University of Liège
Meeting LEMIT-ULiège

31.05.22

UEE
Urban and Environmental Engineering

www.uee.uliege.be

Liège in Belgium

Birthplace of Charlemagne

Witness of a millenary principality

Economic capital of Wallonia

Liège in Belgium

Coal mining,
steelmaking,
weaponry

Aerospace, logistics,
mechanics,...

Exceptional post-
industrial and
natural environments

University of Liège

A widespread campus in the heart of nature

26.863 students among which 22% foreigners

11 faculties (Science, Applied Science, Medicine,…)

Institutional context

1 out of the 4 research units of the ULiège Faculty of Applied Sciences (School of Engineering and Computer Science)

- Urban & Environmental Engineering (UEE)
- Electrical Engineering & Computer Science (Montefiore Institute)
- Aérospatiale & Mécanique (A&M)
- Chemical Engineering

Department and research unit

The Department = in charge of teaching activities
Department name = ArGEnCo
(for Architecture, Geology, Environment and Constructions)

The Research Unit = in charge of the research activities
Research Unit name = Urban and Environmental Engineering

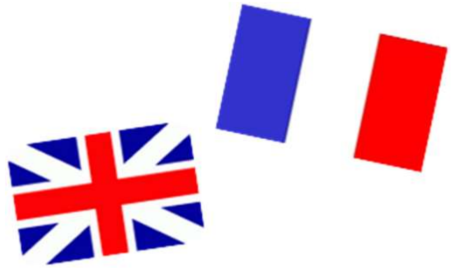
But same people behind…

Department and research unit

Urban and Environmental Engineering research Unit (UEE) Architect ure, Geology, Environment and Construction Department (ArGEnCo)

- 200 professors, researchers, technicians
- 11 laboratories
- 3 masters (civil, architectural and geological engineering)
- 316 students (Bachelor and Master degrees)
- 17.10^{6} euros cash flow (March 2020)
- 87 PhD students (2022)
- 93 on-going research projects

Master Programs



Accredited at European level EUR-ACE Label & CTI

3 civil engineer master degrees

Geology and Mining Engineering
Civil Engineering
Architectural Engineering

2 specialized master's degrees

Urban and regional planning
Transportation management

Continuing education programs

Auscultation et réparation des ouvrages en béton
BIM
MOCC ConstruiREcycler

About our research

Urban and Environmental Engineering

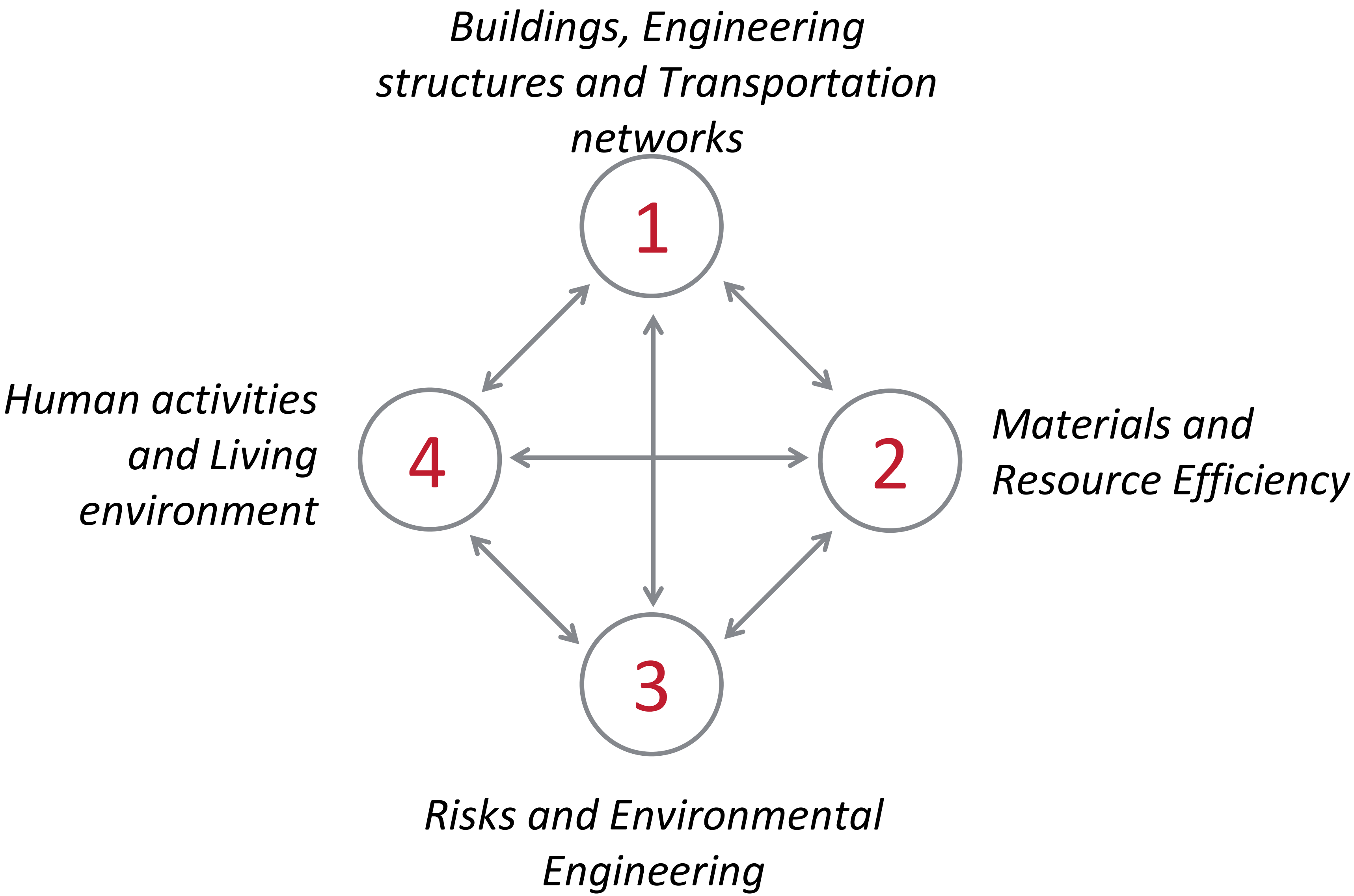
- Developing advanced scientific methods and experimental protocols aimed at fostering a sustainable development, transformation and exploitation of built and natural environments.

- Our research activities typically combine theoretical and numerical modelling, laboratory experiments and field tests to deliver highly innovative simulation, characterization, processes, design or decision-making tools.

- Based on a close partnership with a wide range of enterprises/institutions and on fundamental research funding. Research and teaching & training activities are intimately linked and mutually benefit from each other.

Urban and Environmental Engineering

Four closely intertwined research axes



Urban and Environmental Engineering

A&U – Architecture and Urbanism

- **Sustainable architecture** and sustainable urban development
- Modeling of urban and building systems
- Design engineering

GeMMe – Minerals, Materials and Environment

- **Georesources** and Geoimaging
- **Resources** Efficiency
- Circular economy of **minerals and metals**
- **Concrete surface engineering** and **repair**
- **Bio-based and recycled building materials**

GEO³ – Geotechnics, Hydrogeology & Environmental Geology, Applied Geophysics

- **Environmental Geomechanics**
- Numerical modelling of geostructures
- Groundwater quality /pollution assessment and management
- Characterization and modelling of groundwater quantity and quality
- Hydrogeophysics characterization, monitoring and inverse modeling

MS²F – Mechanics of the Solids, Fluids and Structures

- Engineering hydraulics and flood risk management
- **Multiscale approaches for metallic material behavior**
- Stability of structures and their robustness in case of exceptional events
- Physical-numerical modelling in civil and environmental engineering

SE – Structural Engineering

- Structural and Stochastic Dynamics
- **Concrete** Structures under Extreme Loading, Fire Safety of Structures
- Hydraulic Structures - Ship and Offshore Structures

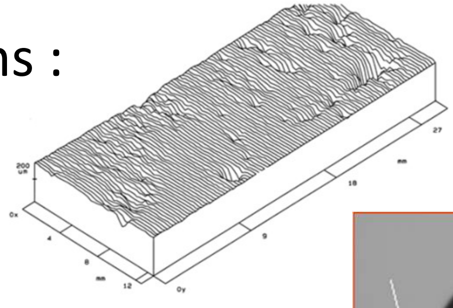
Urban and Environmental Engineering

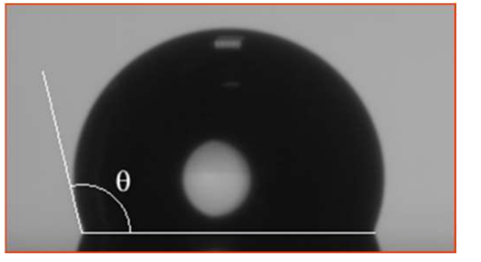
Eleven large testing facilities

- **Building Materials Laboratory**
- Engineering Hydraulics Laboratory
- Fire Resistance Testing Laboratory
- Geotechnologies Laboratories
- Inorganic Hydrochemistry Laboratory
- Laboratory of Human Motion Analysis
- Laboratory for Materials and Structures
- Minerals Engineering and Recycling Laboratory
- The Digital Studio Lab
- Towing tank

GeMMe Building Materials

- Surface properties of inorganic materials
- Design of concrete and transport mechanisms : diffusion, capillary suction,...
- Repair techniques and materials
- Materials recycling/bio-based products
- Concrete carbonation (CO_2)
- *Increasing the quality of compressed earth bricks in Burkina Faso*





New projects

BEXTRUS (2022-2024): designing mixes for 3D printing (modelling, durability of mixes for civil engineering and refractories)

Mineral Loop (2022-2026): recycling mineral wastes by means of carbonation treatment for the production of fillers and sands for industry

ReMIND CARBOC (2022-2025): accelerated carbonation of municipal solid waste aggregates

ReMIND CIBER (2022-2026): prefabricated structural elements for clading with recycled concrete aggregates

Coming soon

- *SARE4BE:* Recycling sand recycled aggregates into concrete
- *Déchets-ressources:* Prefab elements with earth and fine recycled aggregates for rammed concrete
- *FEDER Trîxhe :* Brownfields for molecules and wooden concrete
- *FEDER Magritte:* Development of concrete with river and chenal sediments
- *INTERREG NWE ReBuild*: existing concREte structures in a circular BUILDing industry

Coming soon

- *GreenWin GeoSlags:* Geopolymers with iron steel slags
- *FEDER DUNE^{3}S:* Circularity and upscaling of primary and secondary fine mineral aggregates
- *UpFRA*: Upcycling of fine recycled aggregates for eco-efficient mortar and concrete
- *PRD HaBiMo:* Bio-climatic and modular construction with compressed earth bricks in Ouagadougou (Burkina Faso)

MOOC recycling

https://www.news.uliege.be/cms/c_9884429/fr/nouveau-mooc-construirecycler

Programme FEDER 2014 - 2020

www.enmieux.be

FEDER

UNION EUROPEENNE

Wallonie

LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL
ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

Portefeuille de projet

ECOLISER

MISE AU POINT D'ÉCOLIANTS POUR TRAITEMENT,
ÉTANCHÉITÉ ET ROUTES

Budget ULiège
680.000,94 €

Part FEDER : 40 %
Part Wallonie : 60 %

CTP member of EMRA

MateriaNova MATERIALS R&D CENTRE

LIÈGE université

certech centre de ressources technologiques en chimie

ULB UNIVERSITÉ LIBRE DE BRUXELLES

INISMa member of EMRA

Mise au point d'ÉCO-Liants, pour traitement des Sols, Étanchéité et Routes (ECOLISER)

Main Objectives

-Improve the mechanical properties of unpolluted soil

-Develop the Eco-binders for the soil treatment, permeability and road construction

01/09/2016-31/08/2020

Biomass fly ash: characterizations and formulation

Chemical compositions determined by XRF (%)

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
Classical fly ash	49.3	27.7	7.9	1.6	1.4	0.8	4	0.3	6.6	100.4
Biomass fly ash	24.7	5.3	3.2	9.3	25.8	2.3	7.9	4.9	9.7	94.3
CEM I 52.5 N	20.2	4.8	3.3	1.8	64.2	0.3	0.5	0.4	1.1	100

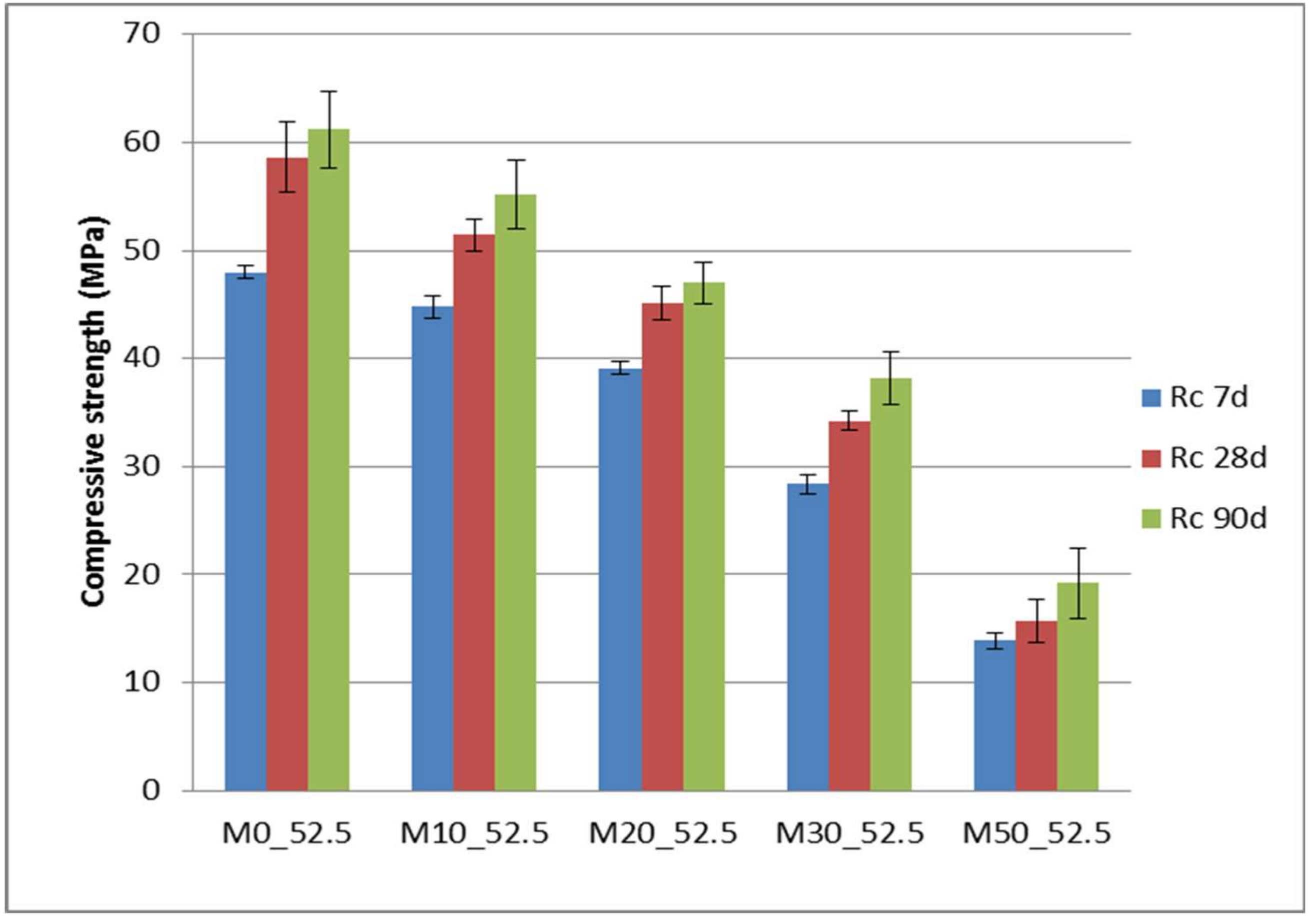
Compositions of mortars

	M0_52.5	*M10_52.5*	*M20_52.5*	*M30_52.5*	*M50_52.5*
Sand (g)	1350	1350	1350	1350	1350
Cement (g)	450	405	360	315	225
Biomass fly ash (g)	0	45	90	135	225
Efficient water (g)	225	225	225	225	225
$E_{eff}/(C+B)$	0.5	0.5	0.5	0.5	0.5

