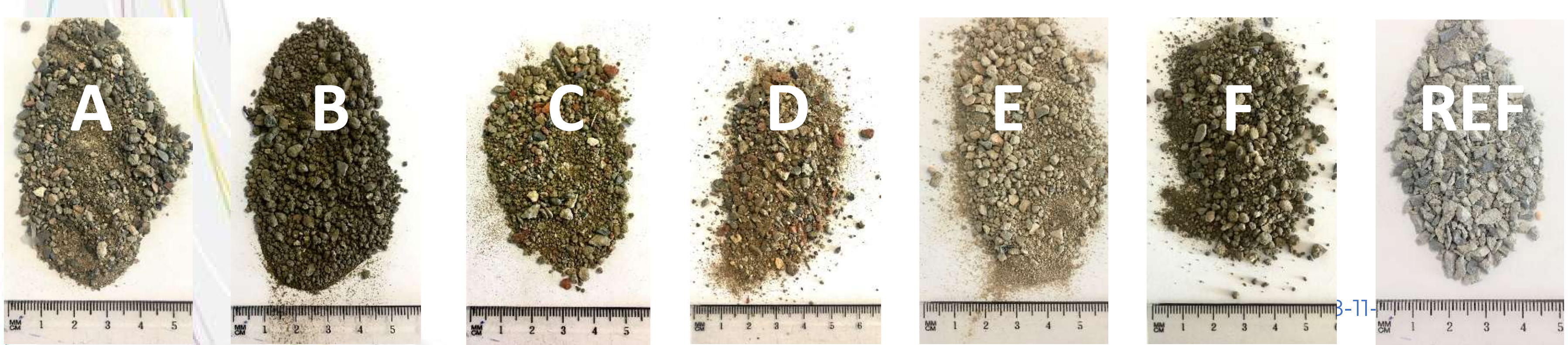
$$3(CaSO_4 \cdot 2H_2O) + 3CaO \cdot Al_2O_3 + 26H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3(CaSO_4) \cdot 32H_2O$$

The macroscopic result of secondary ettringite formation is a swelling.

