Increasing properties of concrete with recycled construction and demolition wastes

Luc Courard, F. Michel, M.K. Bouarroudj, Ch. Colman, S. Delvoie, Z. Zhao

25. Slovenski Kolokvij o Betonih, Ljubljana, 4 June 2018

LIÈGE université Sciences Appliquées

UEE Urban & Environmental Engineering

Global context

What to do?

Global context

- We produce wastes
  - Between **3.4 to 4 billions tons/year** or from 80 to 126 tons/second!
  - Each day, human activiy is contributing for more than 10 billions kg wastes
  - According to Pike Research, we produced 74 millions tons of electric and electronic wastes in 2014 (2346 kilos/second)!

http://www.planetoscope.com/dechets/363-production-de-dechets-dans-le-monde.html

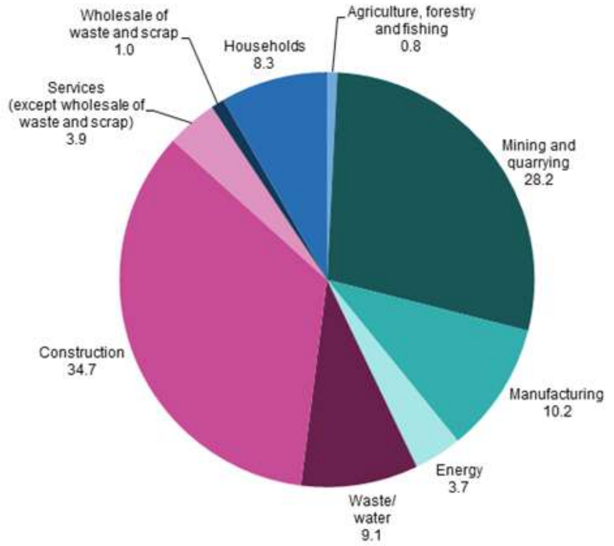
Global context

- We produce wastes
  - Different shapes of wastes
    - 83% wastes are solid
    - 10% wastes are paste
    - 7% wastes are liquid
  - Production of industrial wastes
    - Inorganic wastes (70%)
    - Organic wastes (25%)
    - Unclassified

Direction générale Statistique et Information économique (DGSIE) www.ccfee.be (2012)

Global context

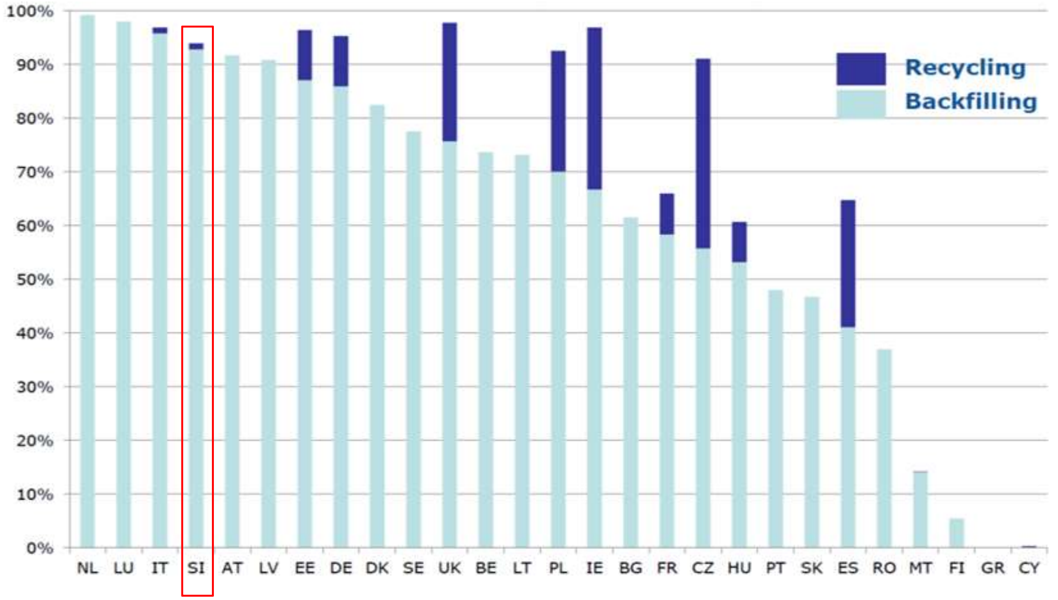
- We produce wastes
  - In EU28 countries, the total waste production by economic activities and households accounted for **2.50 billion tons** (4931 kg per capita) in 2014. **CDW** is estimated to **34.7 %** of the total wastes.



Source: Eurostat (online data code: env_wasgen)

Global context

- ► We produce wastes
  - Annual production of recycled aggregates accounted for 202 million tons in 2015
    - Percentage of CDW recovery in the EU27 countries in 2011 (European Commission, 2017)



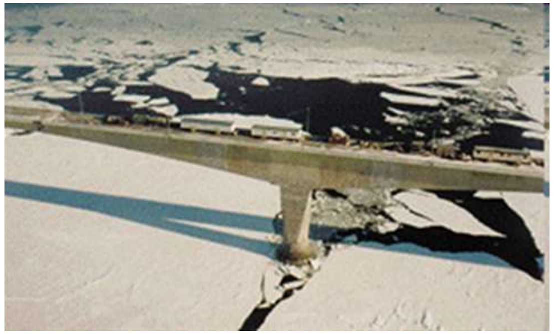
UEPG, 2018, http://www.uepg.eu/statistics/estimates-of-production-data/data-2015