Replacing cement by biomass fly ash at different levels (0%, 10%, 20%, 30% and 50%)

Same Water/(Cement + Biomass fly ash) Ratio

Mortars with biomass fly ash: Rc



- Compressive strengths of mortars after 28 days decreased when the substitution of cement by biomass fly ash increased
- The compressive strength of mortars (M10_52.5 and M20_52.5) are around 87.7% and 76.8% of the reference mortar respectively

VALDEM INTERREG FWVL research project

VALDEM INTERREG FWVL research project

- Integrated solutions for the valorization of Construction and Demolition Wastes. Transborder approach of circular economy - *http://www.valdem-interreg.eu*

3 PhD thesis

Design and properties of SCC with filler from recycling C&DW (M.K. Bouarroudj)

Gypsum residues in recycled materials: chemistry and effects on microstructural and mechanical properties of cementitious mortars (Ch. Colman)

Valorization of fine particles from brick and tile crushing into concrete (A. Grellier)

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Sciences Appliquées

Gypsum residues in recycled materials

UEE
Urban & Environmental Engineering

Research context

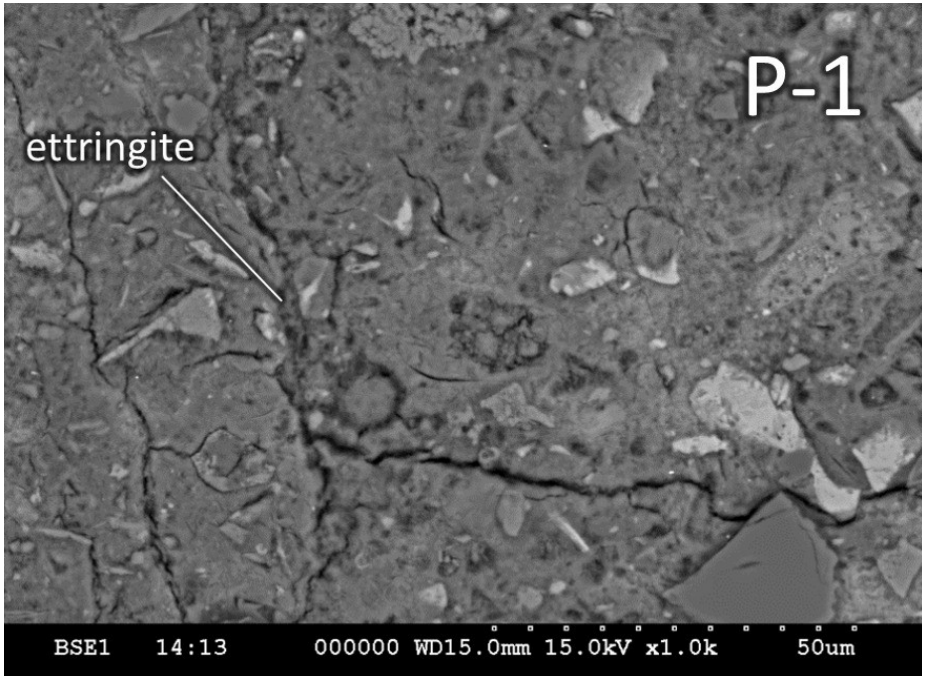
Recycled aggregates, and especially the finer fraction (0/4 mm) are often not valorized because of their residual gypsum ($CaSO_4.2H_2O$) content.

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.



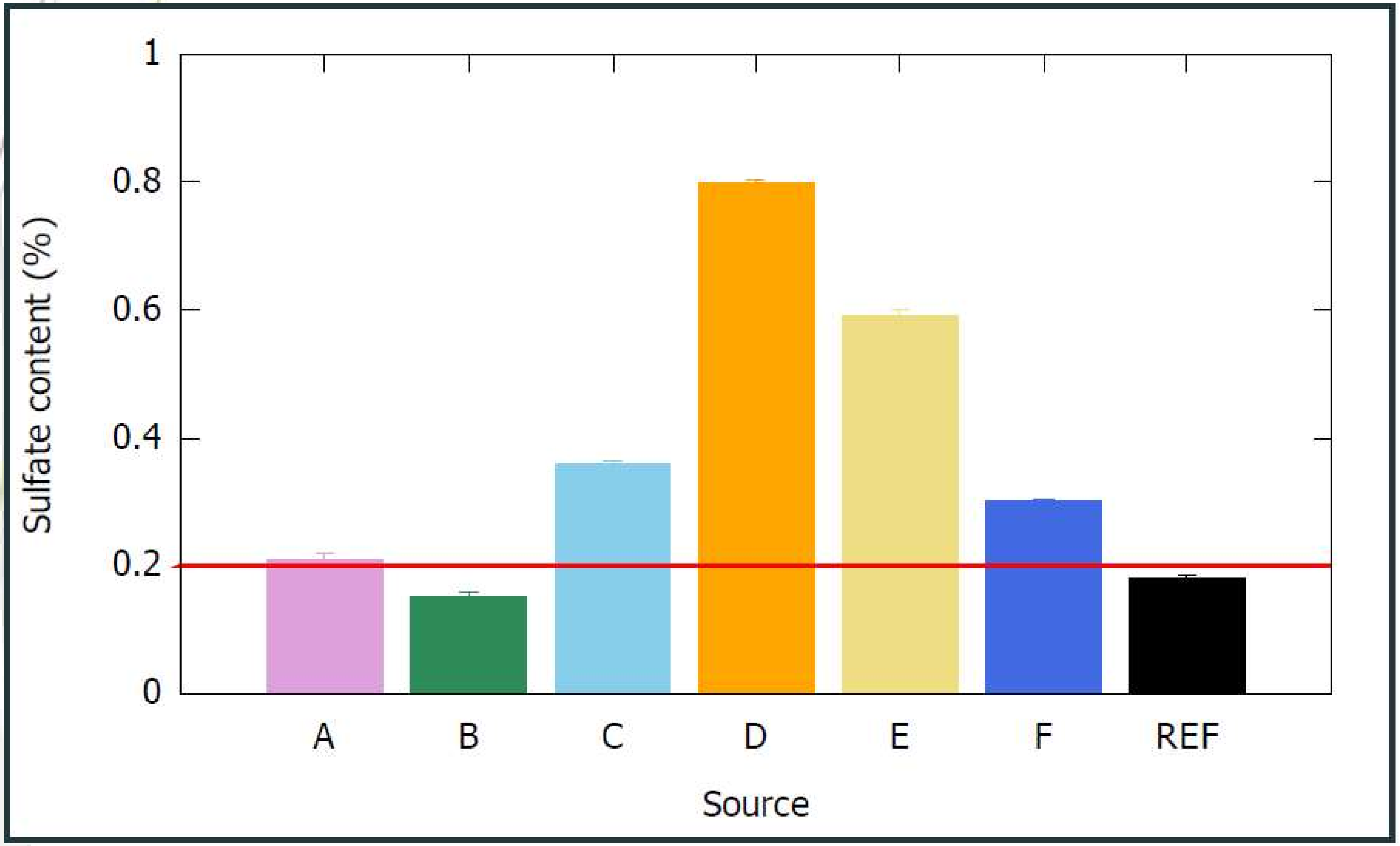
Sulphate attack

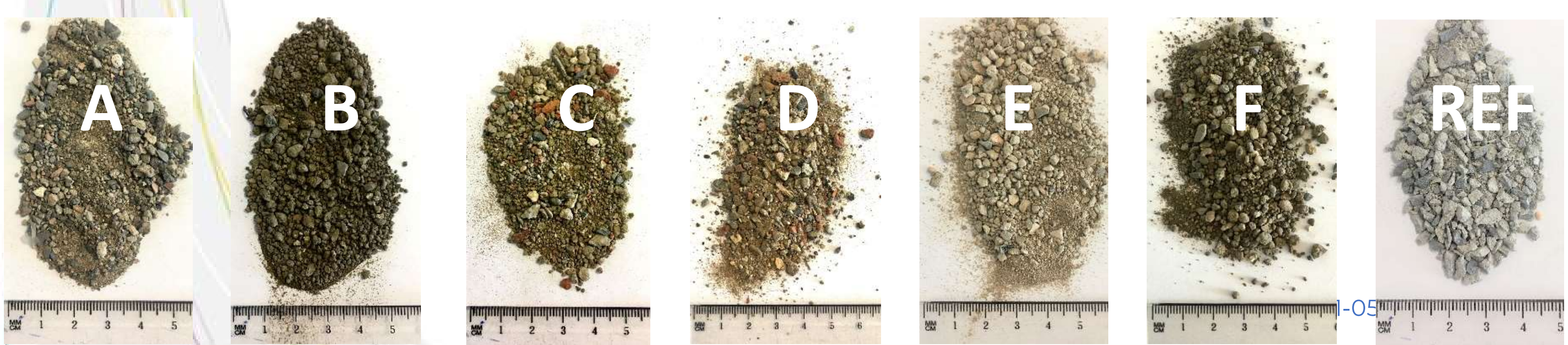
$$3(CaSO_4 \cdot 2H_2O) + 3CaO \cdot Al_2O_3 + 26H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3(CaSO_4) \cdot 32H_2O$$

The macroscopic result of secondary ettringite formation is a swelling.