Divet et al., 2001

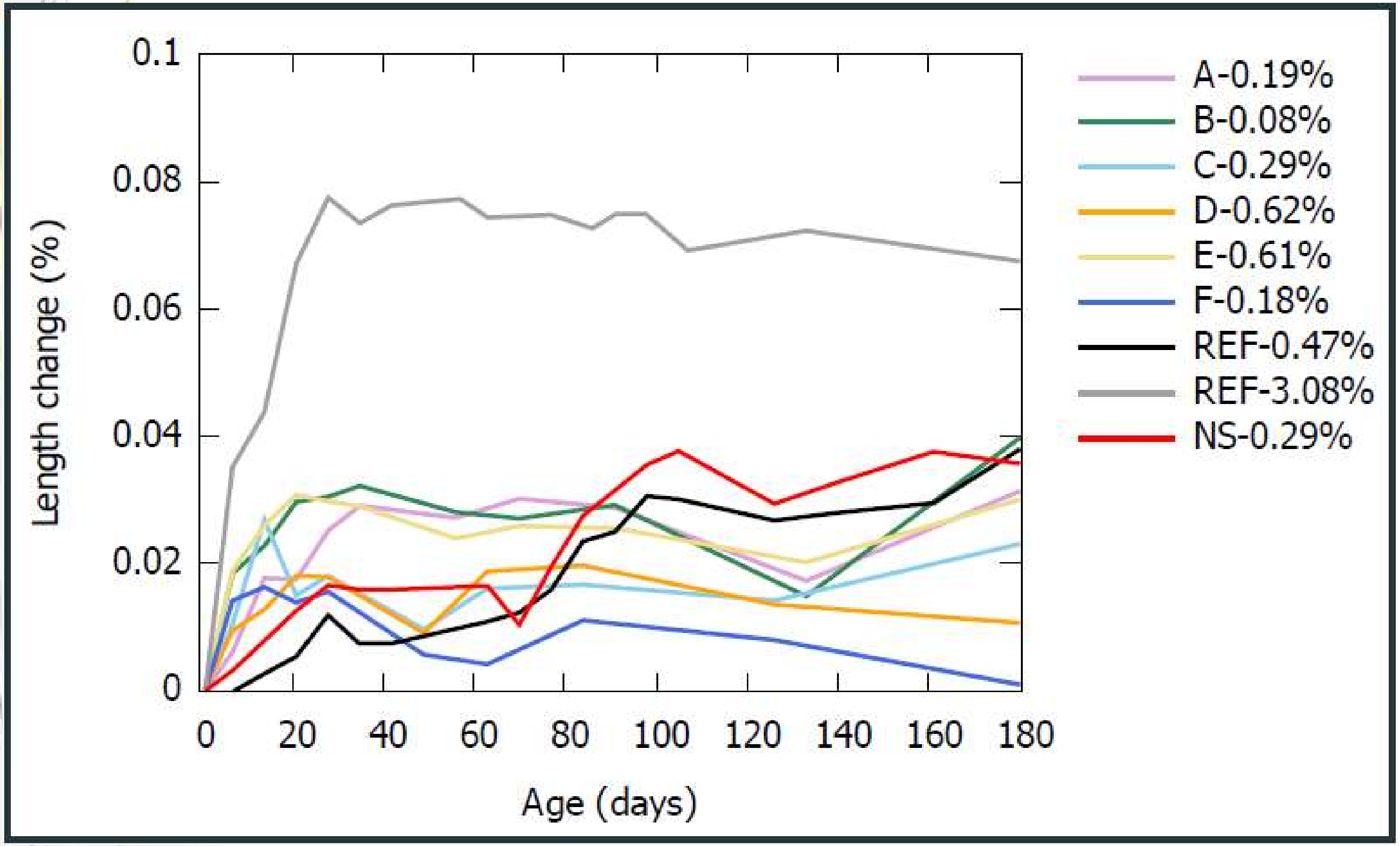
Sulphates in fine RA





Sulphates in fine RA

A very high sulfate level was needed to obtain significant swelling on mortars with fine recycled aggregates.