Global context

- We produce wastes
  - **construction area is producing more or less than 40% of CO_2**
  - *construction area is consuming 40% of energy produced*
  - *construction area is consuming between 40 and 50% of natural resources as primary raw materials*

Global context

- We need materials
  - *construction area is producing more or less than 40% of CO_2*
  - **construction area is consuming 40% of energy produced**
  - **construction area is consuming between 40 and 50% of natural resources as primary raw materials**



UEE
Urban & Environmental Engineering

Global context

- We need materials
  - Concrete: **more than 9 billions tons/year** (= 30000 arches of La Défense in Paris)
    - Aggregates: 4.7 billions tons (670 pyramids of Cheops)
    - Sand: 2.2 billions tons (22 millions wagons = train 264000 km long)
    - Cement: 1.3 billions tons (17000 paquebots Norway = 2.34 billions tons limestone and clay)
    - Water: 800 billions tons (23 times of Seine in Paris river flow)

Global context

- We need construction materials
  - For the EU28 plus EFTA countries, the total 2015 **aggregates production** is estimated just on **2.66 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)

2015 National Production in Tonnes per Capita

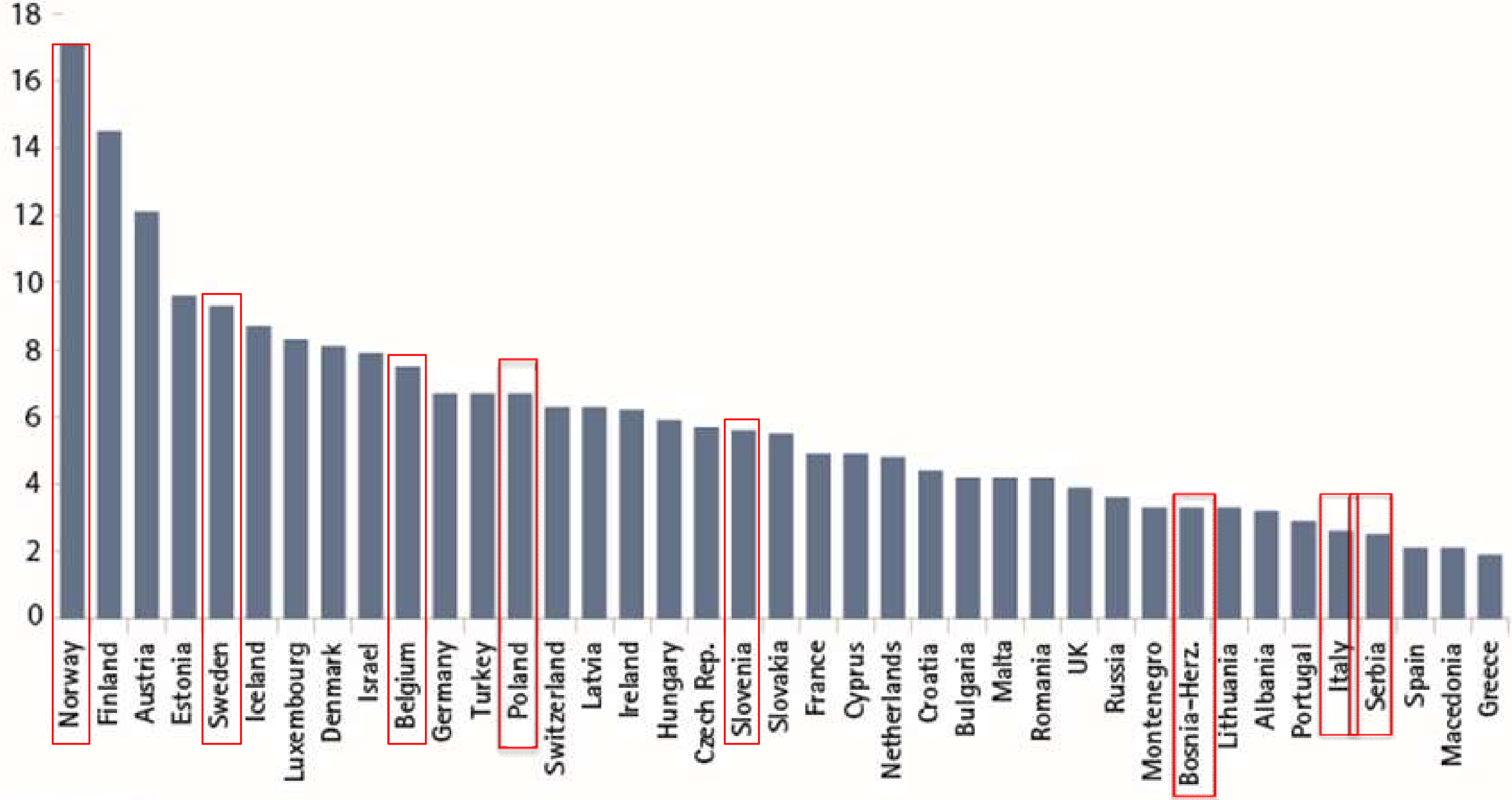


Figure 2 National Production per country in Tonnes per Capita

2015 National Production by Country (mt)

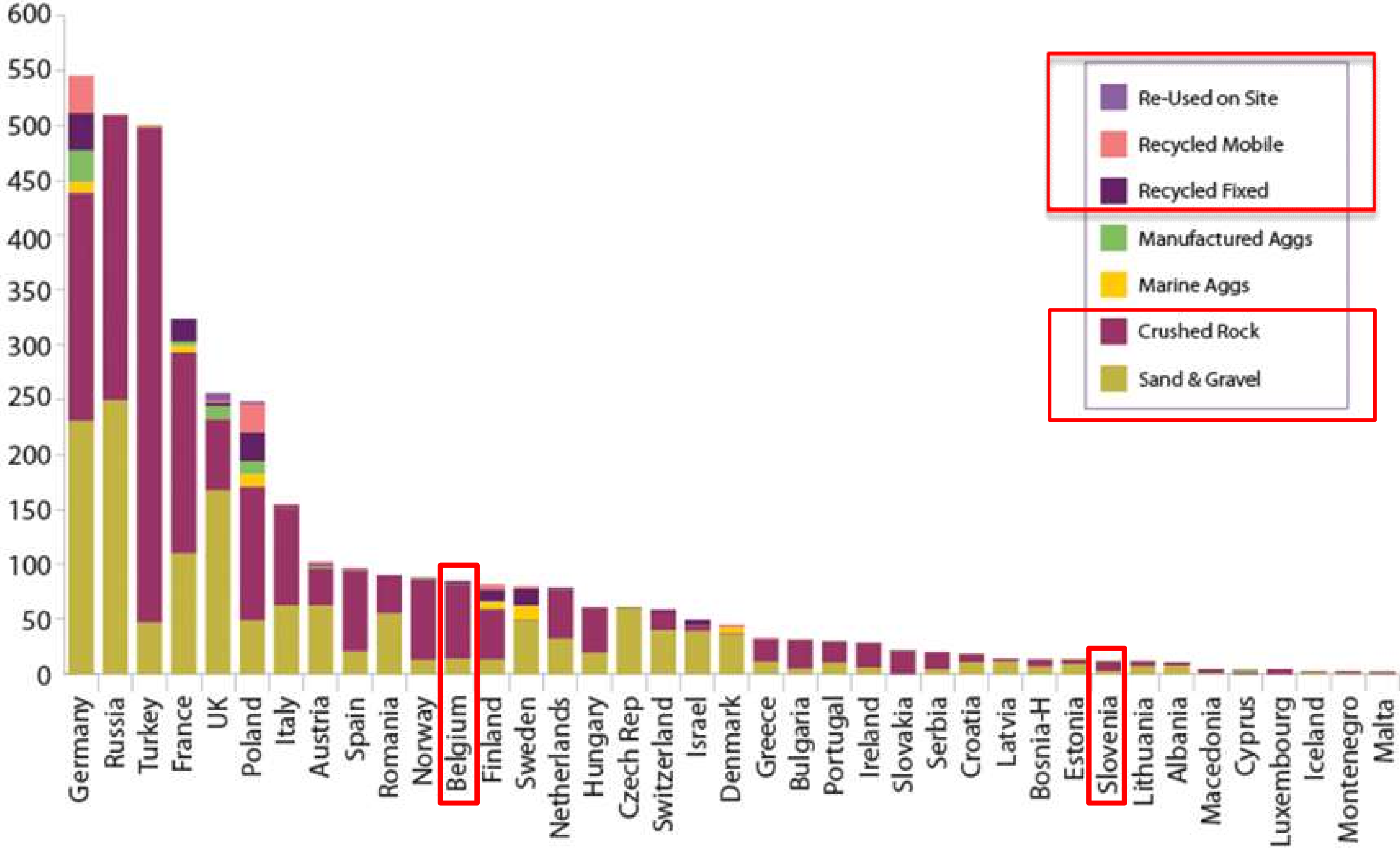
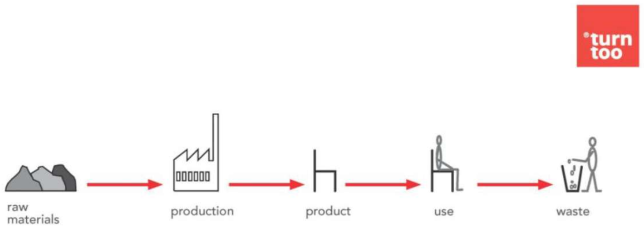


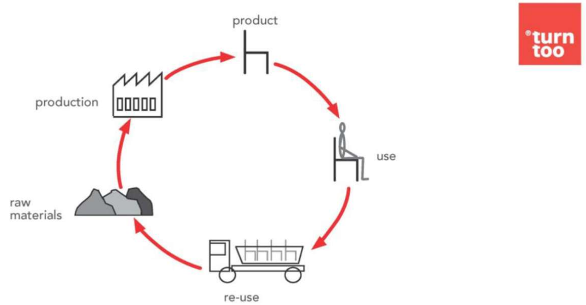
Figure 1 Aggregates Production (in millions of tonnes by country and type)