Divet et al., 2001

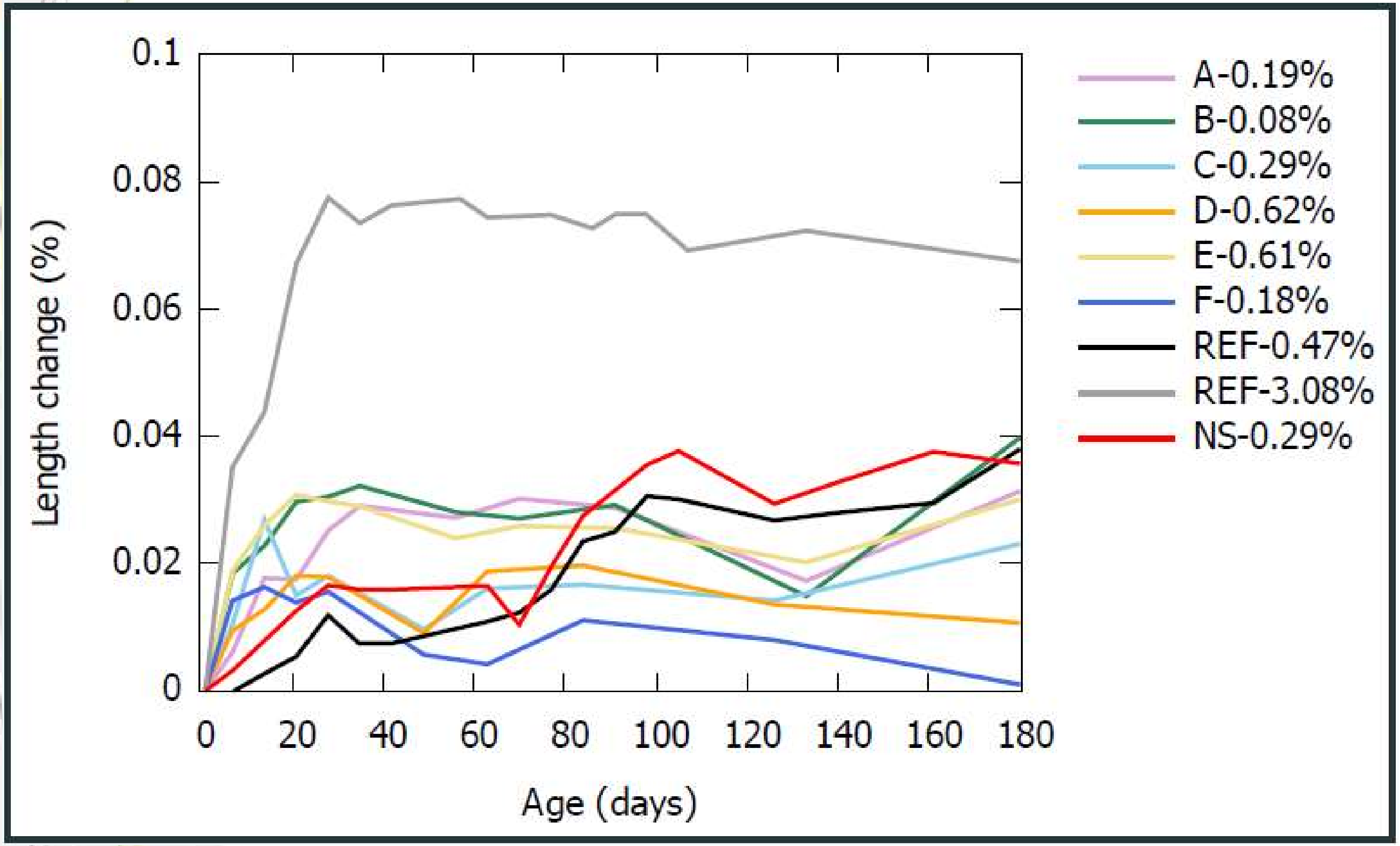
Sulphates in fine RA





Sulphates in fine RA

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



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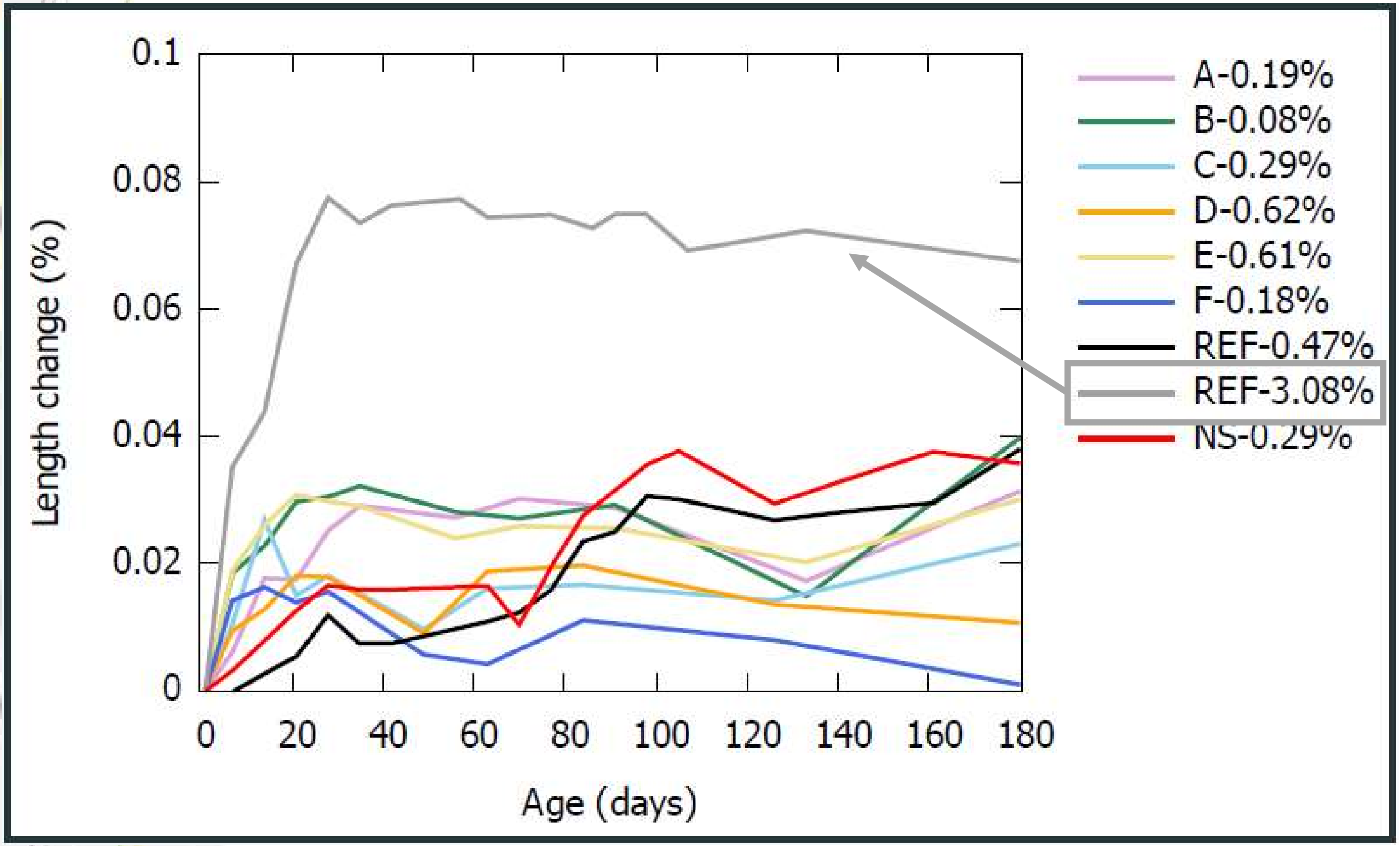
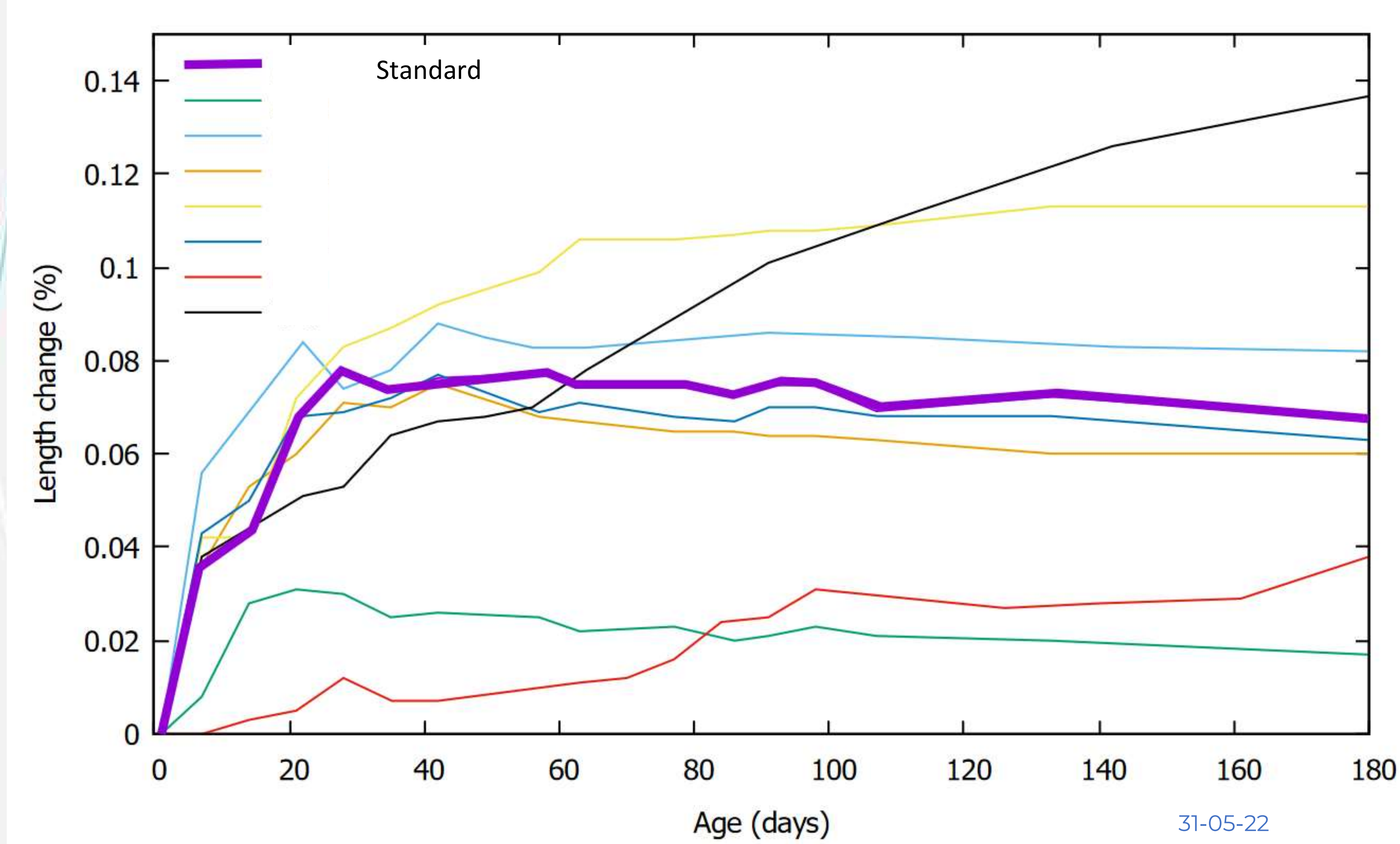


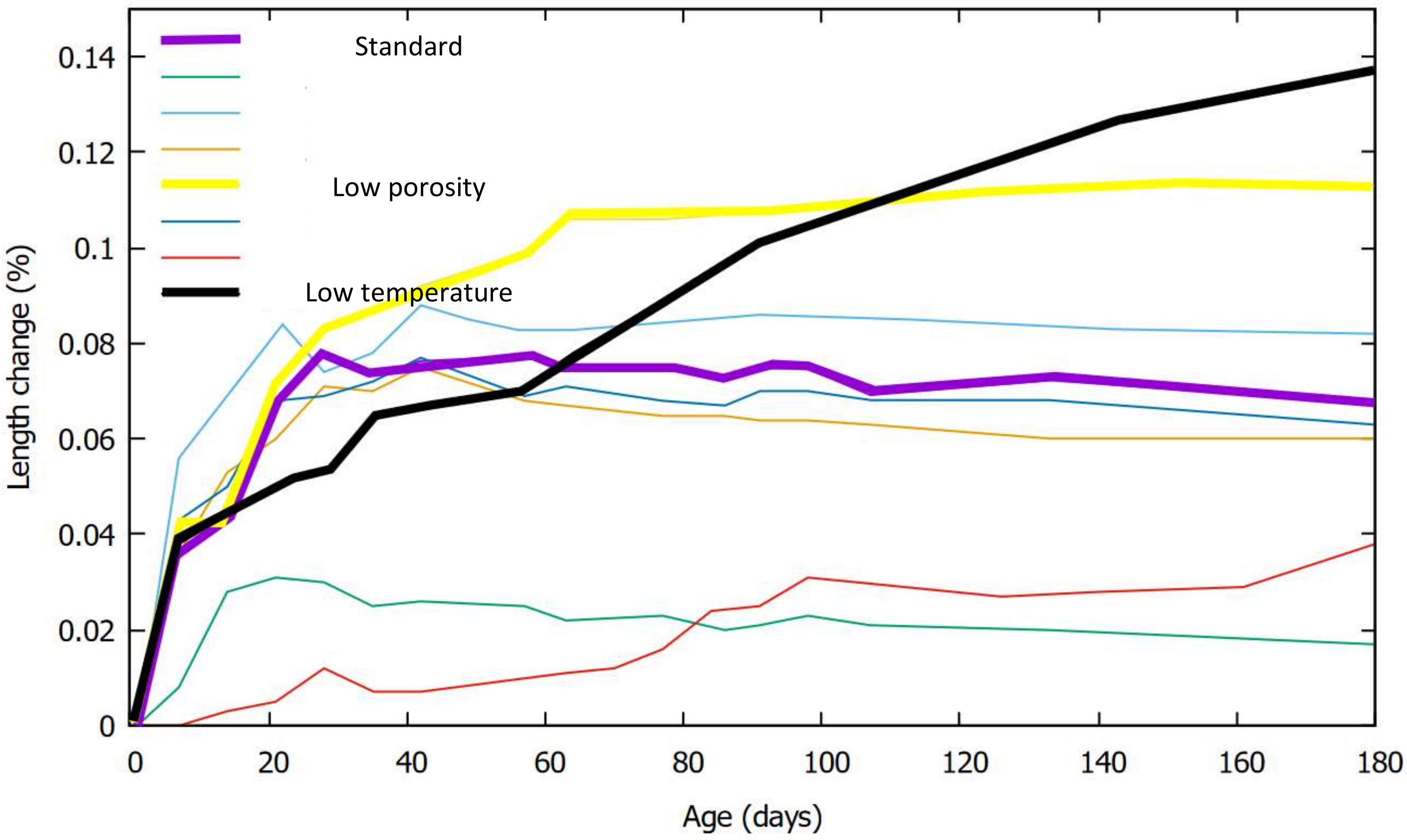
Parameters influencing the reaction

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



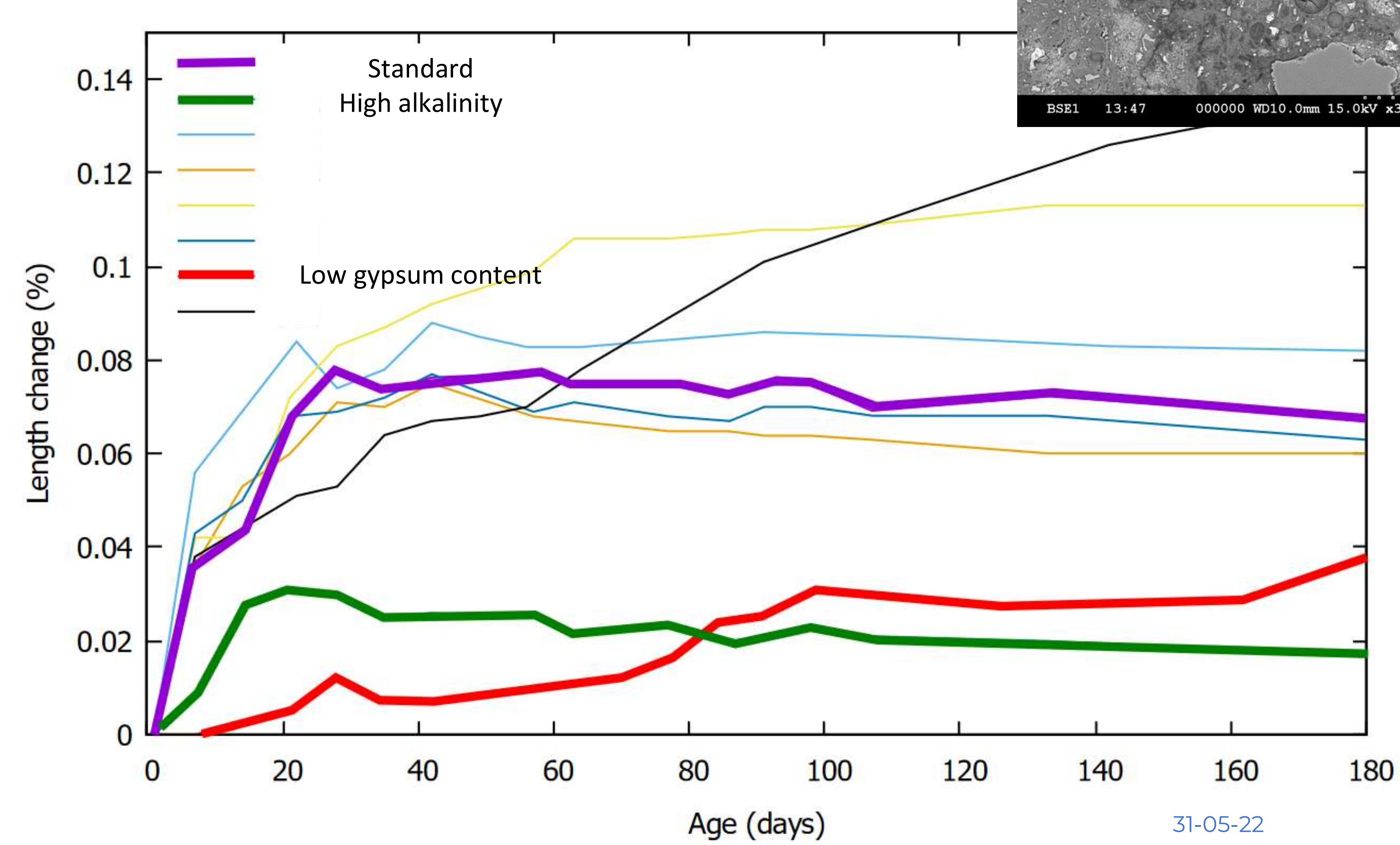
Parameters influencing the reaction

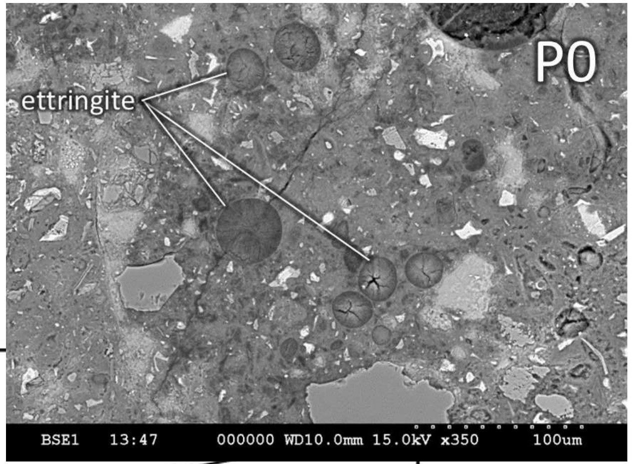
Two factors increased expansion: low storage temperature (carbonate source!) and low porosity (low water content).