Sulphates in fine RA

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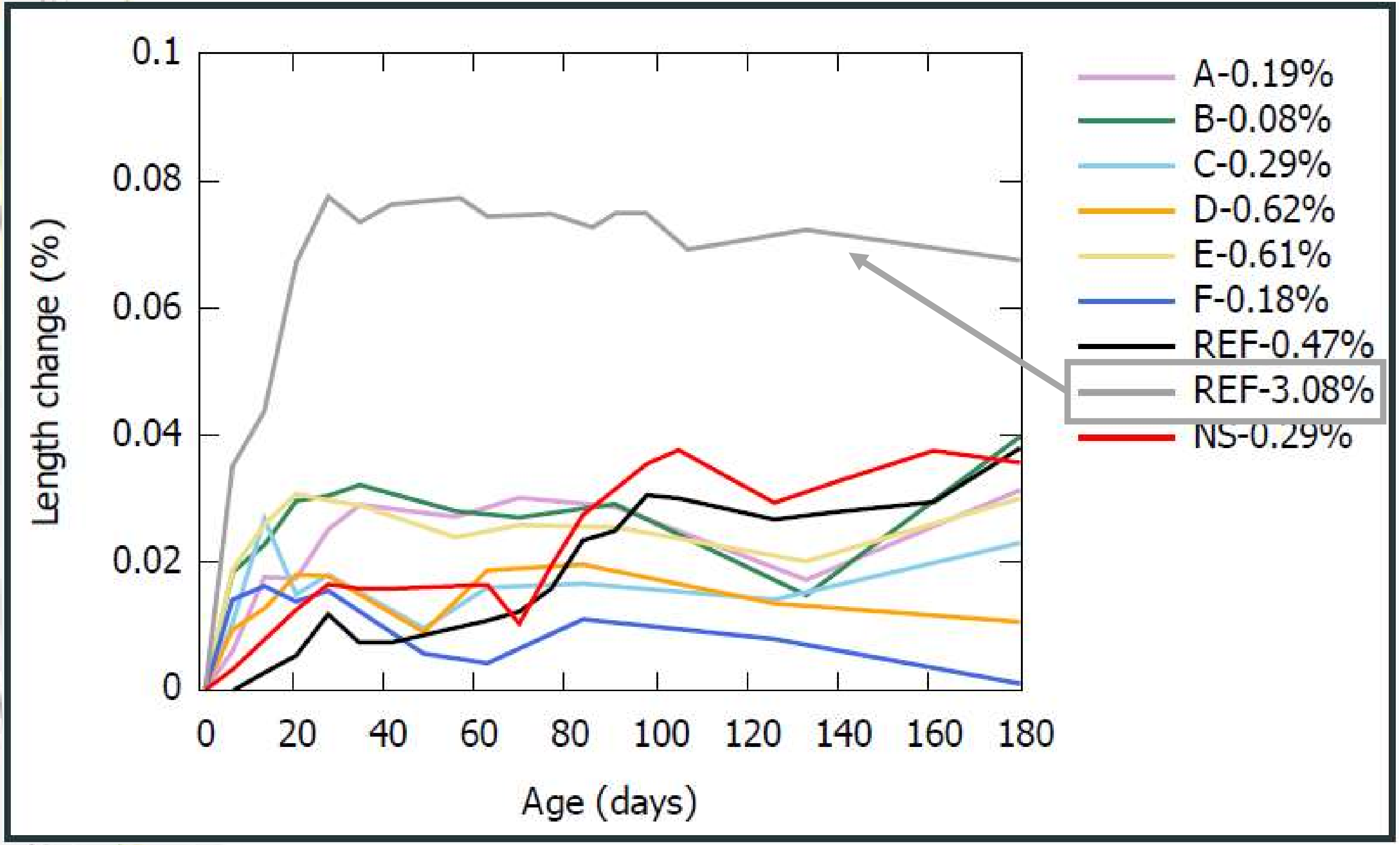
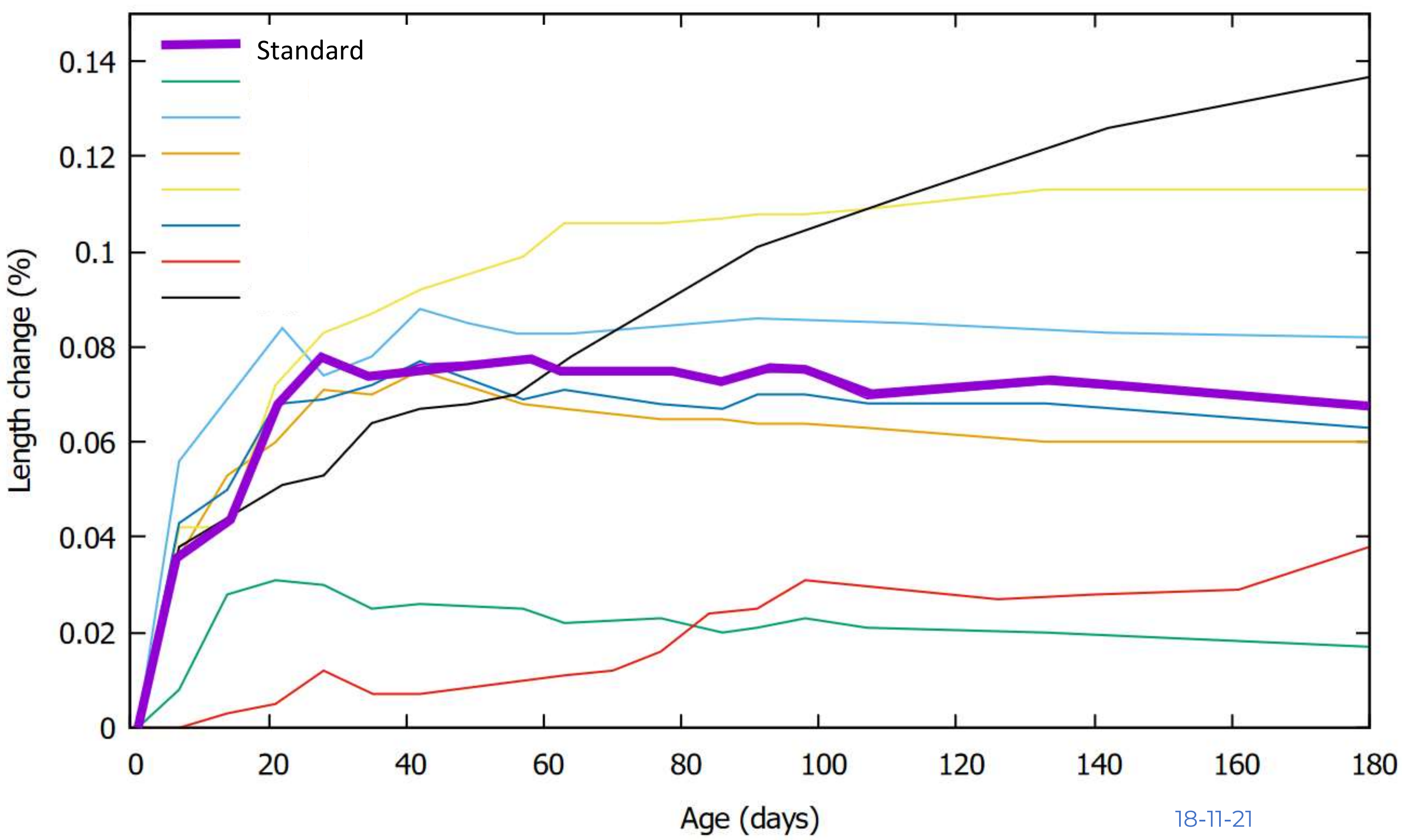