Global context

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



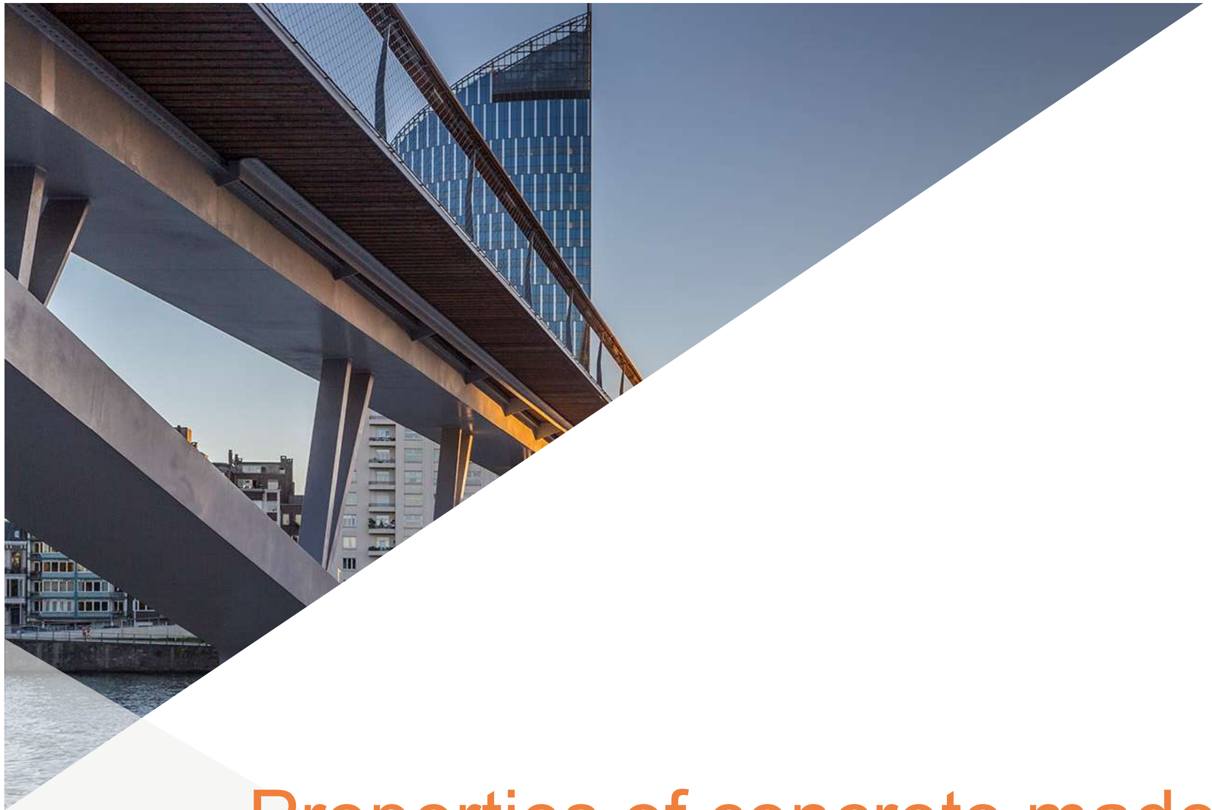
OLD LINEAR ECONOMY - is about ownership



C2C - TECHNICAL NUTRIENT CYCLE

Objectives

- 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)



LIÈGE université
Sciences Appliquées

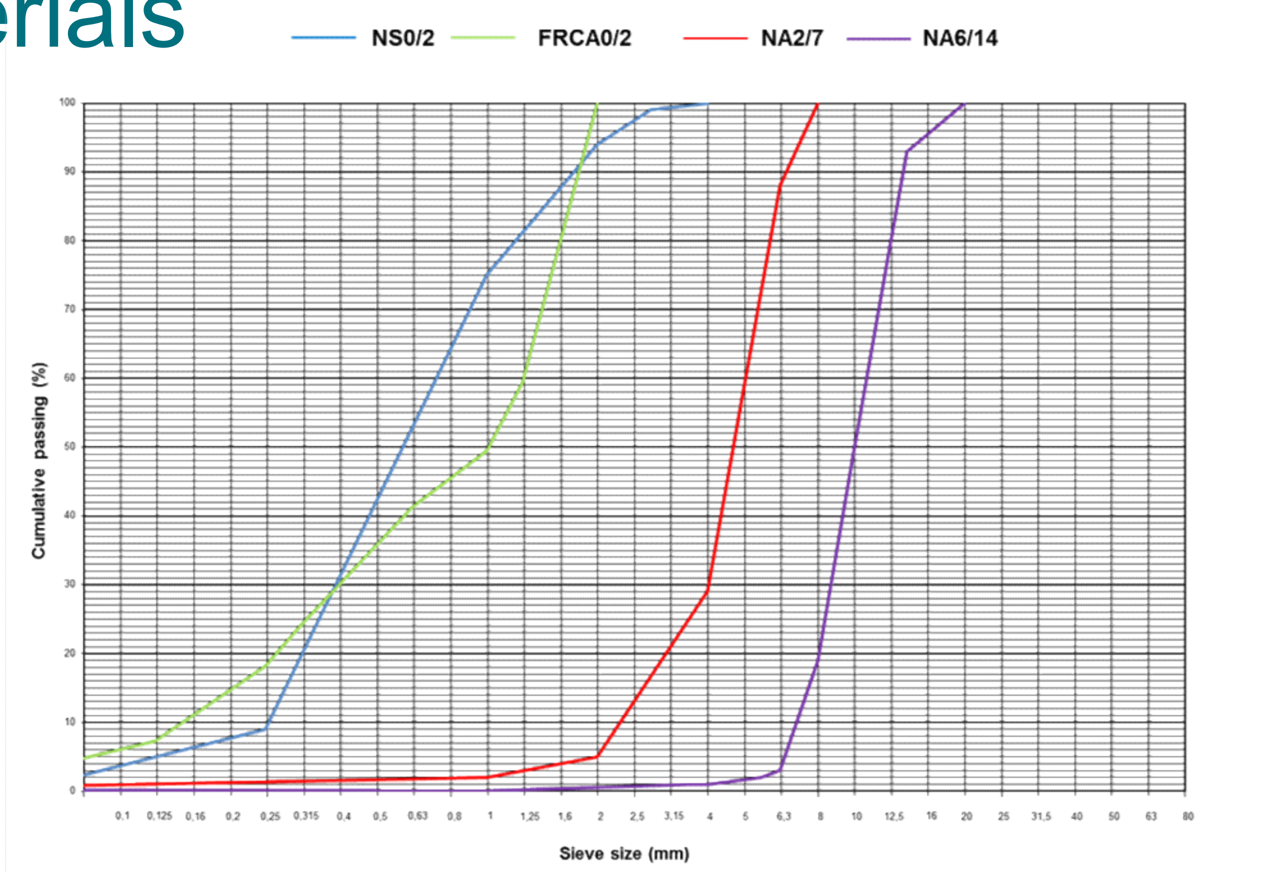
Properties of concrete made with fine recycled concrete aggregates