Parameters influencing the reaction

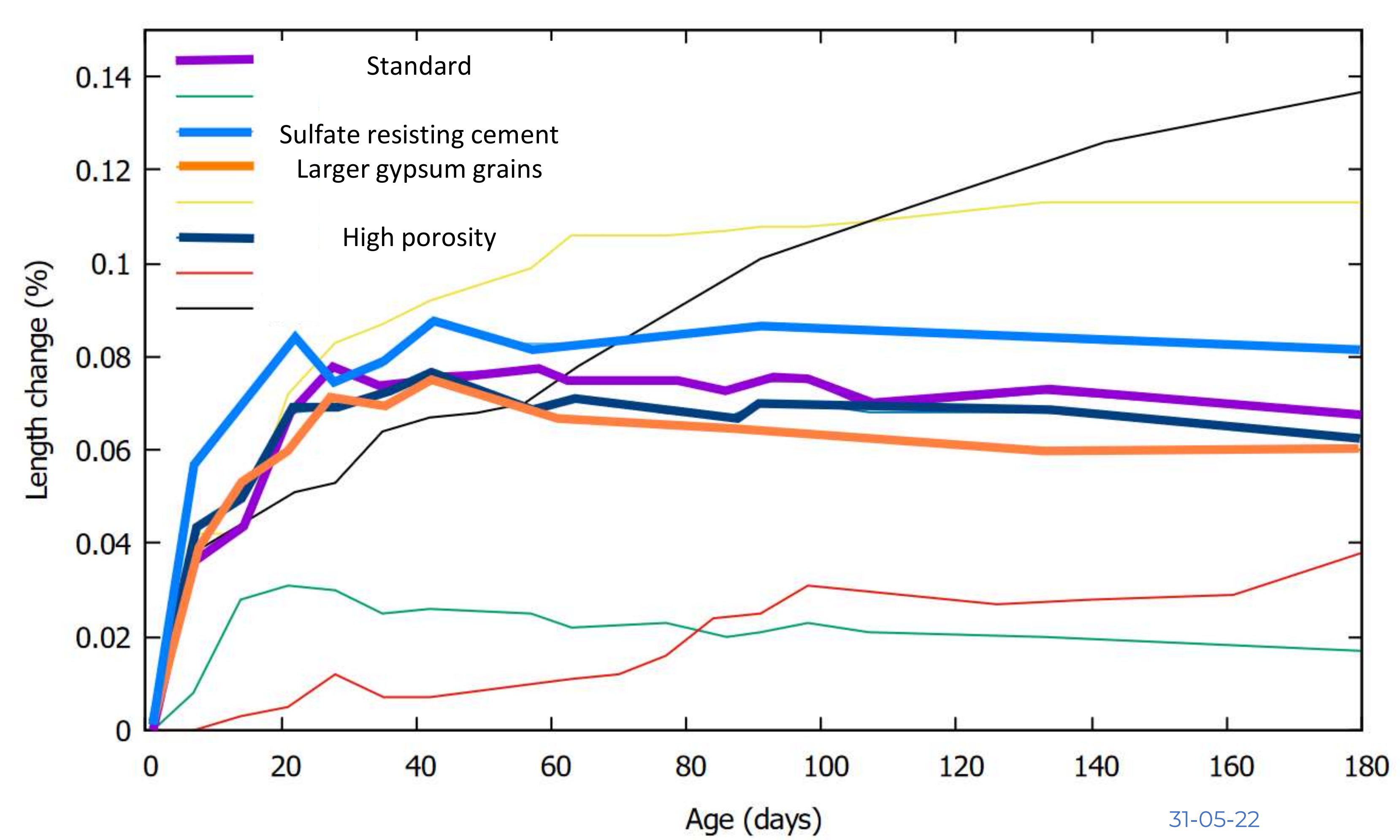
Two factors increased expansion: high alkalinity (ASR!) and low sulfate content.





Parameters influencing reaction

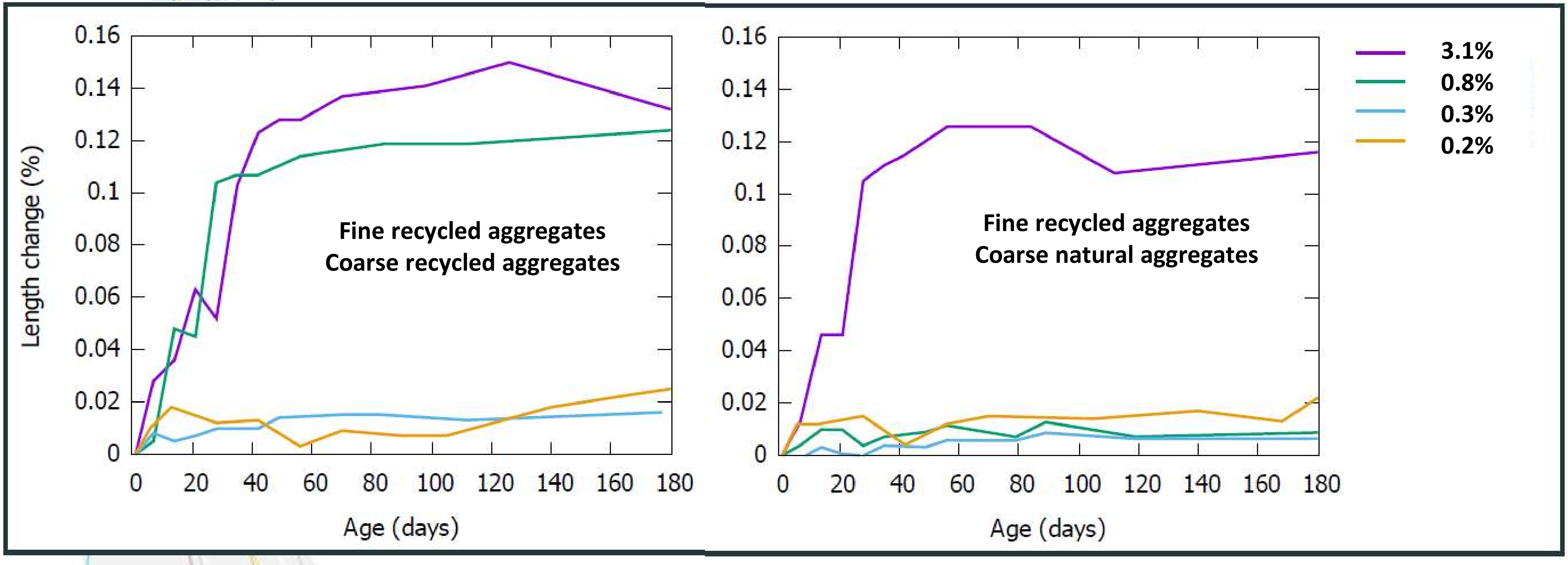
Three factors did not have an influence: High Sulfate Resisting cement, large gypsum particles and high porosity (high water content).



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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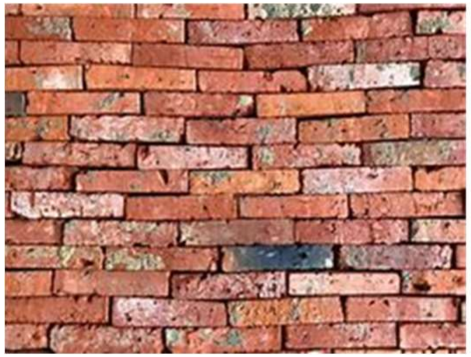
Sciences Appliquées