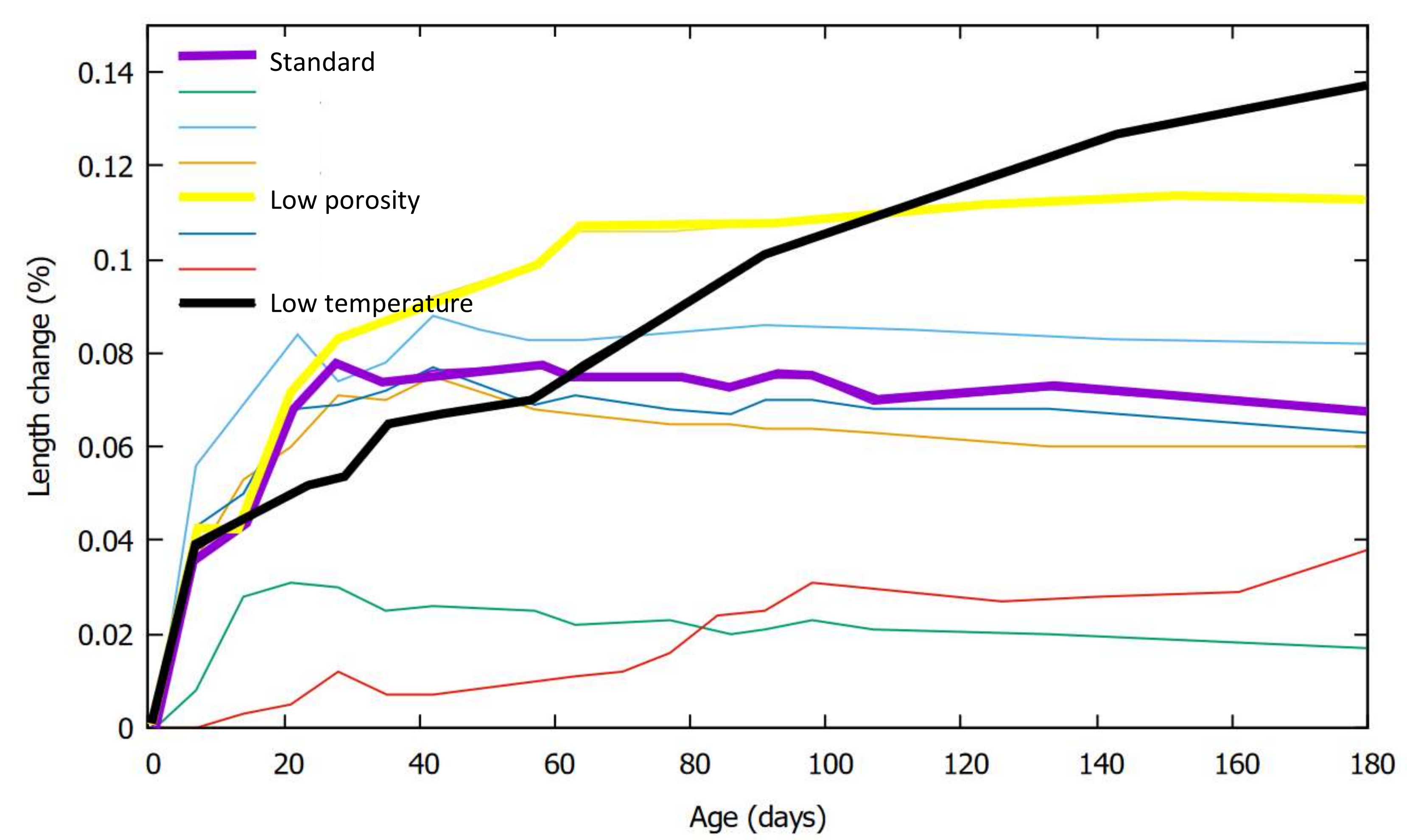
Parameters influencing the reaction

Expansion of mortars made with fine recycled aggregated and a high sulfate content.