UEE
Urban & Environmental Engineering

Materials

- Two phases
  - Natural aggregates (NA)
  - Hardened cement paste (more porous)
- Properties of RCA
  - Depending on proportions and properties of these two phases
  - Influenced by particle size, composition of original concrete, contaminants, crushing method…
- Concrete made with RCA
  - Coarse RCA usually present satisfying properties for the reuse as concrete aggregate
  - Fine RCA present a large water demand which makes them less easy to recycle into concrete

Materials



- FRCA 0/2: Industrial RCA from recycling center (0/31.5mm to 0/2mm) W_A=8.8% according to EN 1097-6
- Natural river sand: NS 0/2; W_A=0.7%
- Limestone aggregates: NA 2/7, NA 6/14

Materials

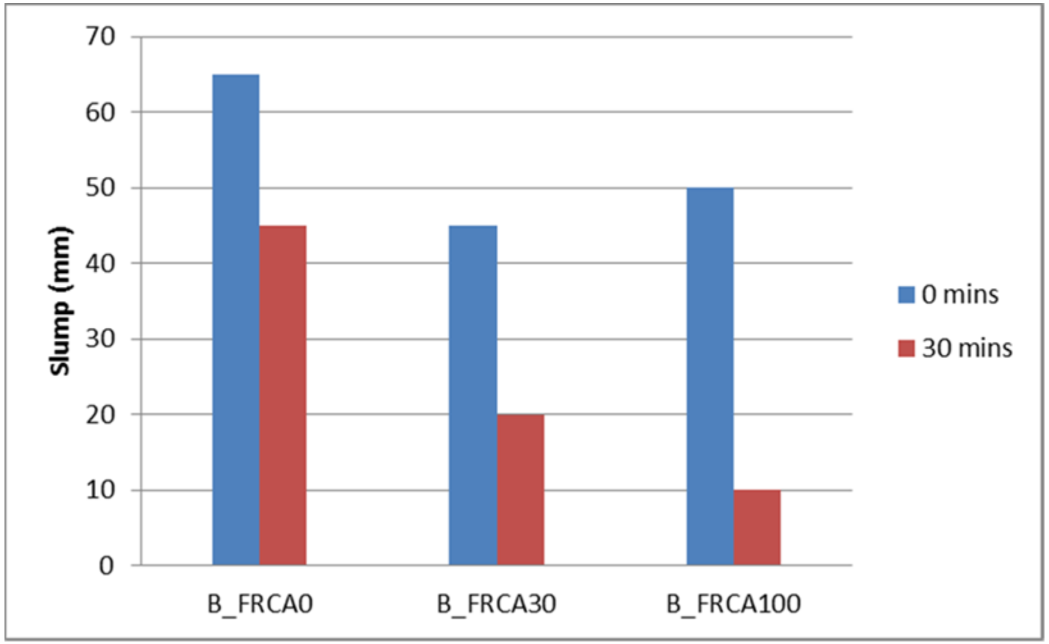
- Mix design

	B_FRCA0	B_FRCA30	B_FRCA100
NA 6/14 (kg)	550.0	550.0	550.0
NA 2/7 (kg)	775.0	775.0	775.0
NS 0/2 (kg)	600.0	420.0	0.0
FRCA 0/2 (kg)	0.0	168.0	559.2
Cement (kg)	320.0	320.0	320.0
Efficient water (kg)	160.0	160.0	160.0
Absorbed water (kg)	11.2	24.7	56.2
Superplasticizer (kg)	3.4	3.4	3.4
W_{eff}/C	0.5	0.5	0.5

- Different substitution rates of NS 0/2 by the same volume FRCA 0/2 (0, 30, 100%);
- Same W_{eff}/C ratio - cement CEM I 52.5 N
- Pre-saturation of aggregates in the mixer 5 min before the addition of cement (by half of total water)