Brick fines valorization

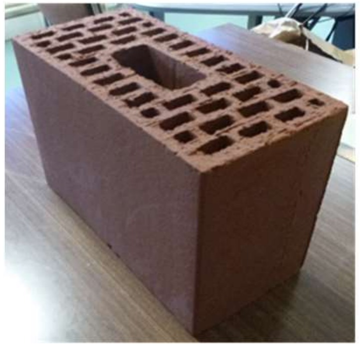
UEE
Urban & Environmental Engineering

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 →

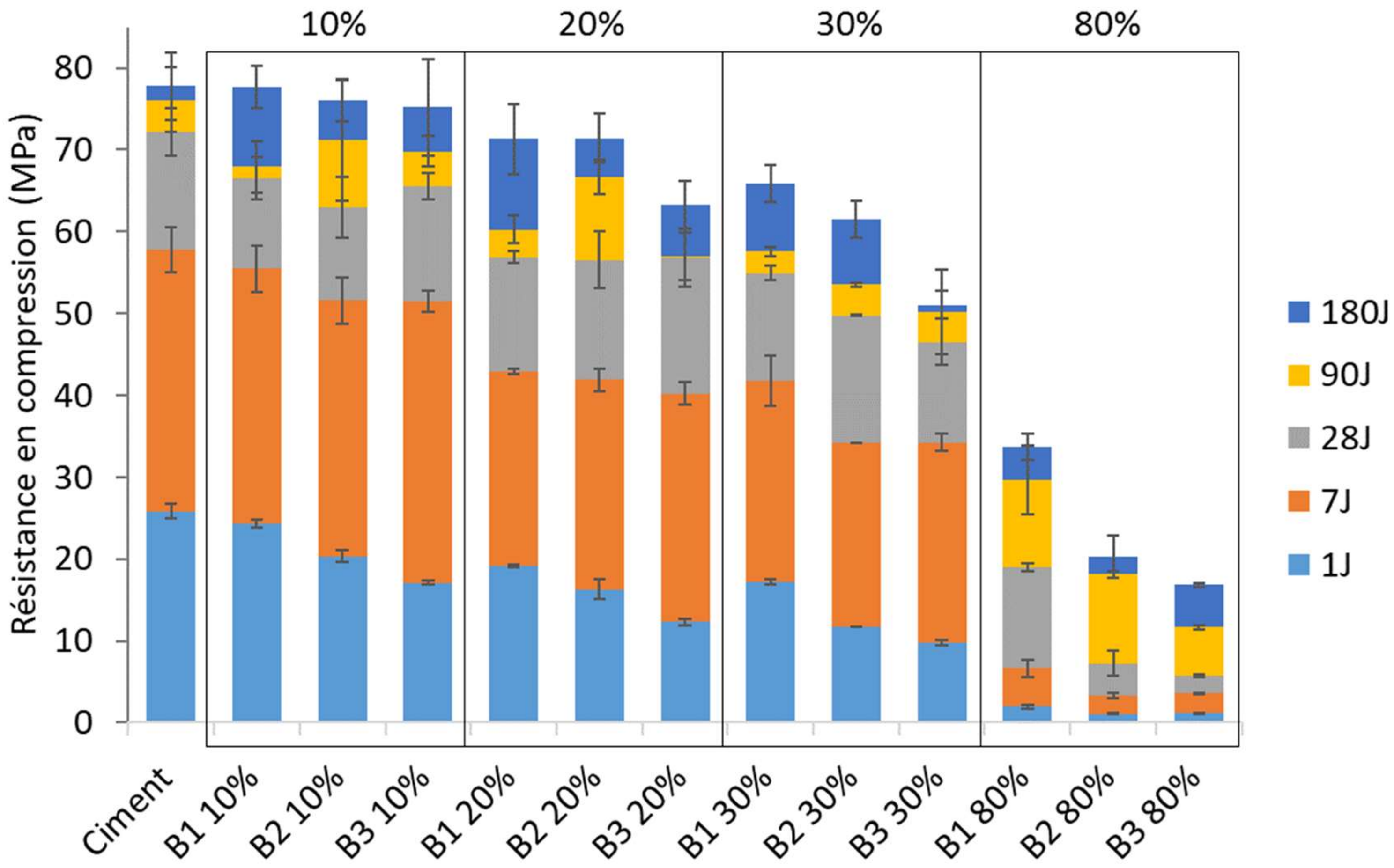
Broyeur à boulets

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

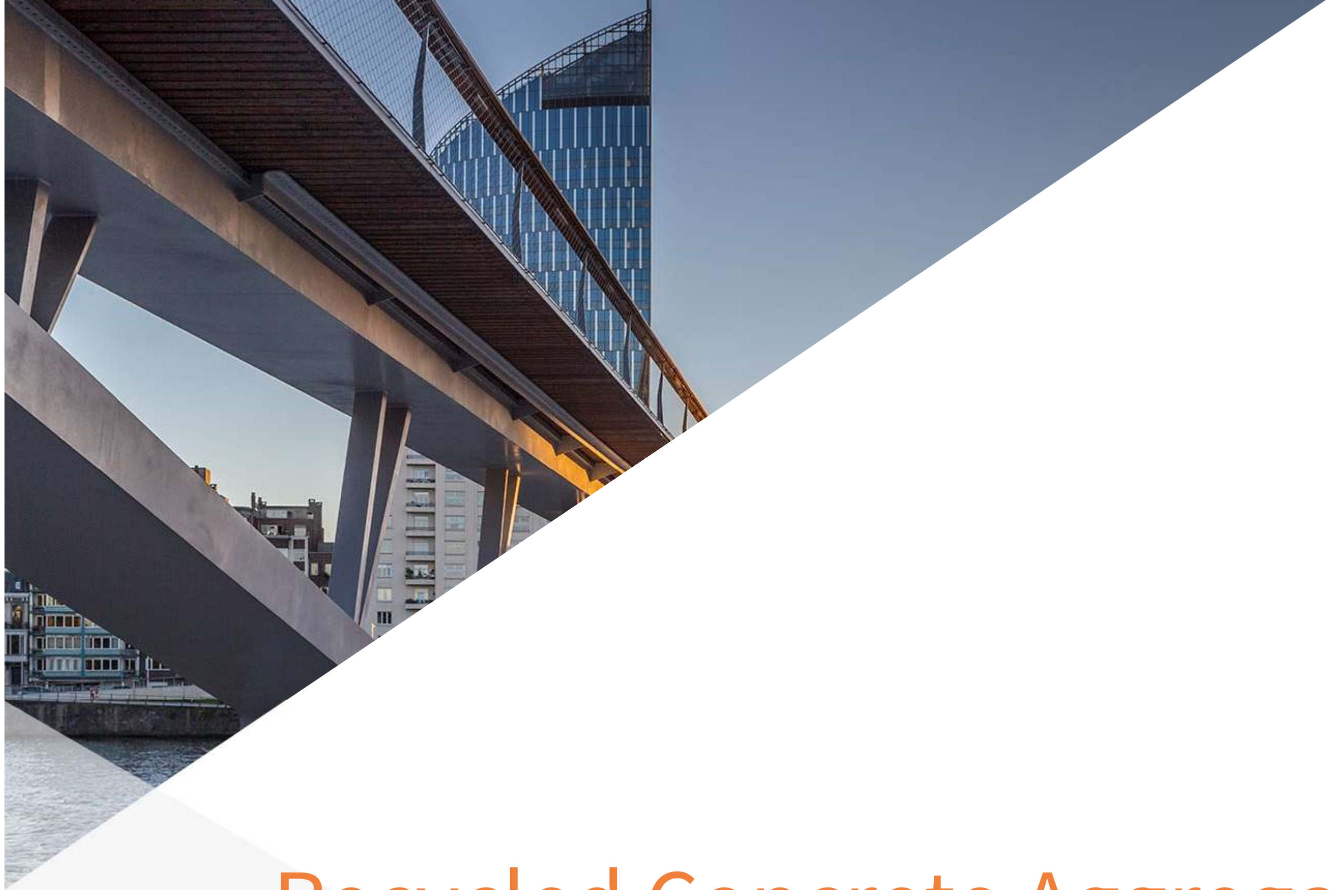
Preparation of brick fines

- 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



Recycled Concrete Aggregates

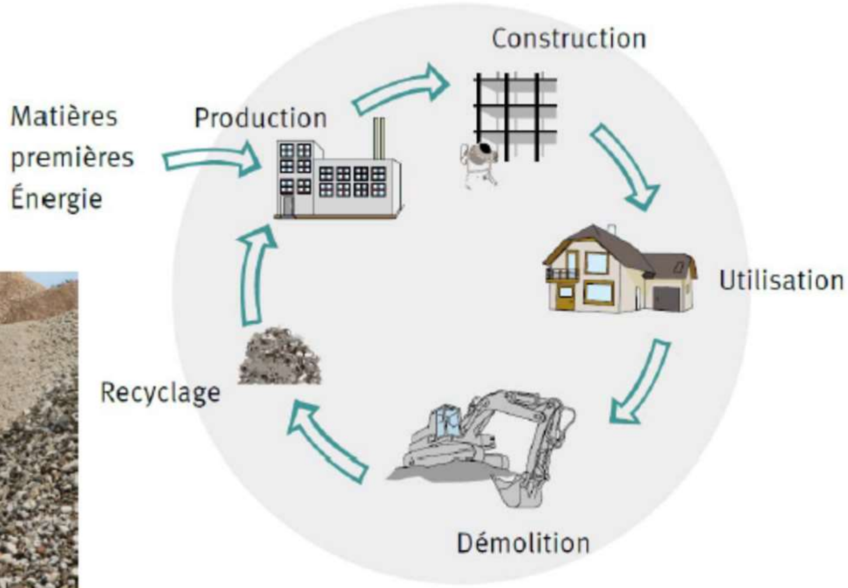
GLOBAL CONTEXT

What to do?

GLOBAL CONTEXT

The construction industry consumes ressources (per year)…

- Sand : 2.2 billions tons
- Aggregates : 4.7 billions tons
- Cement: 4 billions tons
- Water : 800 billions liters
- Concrete: 10 billions tons
- Emission of CO_2 (2018): 5-8% world production

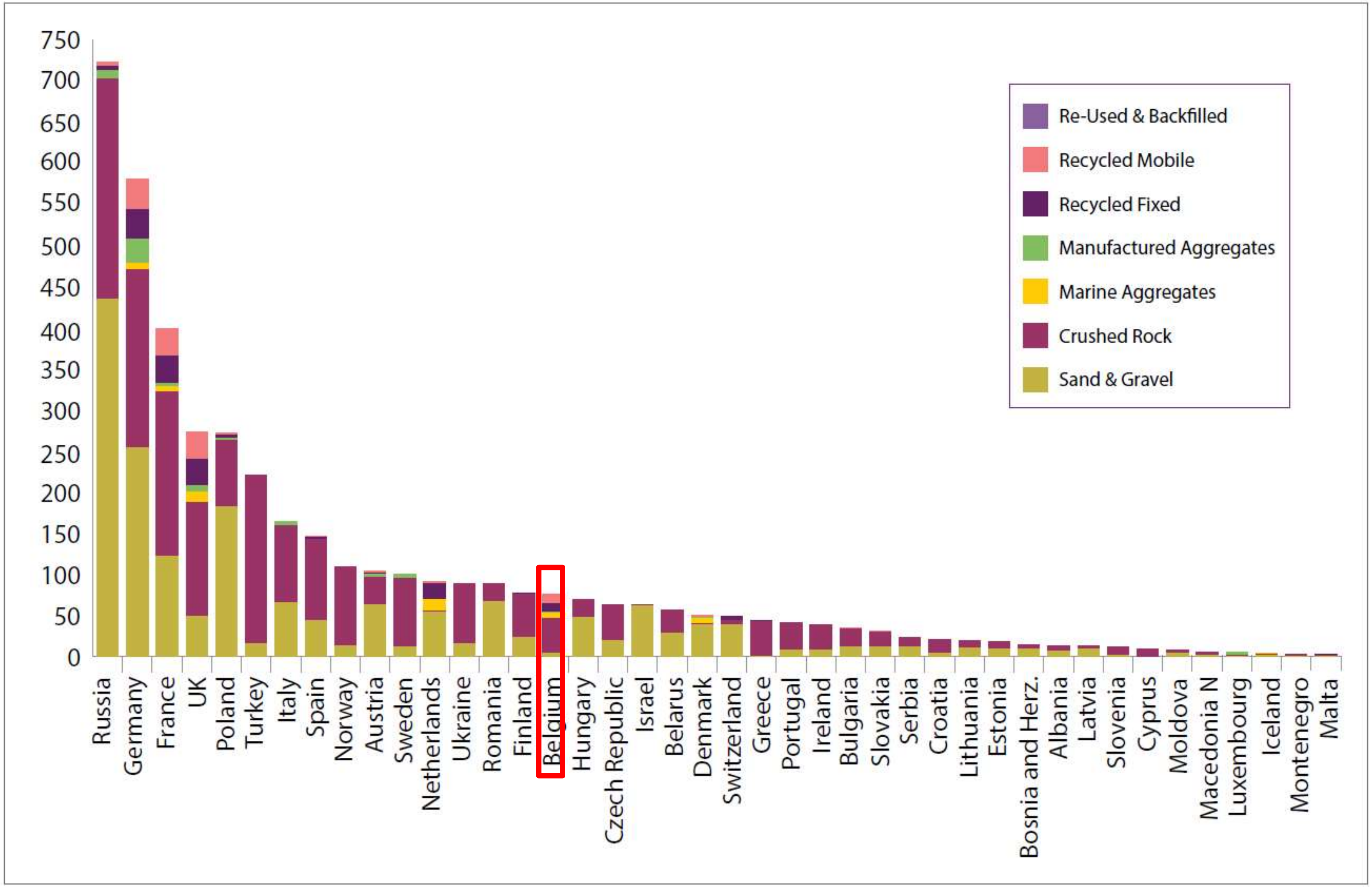


GLOBAL CONTEXT

… and produces construction and demolition waste

- Mixed waste : concrete, brick, ceramic, natural stone, etc. ;
- Concrete waste : composed of at least 90% concrete ;
- Bituminous waste : asphalt and road surfaces ;

PRODUCTION OF RECYCLED AGGREGATES IN EUROPE



Production de granulats en Europe en 2019 par pays et par type en million de tonnes (UEPG, 2021)

PROJET SERAMCO

Objectives of SeRaMCo project: to produce concrete prefabricated éléments with recycled concrete aggregates

Secondary Raw Materials for Concrete precast products

PARTENAIRES DU PROJET

Partenaires:

11 Partenaires
3 Sous-partenaires
3 Partenaires associés

Au total, 17 partenaires provenant de 5 pays européens (Allemagne, Belgique, France, Luxembourg et Pays-Bas)

STRUCTURE DU PROJET

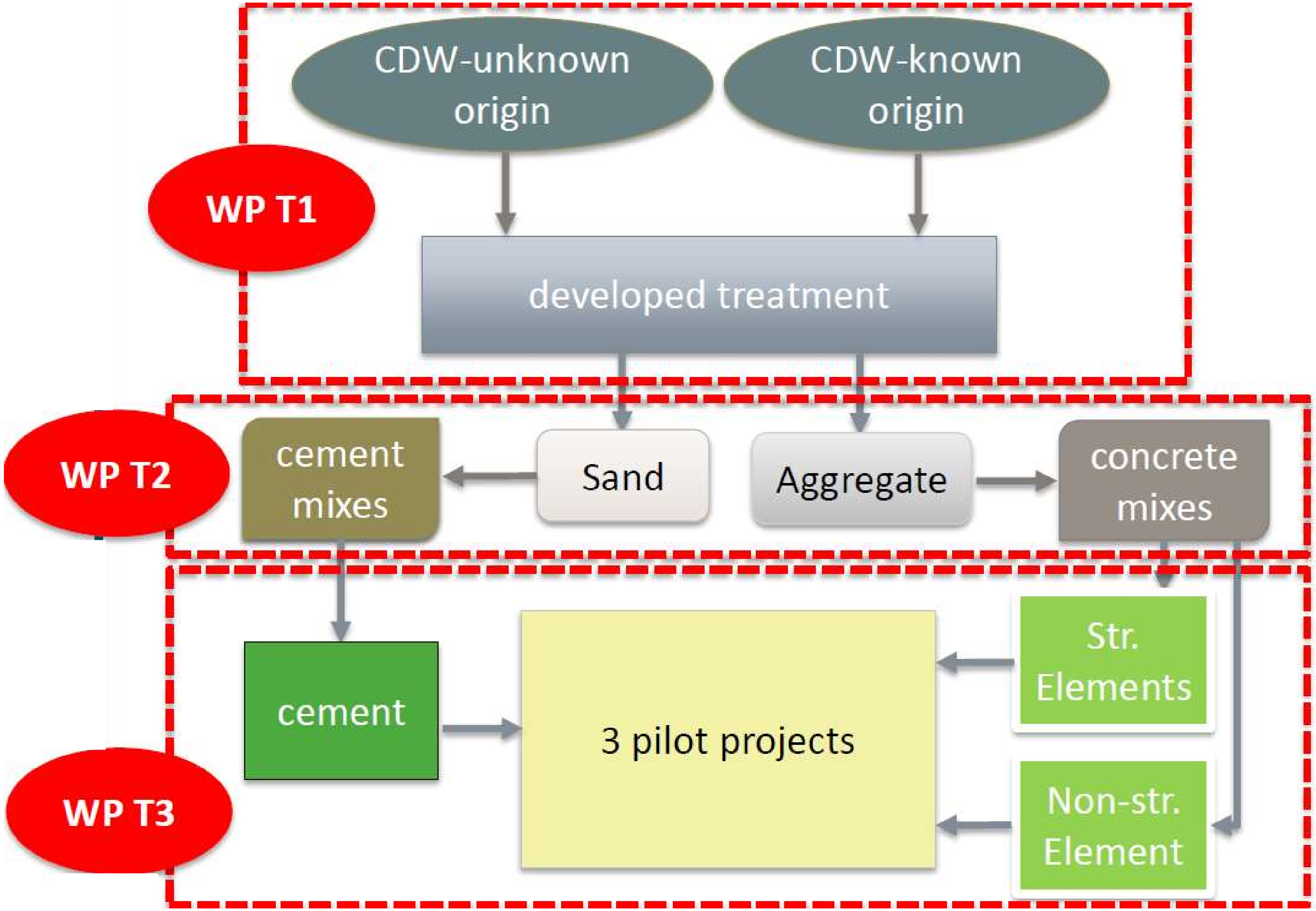


TABLE DES MATIÈRES

CADRE NORMATIF

NBN EN 206 and NBN B 15-001 standards

- Annex E (NBN EN 206): recommandation for the use of recycled aggregates.
- Two types of aggregates (d > 4mm) :

Type A : concrete aggregates

Type B : mix aggregates

CONTEXTE BELGE

NBN B 15-001: requirements for concrete aggregates type A+ :

- d $\geq$ 4 mm and D $\geq$ 10 mm;
- Categories of components
  - Rc_{90}, Rcu_{95}, Ra_{1-}, $XRg_{0.5-}$, FL_{2-}
- Next categories
  - FI_{20}, $f_{1.5}$, LA_{35}, $SS_{0.2}$, A_{40}
- Density higher than 2200 kg/m³;
- Water Absorption lower than 10% with deviation $\pm$ 2%.

Categories in NBN 12620 :

Rc : béton
Ru : pierre naturelle
Ra : matériau bitumineux
XRg : verre
FL : matériau flottant

FI : coefficient d’aplatissement
F : teneur en fines
LA : coefficient Los Angeles
SS : sulfate soluble
A : modification du temps de prise

Usable for concrete class $\leq$ C30/37

CONTEXTE BELGE

NBN B 15-001: requirements for concrete aggregates type B+ :

- $d \geq 4$ mm et $D \geq 10$ mm;
- Categories of components
  - $\mathrm{Rc}_{50}, \mathrm{Rcu}_{70}, \mathrm{Ra}_{5}, \mathrm{R}b_{30-}, \mathrm{XRg}_{0.5-}, \mathrm{FL}_{2-}$
- Next categories
  - $FI_{50}, \mathrm{LA}_{50}, SS_{0.2}, A_{40}$
- Density higher than 1700 kg/m³;
- Water Absorption lower than 15% with deviation $\pm$ 2%.