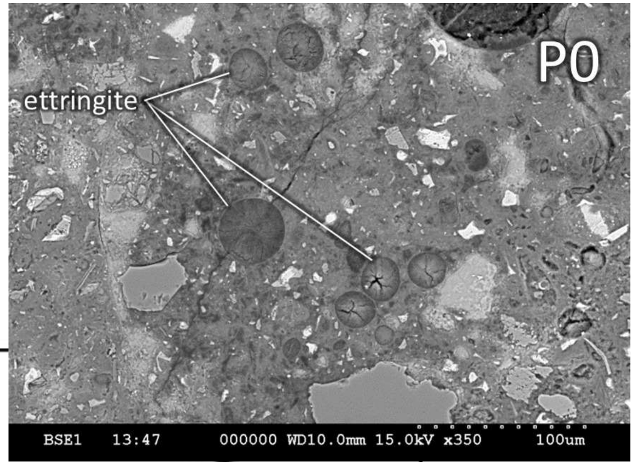
Parameters influencing the reaction

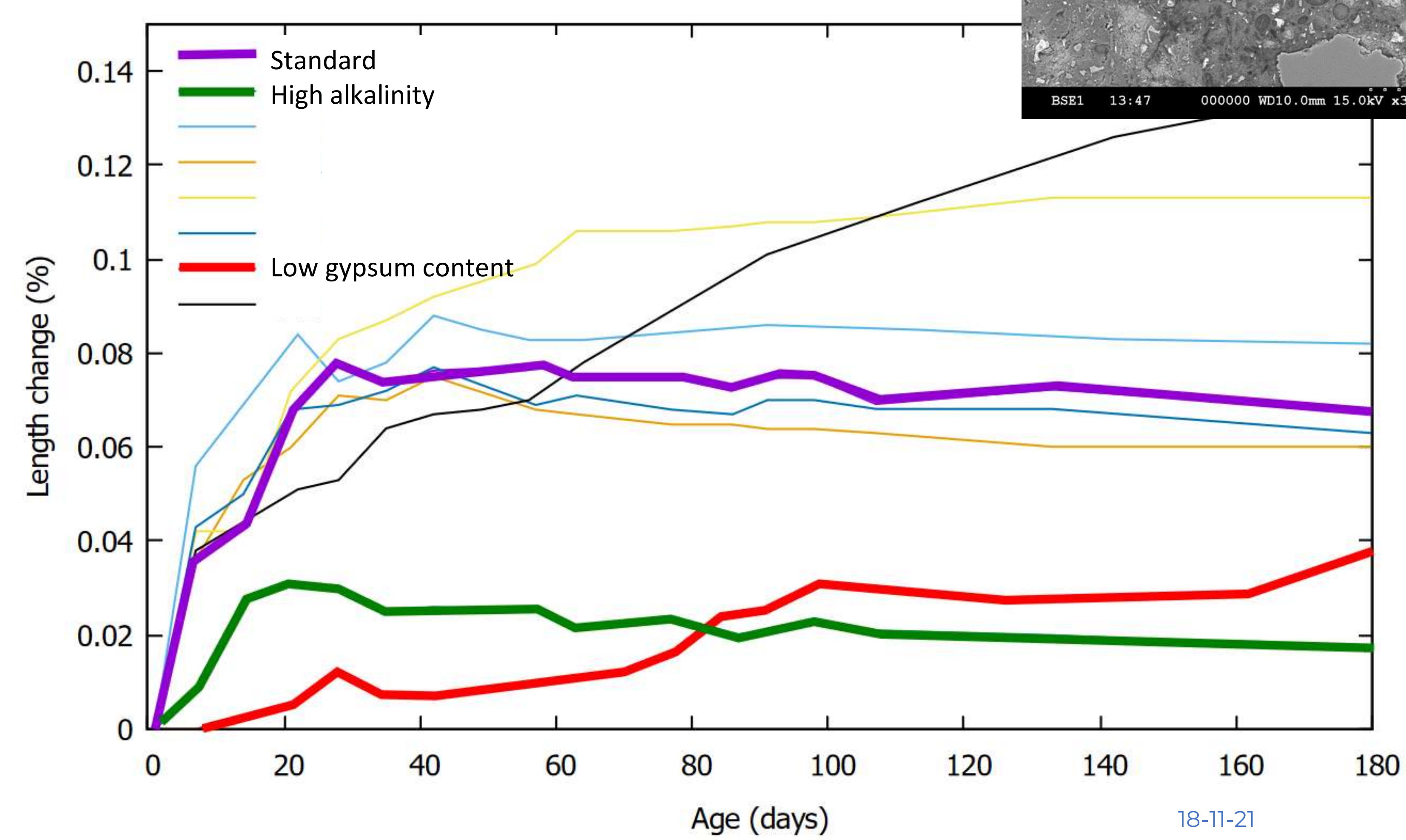
Two factors increased expansion: low storage temperature (carbonate source!) and low porosity (low water content).