Properties

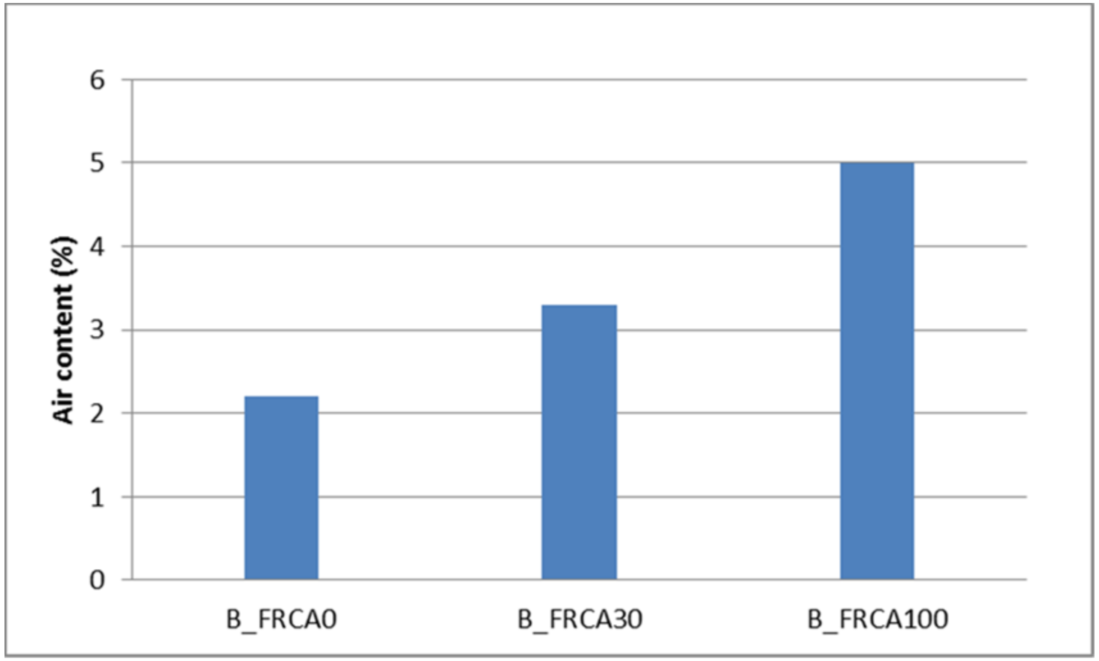
- ▶ Slump test



- Initial slump decreases for concretes with recycled sand
- The slump of all types of concrete decreases whatever the different substitutions
- The rate of slump loss is larger as the substitution increases

Properties

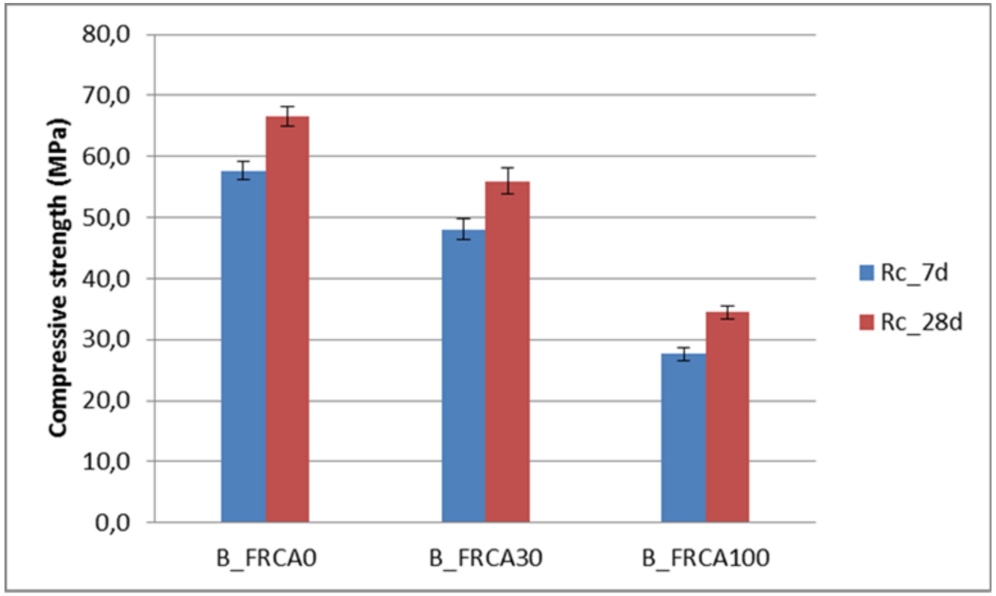
- Air content



- The air content of concrete increases when the substitution of recycled sand increases
  - 2.2% for B_FRCA0
  - 3.3% for B_FRCA30
  - 5.5% for B_FRCA100