Categories in NBN 12620 :

Rc : béton
Ru : pierre naturelle
Ra : matériau bitumineux
XRg : verre
FL : matériau flottant

FI : coefficient d’aplatissement
F : teneur en fine
LA : coefficient de Los Angeles
SS : sulfate soluble
A : modification du temps de prise

Usable for concrete class $\leq$ C25/30

TAUX DE SUBSTITUTION AUTORISÉS

Type of aggregates	Environmental classes NBN B 15-001						
	E0	EI	EE1	EE2	EE3,EA1	ES1, ES2,ES3	EE4, ES4, EA2, EA3
Reinforced concrete							
Type A+	-	**30%**	**30%**	**20%**	**20%**	0%	0%
Type B+	-	**20%**	0%	0%	0%	0%	0%
Non reinforced concrete							
Type A+	**50%**	**50%**	**50%**	**20%**	**20%**	**20%**	0%
Type B+	**20%**	**20%**	**20%**	0%	0%	0%	0%

It is allowed to use recycled aggrgates in some specific outside environments

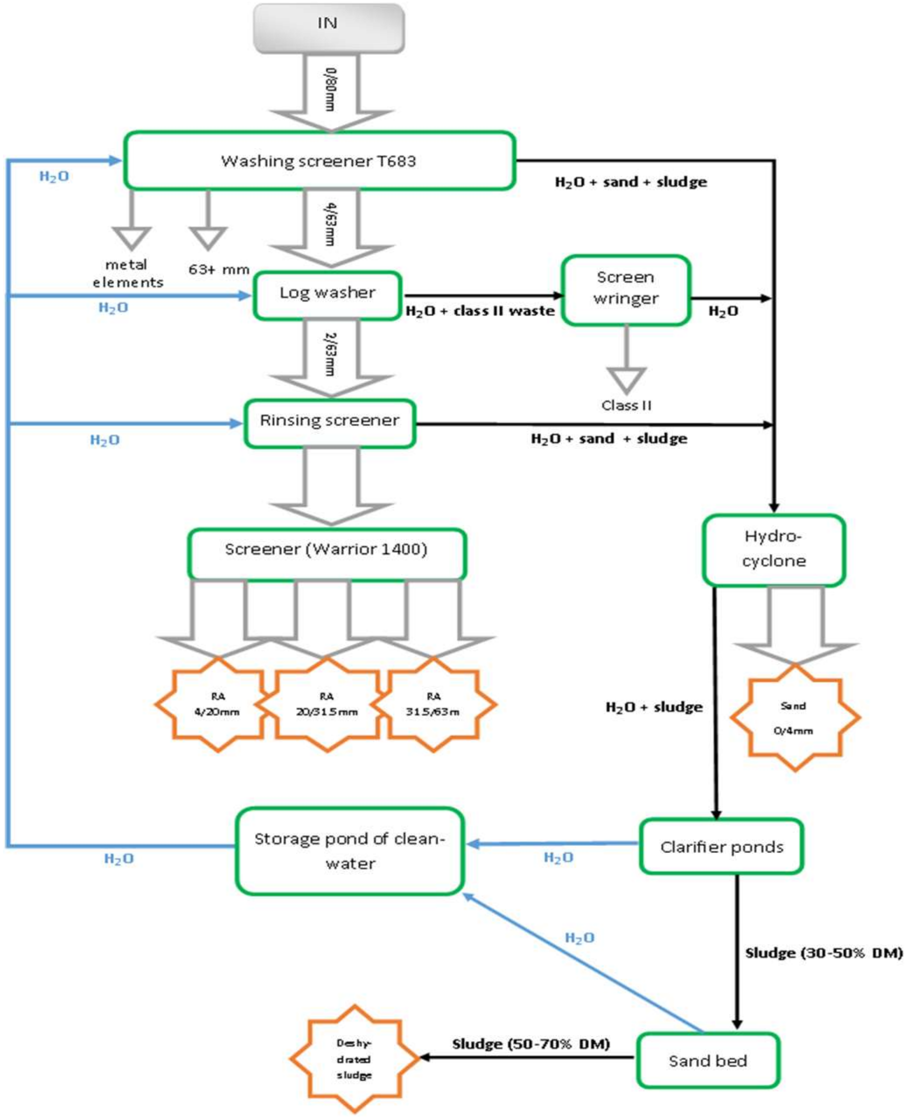
TABLE DES MATIÈRES

RECYLED AGGREGATES PRODUCTION

"SeRaMCo recycling plant" Saint-Ghislain (Tradecowall)

RECYLED AGGREGATES PRODUCTION

1st Step : Conveyor belt EDGE



RECYLED AGGREGATES PRODUCTION

2nd Step : Washing screen Terex Finlay 683

- Screening
- Overband
- Washing

Zoom

RECYLED AGGREGATES PRODUCTION

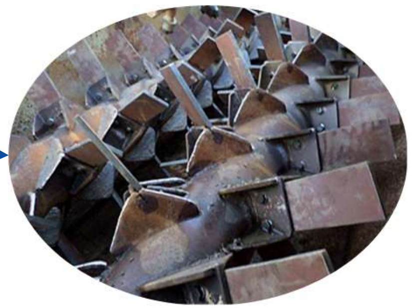
2nd Step : Washing screen Terex Finlay 683

- 1st Washing
  - 63+ mm → rejected
  - 0/63mm

- 2nd washing
  - 0/4 mm → hydrocyclones (step 7)
  - 4/63 mm → Sludge trap (step 3)

RECYLED AGGREGATES PRODUCTION

3rd Step : Log washer



- 3rd washing

Water loaded with fine particules → Dewatering screen (step 6)

4/63mm → Rinsing screen (step 4)

RECYLED AGGREGATES PRODUCTION

4th and 5th Steps : Rinsing screen Mogensen and Screen Warrior 1400

- 4th washing

0/4mm → hydrocyclones (step 7)

4/63mm → Screen Warrior 1400 (step 5)

End product with 3 différents particle size:

- 4/20mm
- 20/31,5mm
- 31,5/63mm

RECYLED AGGREGATES PRODUCTION

8th step : Clarifying pond

- Waste water

Precipatated particles → sand bed

Clean water → water reservoir

RECYLED AGGREGATES PRODUCTION

9th step : Sand bed and water reservoir

RECYLED AGGREGATES PRODUCTION

RECYLED AGGREGATES PRODUCTION

End product

- **Sand :**
  - 0/4 mixed
  - 0/4 concrete
- **Aggregates :**
  - 4/6 mixed
  - 4/6 concrete
  - 6/14 mixed
  - 6/14 concrete
  - 14/20 mixed
  - 14/20 concrete

INFLUENCE OF THE WET PROCESS

Expectations of washing aggregates:

- Constrain grain size distribution
- Decrease fine content
- Decrease the quantity of unwanted components (clay, plaster, wood, etc.)
- Increase resistance to fragmentation

Methodology

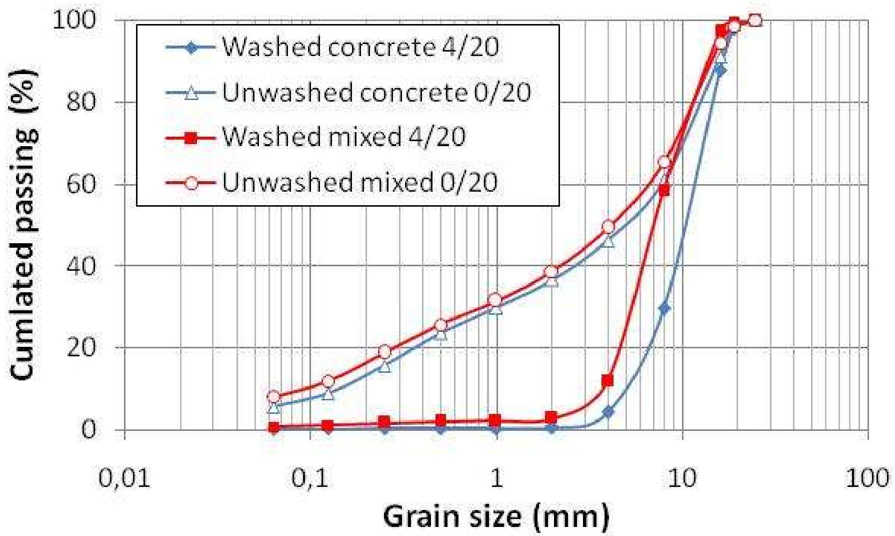
Unwashed		Washed
Concrete aggregate 0/20	⟷	Concrete aggregate 4/20
Mixed aggregate 0/20	⟷	Mixed aggregate 4/20

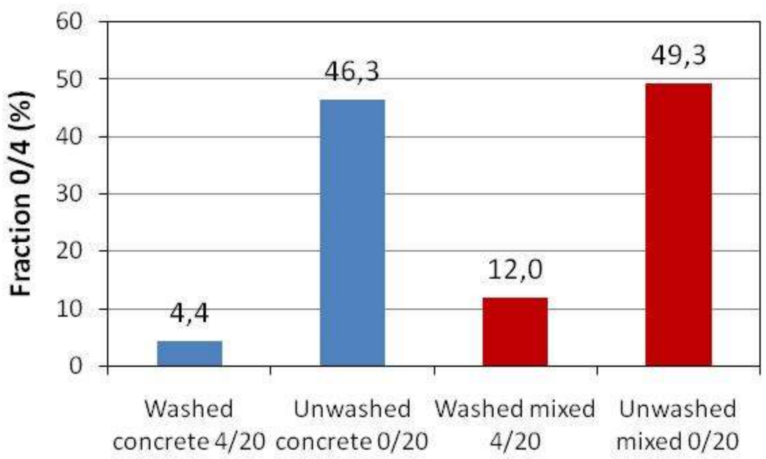
GRAIN SIZE DISTRIBUTION

0/4 fraction comprises nearly 50% of the unwashed aggregates composition

0/4 fraction a bit higher in mixed aggregates

Washing significantly reduces the sand fraction of the aggregates



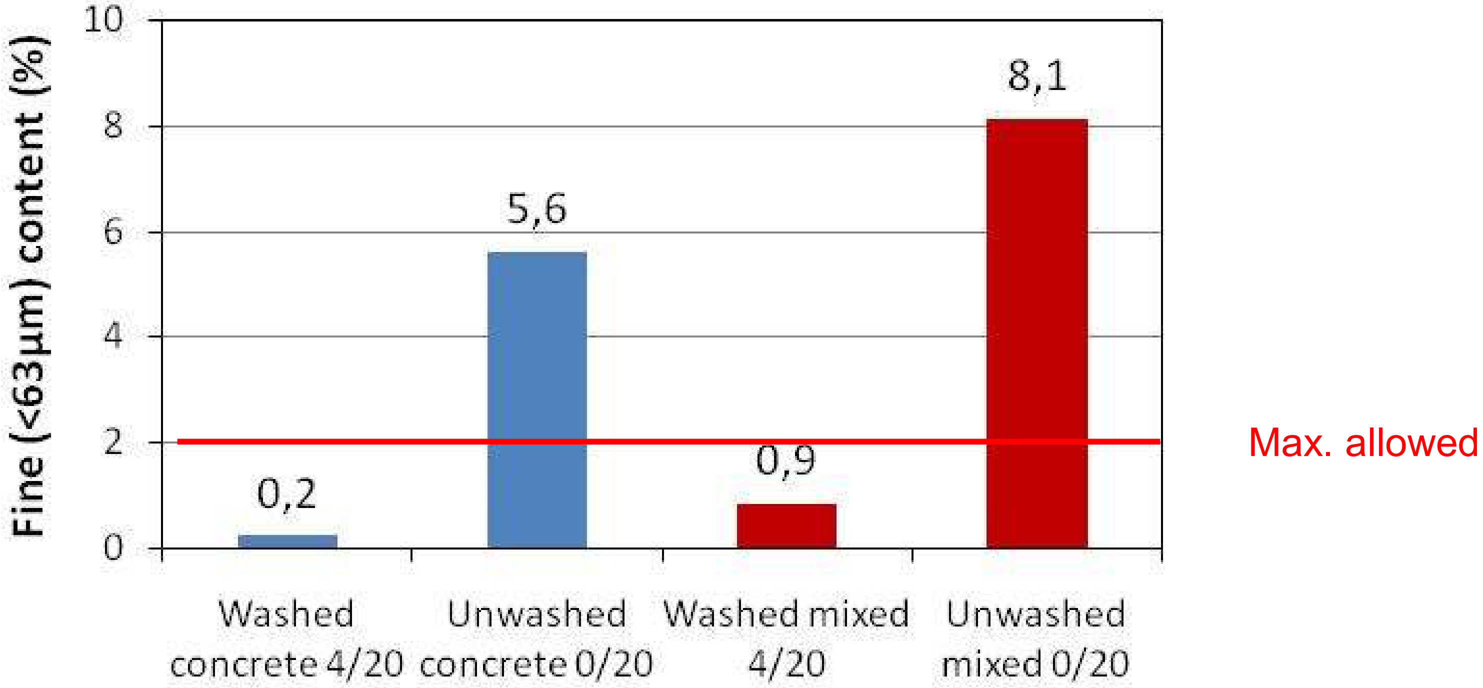


FINE CONTENT

Fine content (< 63µm) higher in mixed aggregates and significantly reduced by washing

Fine fraction higher in mixed aggregates

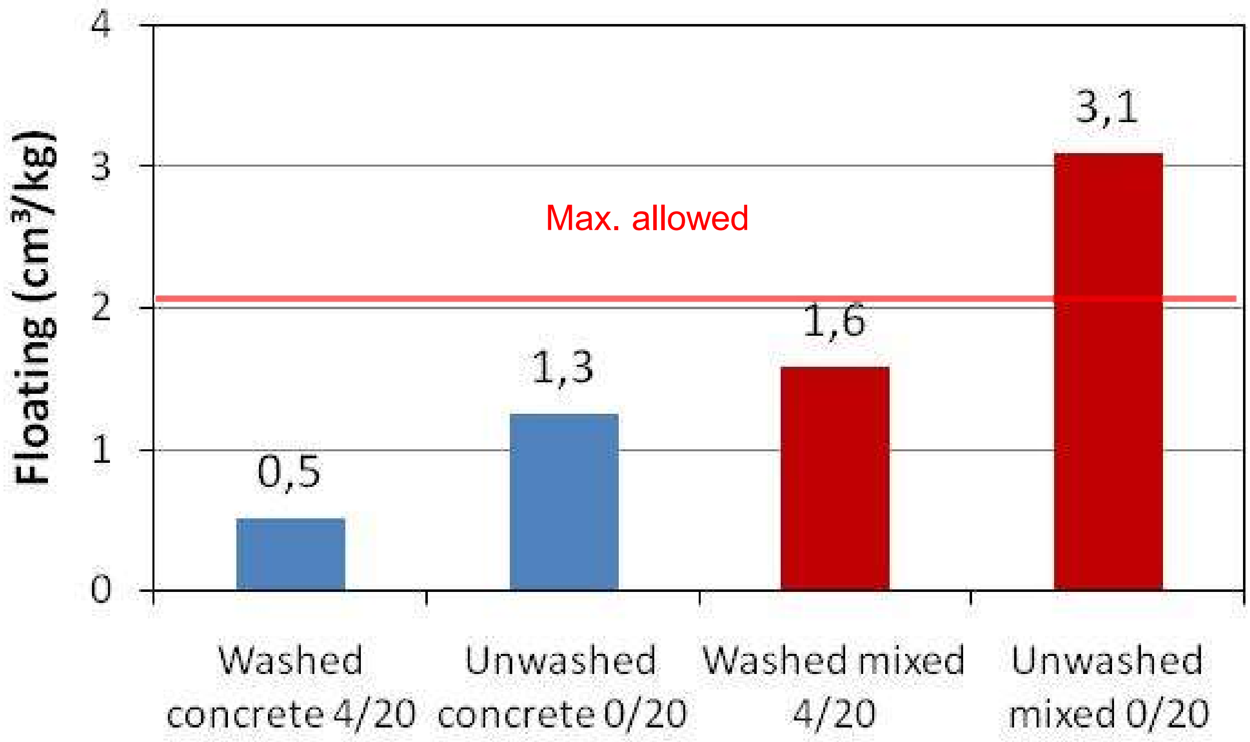
Washed aggregates respect regulations in all considered countries



FLOATING ELEMENTS

Floating elements reduced by 50% after washing and reach suitable values for standards (max. 2 cm³/kg)