Parameters influencing the reaction

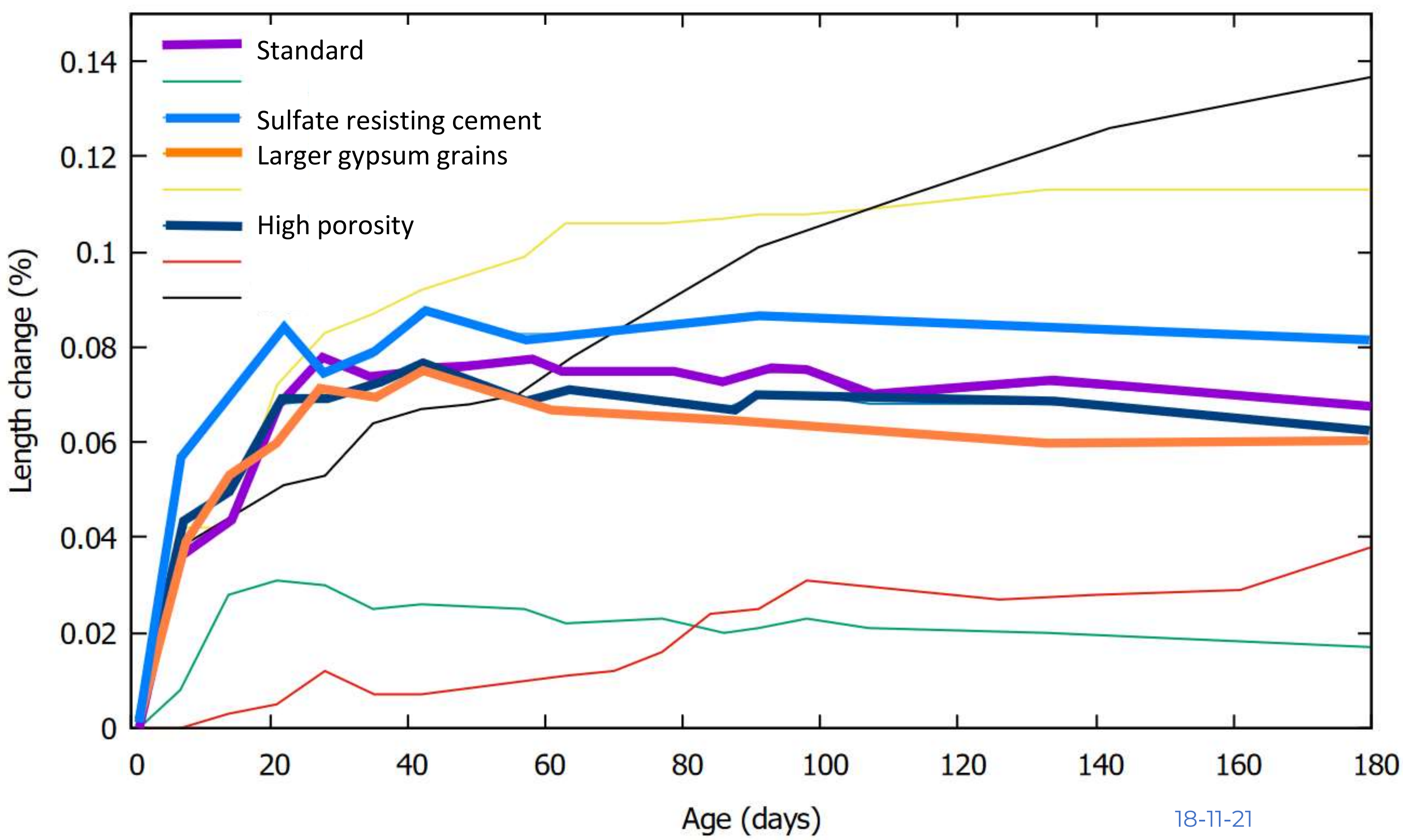
Two factors increased expansion: high alkalinity (ASR!) and low sulfate content.





Parameters influencing reaction

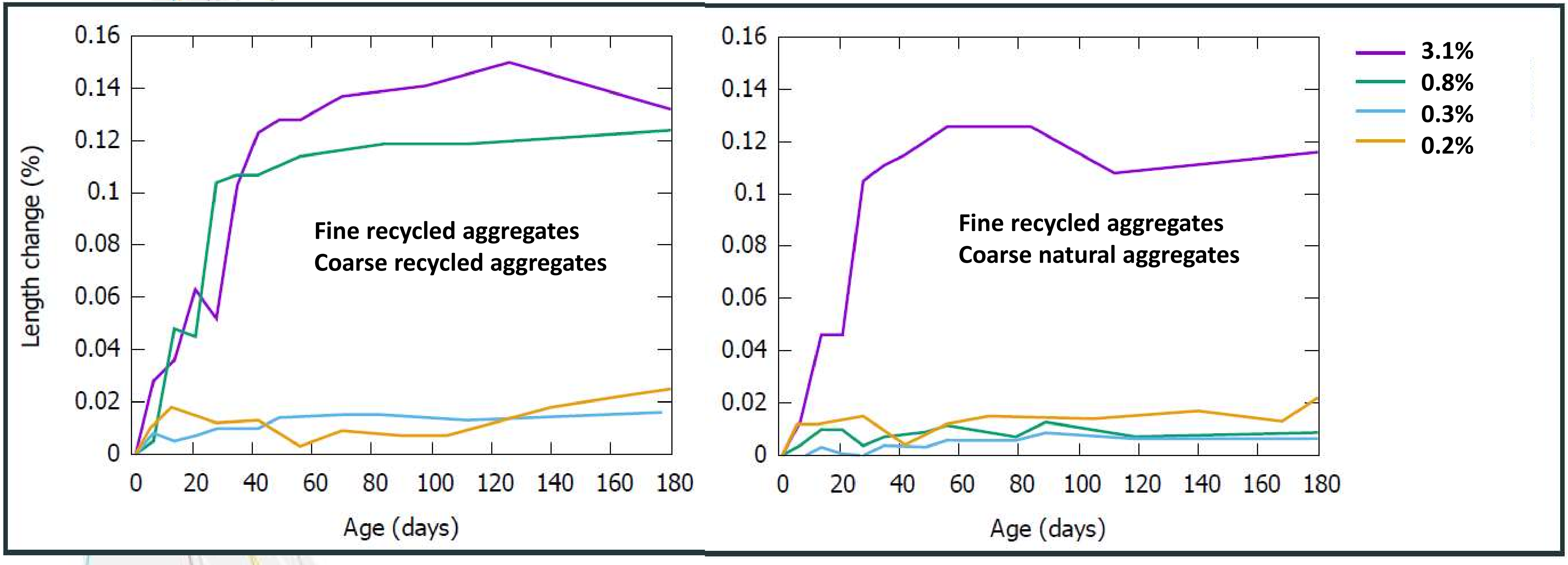
Three factors did not have an influence: High Sulfate Resisting cement, large gypsum particles and high porosity (high water content).