Properties

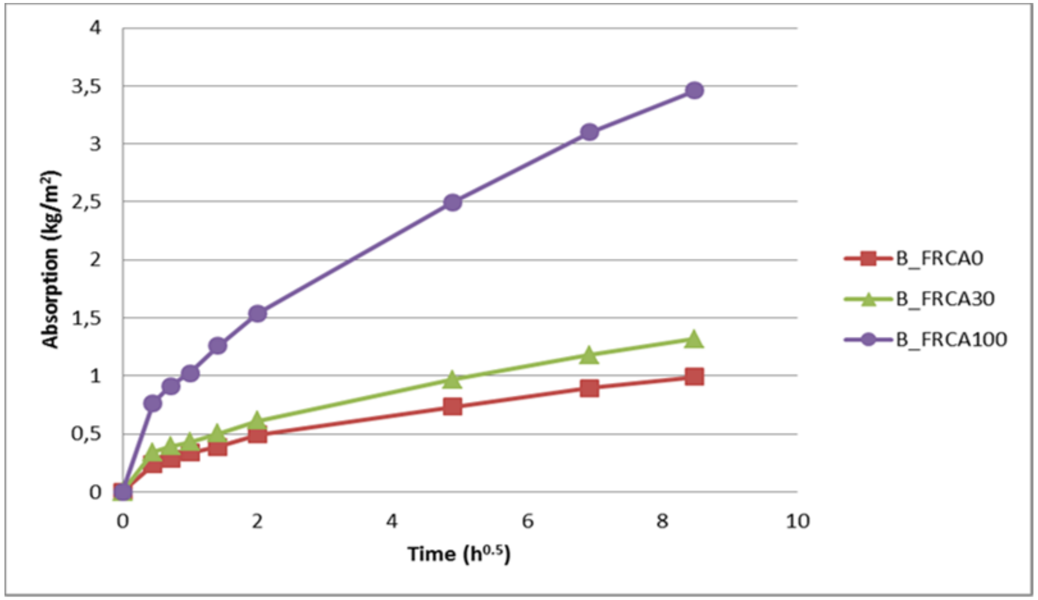
- Compressive strength



  - Compressive strengths of concretes with FRCA are lower than those of concrete with natural sand
  - Compressive strength of concrete made with 100% FRCA at 28 days decreases 48.2% comparing with the reference concrete (decreases **only 15.9% for B_FRCA30**)

Durability

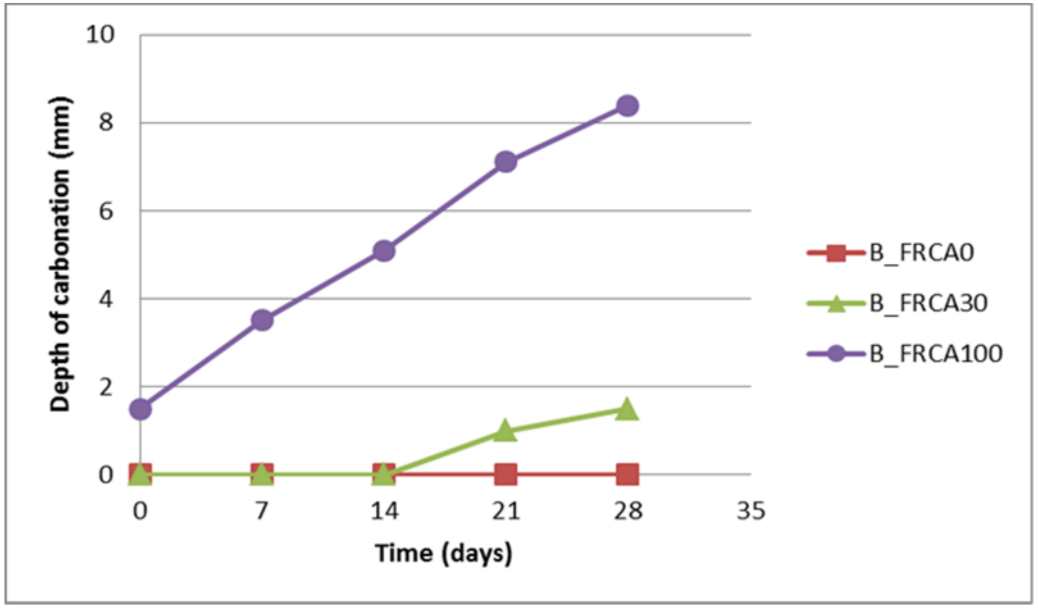
- Capillary absorption



- Rates of absorption of recycled concrete are much larger than the reference concrete;
- The coefficient of capillary absorption of concrete B_FRCA100 is 0.38 $kg/m^2/h^{0.5}$ (0.11 and 0.14 $kg/m^2/h^{0.5}$ for B_FRCA0 and B_FRCA30 respectively)
- Total porosity estimated by water absorption is 9.5% for concrete B_FRCA100 (4.2% and 5.3% for the reference concrete and B_FRCA30 respectively)

Durability

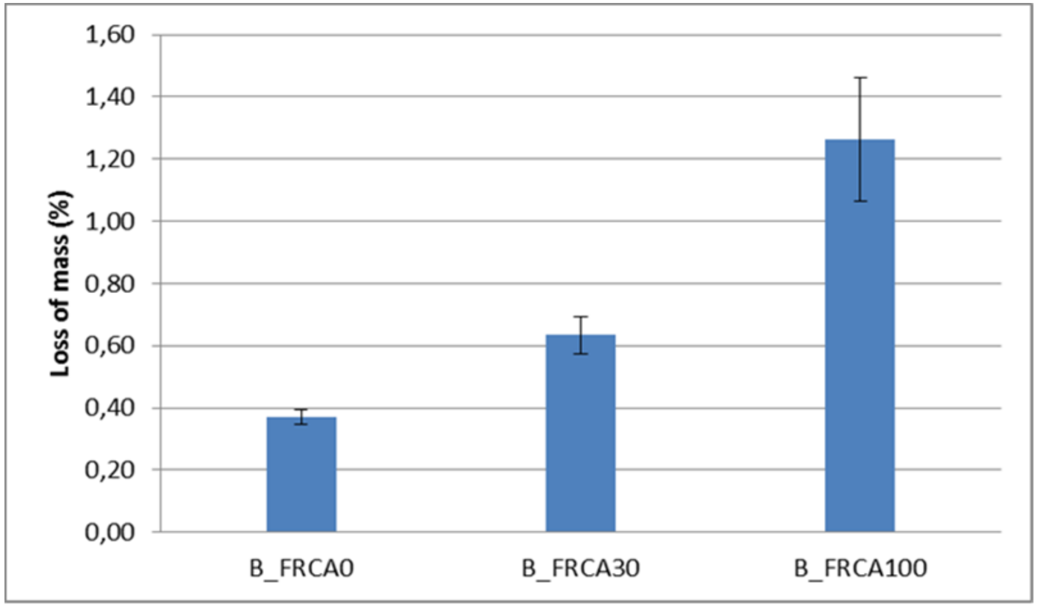
- Carbonation depth



  - Carbonation depths of B_FRCA0 and B_FRCA30 are zero for the first 14 days (5 mm for B_FRCA100)
  - Carbonation depth of concrete increases as the substitution increases