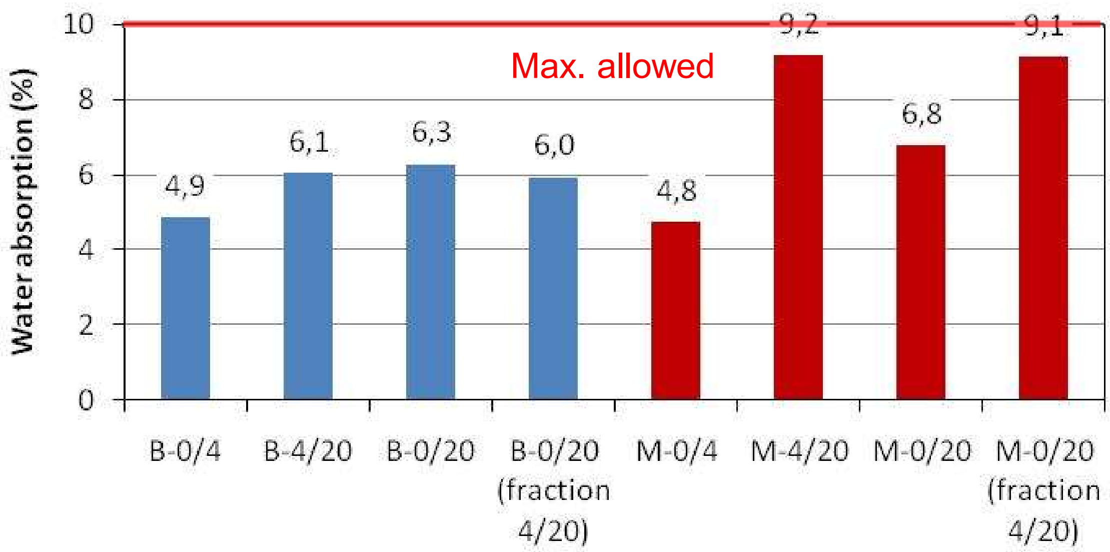
Washing required for mixed aggregates



WATER ABSORPTION

Water absorption is higher for mixed aggregates

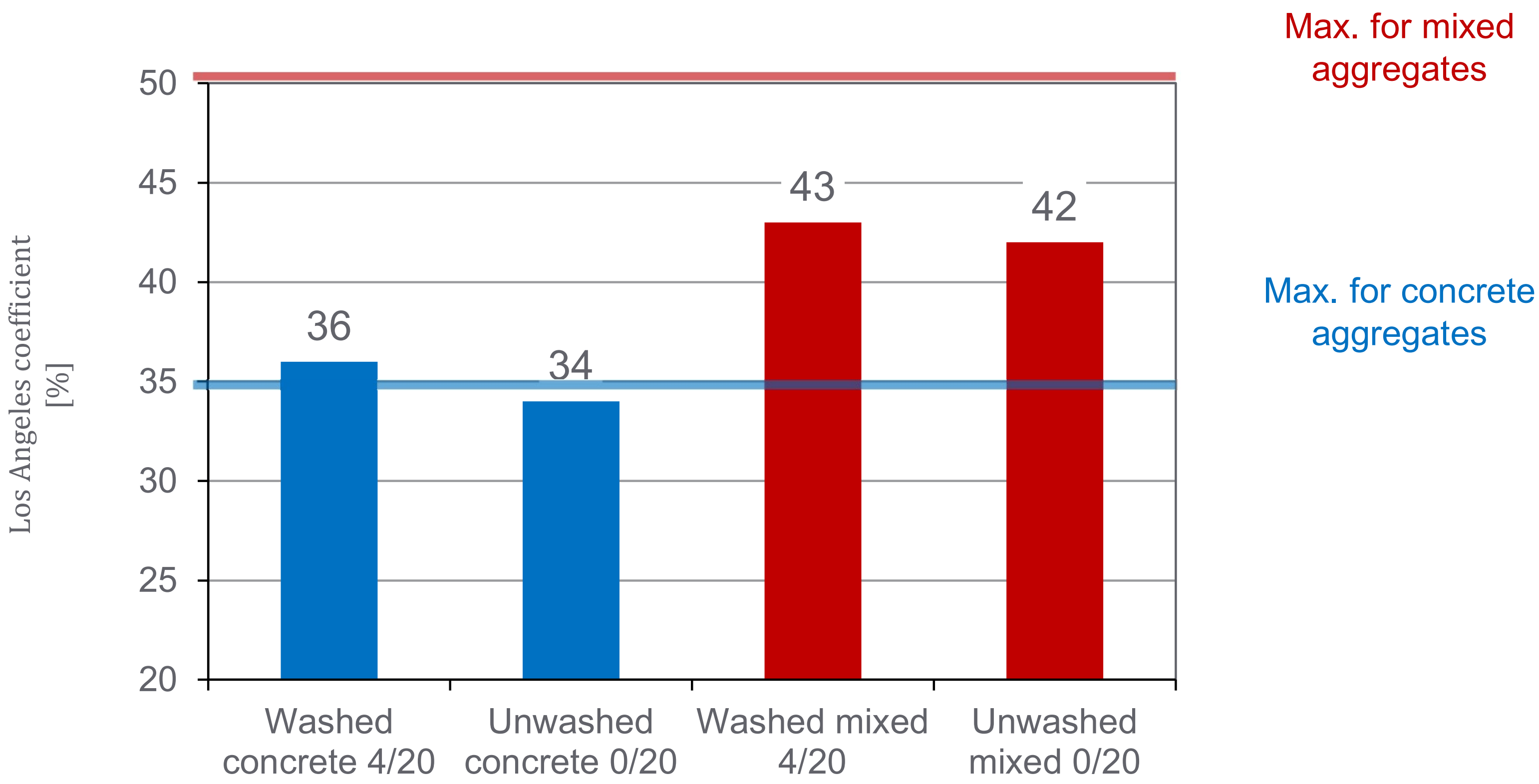
Both washed and unwashed aggregated respect the requirements



RESISTANCE TO FRAGMENTATION

Concrete recycled aggregates have better resistance to fragmentation

No effect of the washing process



CONCLUSIONS

Expected improvement :

- More constrained grain size distribution ✓
- Decrease in fine content ✓
- Decrease in the quantity of unwanted elements (clay, plaster,etc.) ✓
- Increased resistance to fragmentation ✗

Other effects :

- No effect on the water absorption
- Decrease in aggregates density

Conformity to requirements

- NBN EN 206 et NBN B 15-001

	B-4/20	B-0/20	M-4/20	M-0/20
FL (cm³/kg)	0.51	1.25	1.58	**3.10**
Rc (%)	**81.43**	**86.78**	61.05	63.04
Ru (%)	10.60	5.47	11.80	9.80
Rb (%)	7.53	6.24	24.89	25.42
Ra (%)	0.01	0.18	0.00	0.00
XRg (%)	0.02	0.018	1.23	0.32
f (%)	0.2	**5.6**	0.9	8.1
LA	36	34	43	42

INFLUENCE OF THE CRUSHING METHOD

Methodology

Production of 0/25

Impact crusher

Set at 6,5 kW (40% of maximum power)

Jaw crusher

Jaw crusher set at a 22 mm opening

INFLUENCE OF THE CRUSHING METHOD

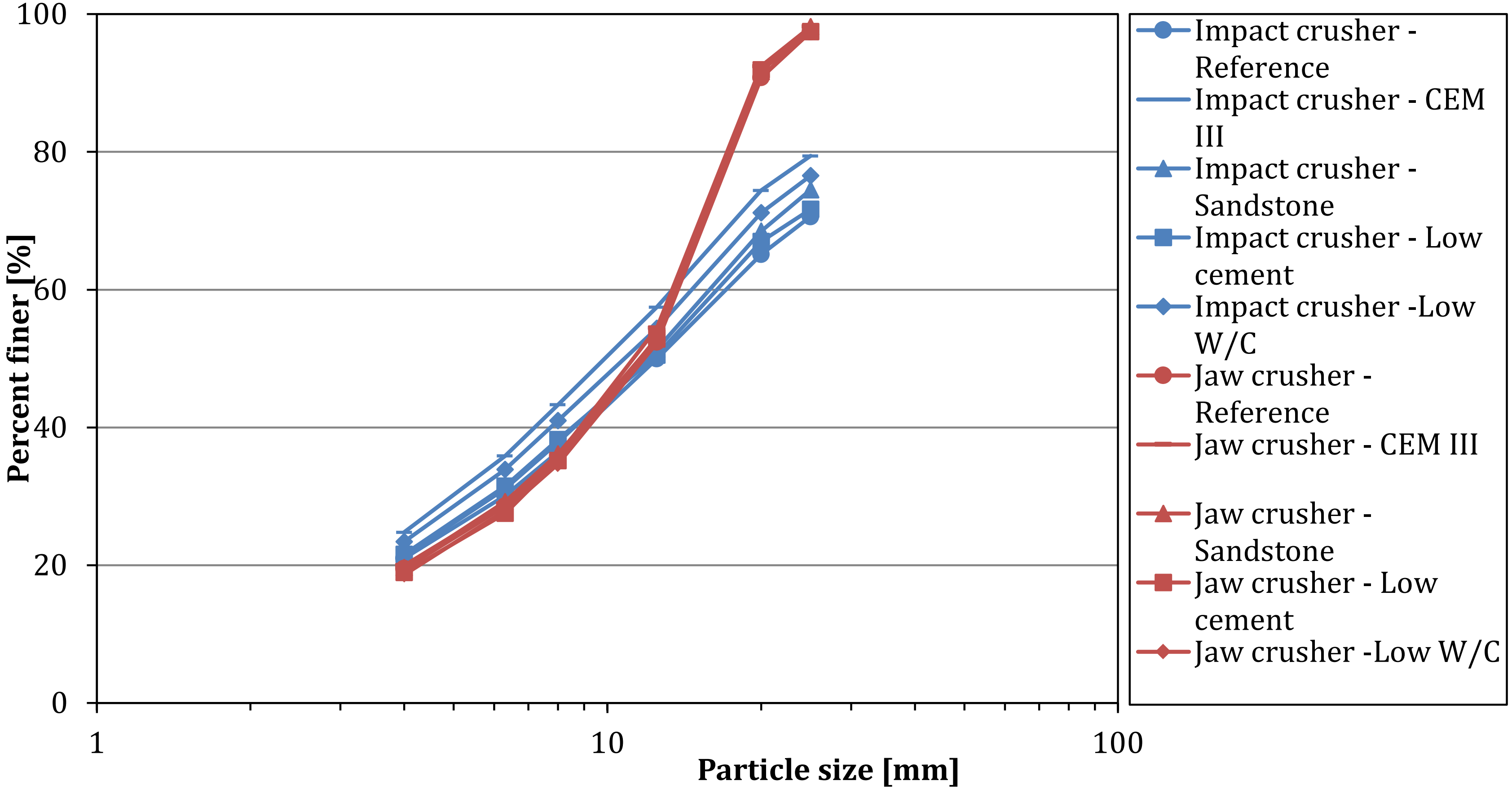
Lab produced concrete to obtain recycled aggregates of known origin

5 concrete mixes to study influence of key parameters

	1.0	1.1	1.2	2	3
Name	Reference	CEMIII	Sandstone	Low Cement	Low W/C
Aggregates type	Limestone	Limestone	**Sandstone**	Limestone	Limestone
Cement type	CEMI 52.5	**CEMIII 52.5**	CEMI 52.5	CEMI 52.5	CEMI 52.5
Cement quantity (kg/m^3)	400	400	400	**320**	452
Cement paste volume (dm^3/m^3)	351	358	351	**282**	351
W/C	0.56	0.56	0.56	0.56	**0.46**

GRAIN SIZE DISTRIBUTION

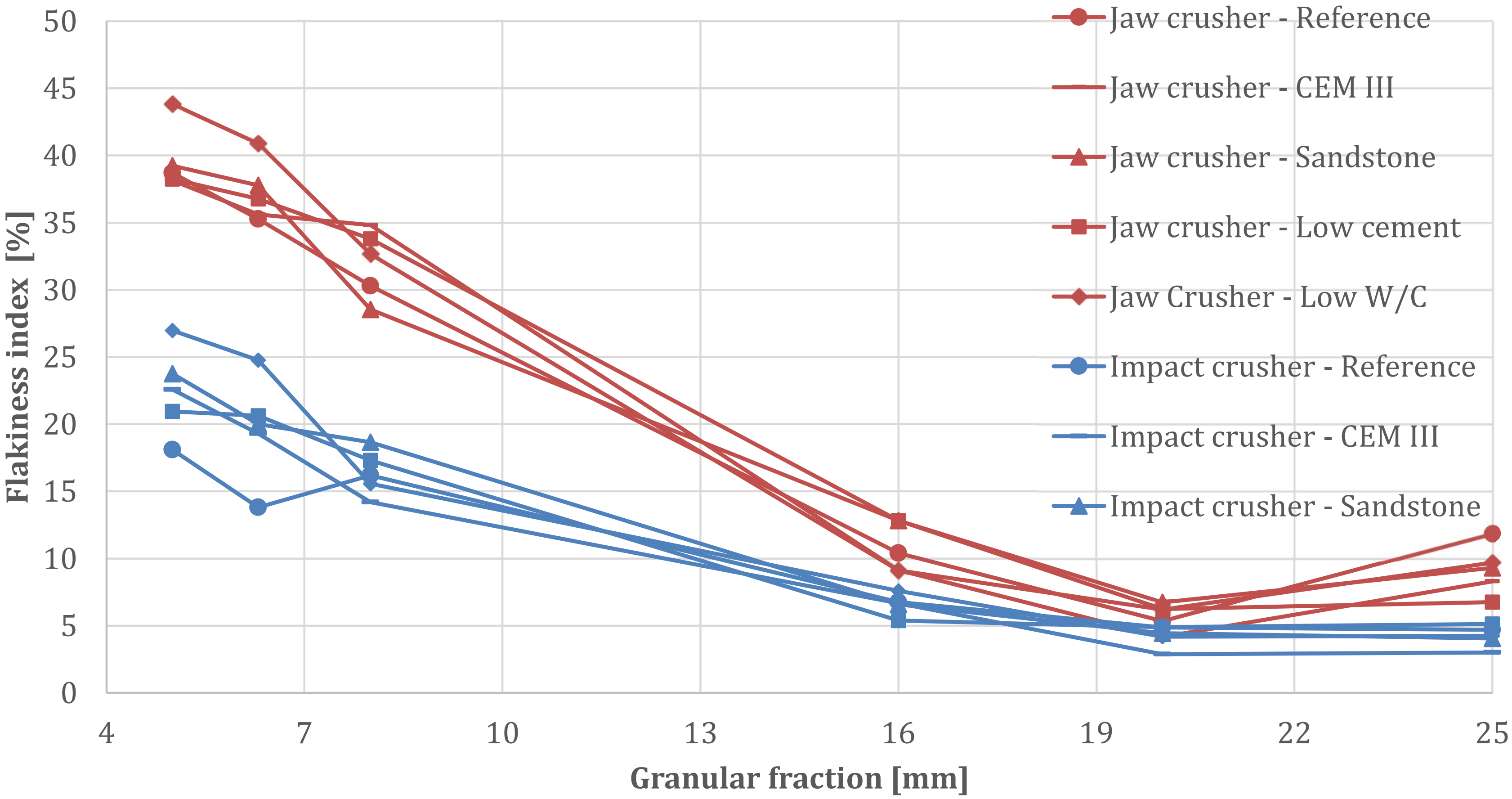
The jaw crusher produces aggregates with a more constrained grain size range (for all the tested composition)



FLAKINESS INDEX

The flakiness index decreases with increasing granular fraction and the jaw crusher produces flakier aggregates