Sulphate limits

Concrete with all recycled aggregates: at least 0.3% of sulfates is safe

Concrete with only fine recycled aggregates: up to 0.8% of sulfates is safe



Conclusions and perspectives

- ✓ Large variations between the different sources of industrial FRA, sulfates are predominantly present in the smaller size fractions.
- ✓ A sulfate content in FRA up to 0.3 % was always safe, but higher sulfate contents could be possible depending on the mix design (type of coarse aggregate, mix design)
- ✓ The sulfate contents routinely found in industrial FRA did not cause any swelling.

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Brick fines valorization

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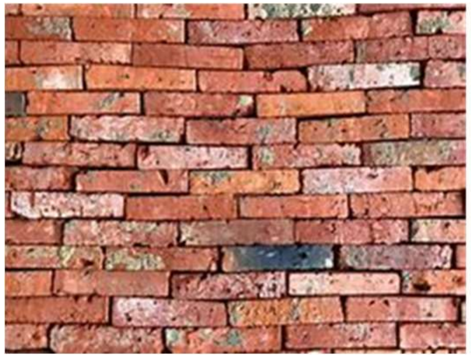
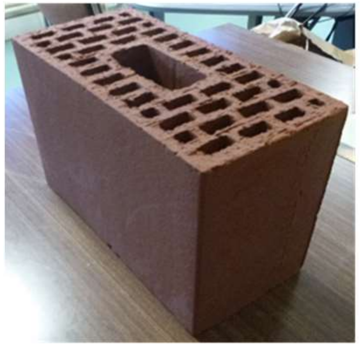
Objectives

- Brick waste flow: 1-2 % C&DW
- Recycling
  - Bricks reused in construction industry
  - Production of aggregates for embankments
  - Brick fines
- Brick fines
  - Increasing specific surface
  - Activating amorphous components