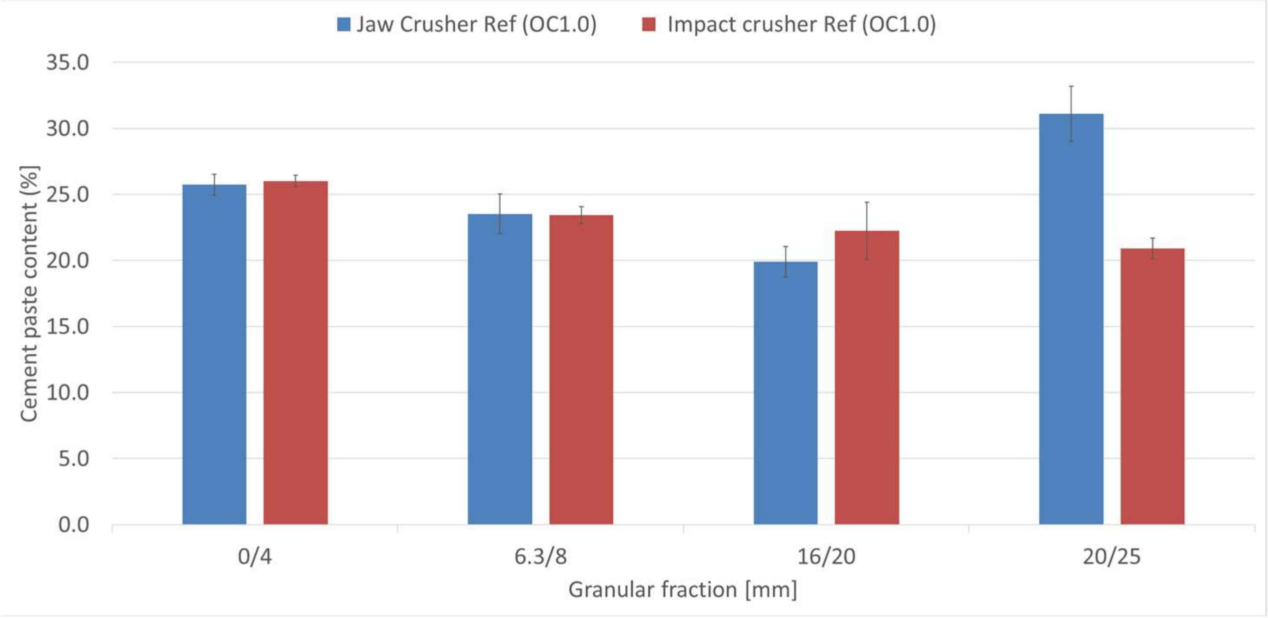
No influence of the concrete composition



CEMENT PASTE CONTENT

Decrease in cement paste content with increasing granular fraction

No influence of the crushing method

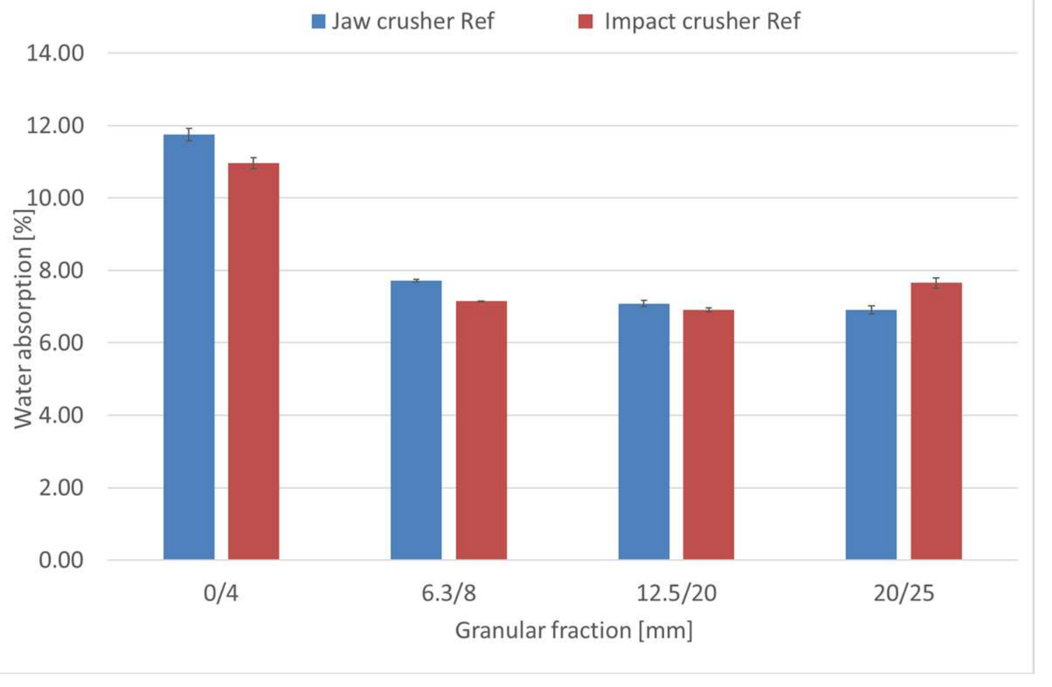


Exception : fraction 20/25 with the jaw crusher (abnormal results)

WATER ABSORPTION

Decrease in water absorption with increasing granular fraction

No influence of the crushing method



Good correlation with cement paste content

ENERGY CONSUMPTION

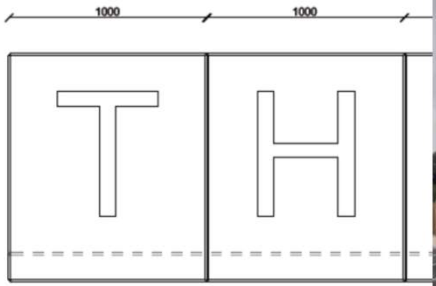
Jaw crusher less energy consuming because of its lower running power

	Jaw crusher	Impact crusher
(a) Running power (kW)	1,8-2,0	6,5-6,6
(b) Mean net power (kW)	1,9-2,1	0,5-0,8
(c) Mean crushing duration (s)	200	252
(d) Crushed mass of material per hour (t/h)	2,0-2,3	1,6-1,7
(e) Net specific energy consumption (kWh/t) **(b/d)**	0,9-1,0	0,30-0,50
(f) Total specific energy consumption (kWh/t) **((a+b)/d)**	1,8-1,9	4,1-4,5
(g) Percentage of energy consumed for crushing **(=b/(a+b))**	~50	~10

CONCLUSION : TYPE DE CONCASSEUR

	Impact	Jaw
Morphology	(+)	
Sieving curve	(−)	(+)
Fine content	(−)	(+)
Cement paste content	-	-
Water absorption	-	-
Energy consumption	(−)	(+)
Crushing time	(−)	(+)

FRENCH PILOT SITE



GERMAN PILOT SITE

SITE PILOTE BELGE : PARKOUR PARK DE SERAING

DÉFINITION DES CIBLES POUR LE SITE PILOTE BELGE

Eléments en béton préfabriqué

- NBN EN 206-1
  - Les éléments sont en extérieur, soumis à la pluie, au gel et potentiellement à des sels de déverglaçage ⟹ classe d'environnement EE4

    W/C ≤ 0.45

    Ciment ≥ 340 kg/m³

    C 35/45 $\Longrightarrow F_{ck} = 45\ MPa \Longrightarrow R_c = 51.75\ MPa$

- NBN B 15-001
  - $D_{max} > 16 \Longrightarrow WA_{24} \leq 5.5\%$
  - $8 < D_{max} \leq 16 \Longrightarrow WA_{24} \leq 6.5\%$
  - $4 < D_{max} \leq 8 \Longrightarrow WA_{24} \leq 7.5\%$
  - Granulat : $D_{max} = 14$ mm

Cibles
R_c : 50-55 MPa
W/C <= 0,45
Ciment >= 340 kg/m³
Absorption d'eau <= 6,5%

COMPOSITION DU BÉTON

Pour chaque type de granulats, trois taux de substitution ont été envisagé afin de pouvoir quantifier l'influence des granulats recyclés sur les propriétés des bétons

Concrete mixes		Test series n°3 - CEM I 52 R LA						
		REF - 0 %	Granulat de béton recyclé			Granulat recyclé mixte		
		N100	B100	B75	B40	M100	M75	M40
Eau	[kg]	180	180	180	180	180	180	180
Eau de gâchage	[kg]	9	50	40	25	53	41	26
Ciment	**[kg]**	**400**	**400**	**400**	**400**	**400**	**400**	**400**
E/C efficace	**[-]**	**0,45**	**0,45**	**0,45**	**0,45**	**0,45**	**0,45**	**0,45**
E/C	[-]	0,47	0,57	0,55	0,51	0,58	0,55	0,51
Sable 0/2	[kg]	615	615	615	615	615	615	615
Granulat naturel 2/6	[kg]	273	-	273	273	-	273	273
Granulat naturel 6/14	[kg]	909	-	-	454	-	-	454
Granulat recyclé 2/6	[kg]	-	237	-	-	216	-	-
Granulat recyclé 6/14	[kg]	-	791	791	395	723	723	362
Taux de substitution	**[-]**	**0%**	**100%**	**77%**	**38%**	**100%**	**77%**	**38%**
Superplastifiant	[%]	0,5%	0,5%	1%	1%	1%	1%	1%

RÉSULTATS DES TESTS DE CARACTÉRISATION

Les bétons produits à base de granulats recyclés respectent la majorité des critères d'une classe d'environnement EE4 (pluie, gel, soumis à des agents de déverglaçage)

Cibles

R_c : 50-55 MPa
W/C <= 0,45
Ciment >= 340 kg/m³
Absorption d'eau <= 6,5%

Résultats		REF - 0 %	Granulat de béton recycle			Granulat recyclé mixte		
		N100	B100	B75	B40	M100	M75	M40
Ciment	[kg]	400	400	400	400	400	400	400
E/C efficace	[-]	0,45	0,45	0,45	0,45	0,45	0,45	0,45
E/C	[-]	0,47	0,57	0,55	0,51	0,58	0,55	0,51
E/C mesuré	[-]	0,41	0,44	0,41	0,44	0,42	0,41	0,44
Test d'affaissement au cone d'Abrams cone (EN12350-2)	[-]	S4(21cm)	S3(10cm)	S4(18cm)	S4(21cm)	S3(10cm)	S4(18cm)	S4(17cm)
Masse volumique à l'état frais	[kg/m³]	2344	2254	2319	2229	2299	2261	2326
Résistance en compression à 28 jours	[MPA]	***47,5***	***42,5***	74,3	72,4	59,0	69,6	75,8
Absorption d'eau	[%]	5,2	***9,1***	5,6	5,9	**7,1**	6,0	5,5
Masse volumique	[kg/m³]	2280	***2051***	2195	2282	2071	2195	2234
Perte de masse – cycles de gel-dégel à 28 jours	[kg/m²]	0,67	**5,28**	**1,73**	**1,77**	**2,61**	**2,54**	**1,87**

DURABILITÉ

Résultats des essais de cycles gel-dégel à 28 jours

- La surface des échantillons produit à base de granulats recyclés est fortement endommagée

N100 (Ref)
0,72 kg/m²
0,43 kg/m²

B75
1,27 kg/m²

B40
2,15 kg/m²

M75
1,96 kg/m²

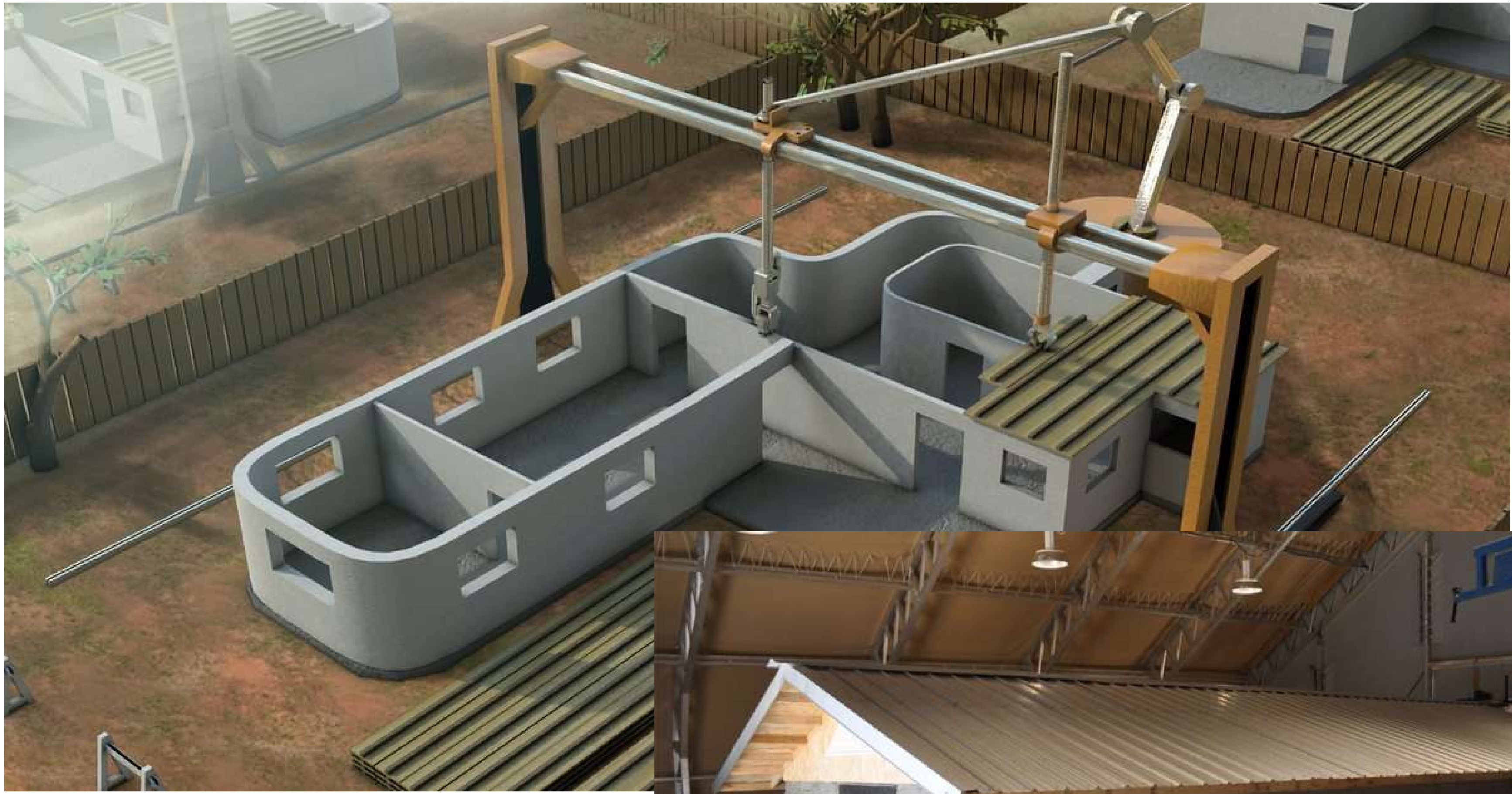
CIRMAP

Main Objective

Valorisation of Recycled fine aggregates through 3D printing.

01/04/2020-31/03/2023

3D printing



www.build-green.fr

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Rammed concrete

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Ackowledgement to

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