Preparation of brick fines



Bloc 238x138x138 mm

Concassage →

Concasseur à mâchoire

Broyage →

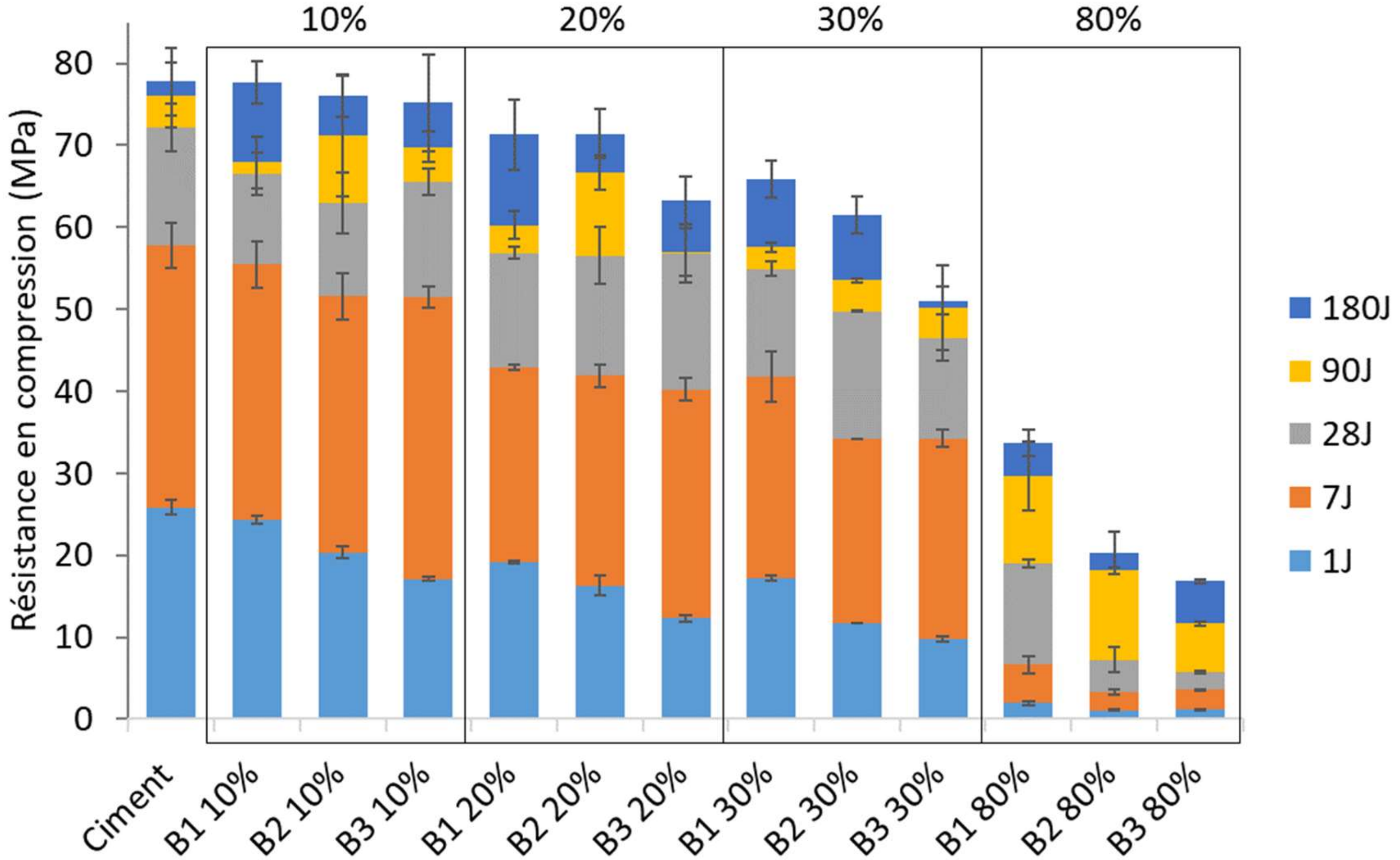
Broyeur à boulets

Crushing *Jaw crusher* *Grinding* *Impact crusher*

Preparation of brick fines

- Reference brick fines
  - 3 granulometries
    - B1 : d_{50} = 3.3 µm (with supplementary cyclocrushing)
    - B2 : d_{50} = 20 µm
    - B3 : d_{50} = 191 µm
  - Percentages of substitution: 10, 20, 30 and 80%

Compressive strength



- ↗ fines content ↘ strength but even 30% substitution is OK for B2
- Quicklier strength increase for B1

Conclusions

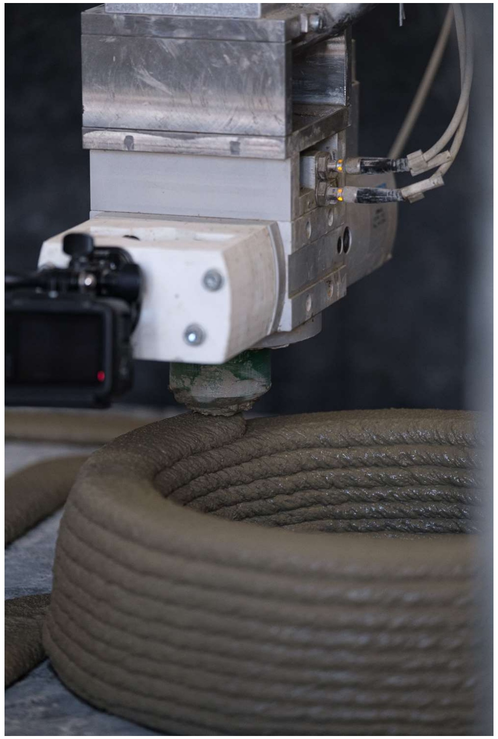
- It is possible to recycle C&DW fines!

Prefabricated concrete

Concrete blocks

Rammed concrete

Parkour park



3D printing

Acknowledgment

- VALDEM INTERREG FWVL
  - "Integrative solutions for the valorization of CDW for transborder circular economy" - *http://www.valdem-interreg.eu*
- CirMAP INTERREG NWE
  - "Design and manufacture of customized 3D printed urban furniture using recycled sand" - https://www.nweurope.eu/projects/project-search/cirmap-circular-economy-via-customisable-furniture-with-recycled-materials-for-public-places/
- SeRaMCo INTERREG NWE
  - "Secondary Raw Materials for Concrete Precast Products (introducing new products, applying the circular economy)" - *http://www.nweurope.eu/seramco*

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Interreg North-West Europe EUROPEAN UNION SeRaMCo European Regional Development Fund

Interreg North-West Europe EUROPEAN UNION CIRMAP European Regional Development Fund