Durability

▸ Freeze-thaw cycles

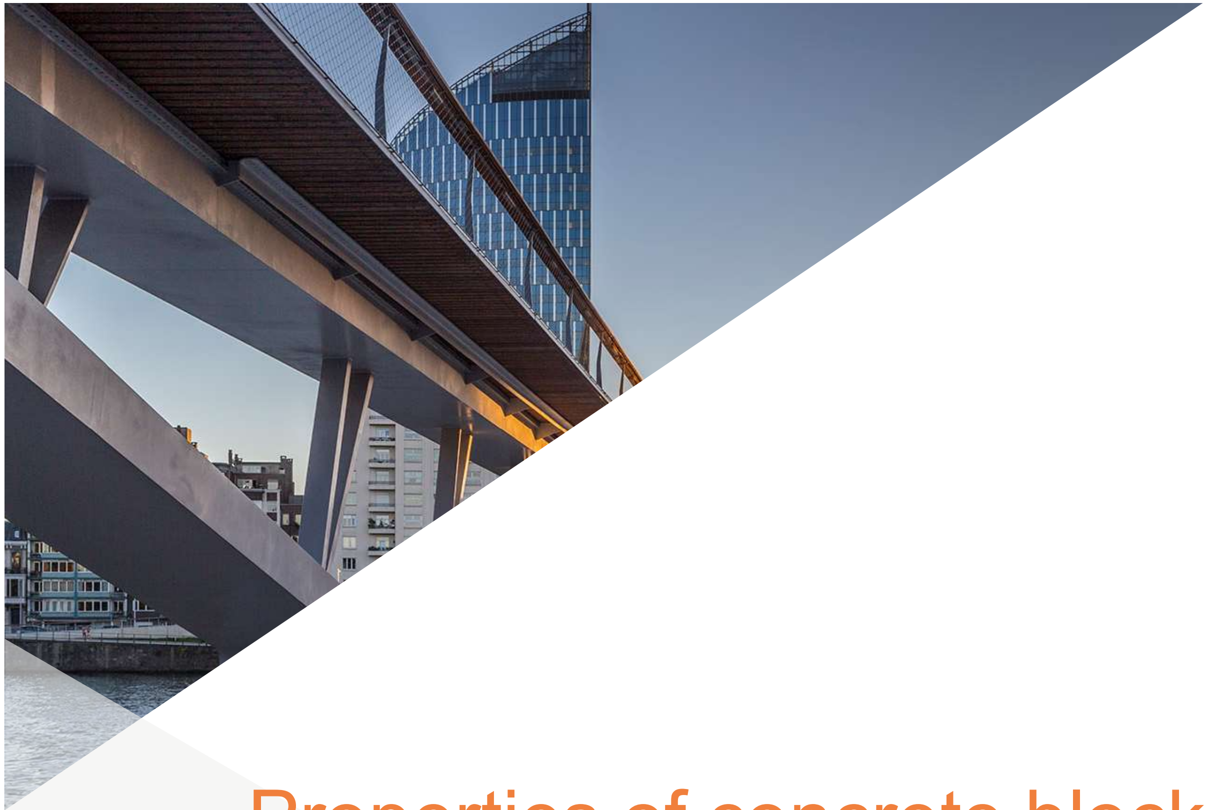


- After 14 freeze-thaw cycles, the visual specimen's examination does not allow detecting any significant deterioration for all the concretes
- The recycled concretes have lower freeze-thaw resistance comparing with the reference concrete, which is due to higher porosity in the recycled concrete

Conclusions

- Durability of concrete could be strongly influenced by the high porosity and water absorption of recycled concrete aggregates.
- The durability properties of concrete made with **30% FRCA** are comparable to the reference concrete, especially for capillary absorption and carbonation
- Use of FRCA in concrete structures can be envisaged depending on their class of exposure and the concrete grade requirement (for example the concrete **C25/30** with no risk of corrosion or attack)

LIÈGE université
Sciences Appliquées



Properties of concrete blocks made with recycled concrete aggregates: from block wastes to new blocks

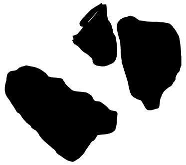
UEE
Urban & Environmental Engineering

Materials

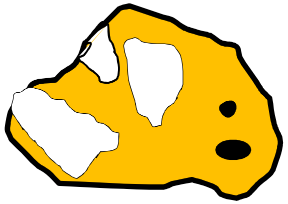
- RCA manufactured in laboratory
  - Old concrete from block wastes (C8/10, from PREFER Company)
  - Crushing (jaw crusher in laboratory, opening ≈10mm)
  - Drying in oven at 105°C
  - Separation of RCA by sieving (0/20mm)
    - Four granular classes: 0/2 - 2/6.3 - 6.3/14 - 14/20

Properties of RCA

- Hardened Cement Paste Content (CPC) of RCA
  - Principal soluble and insoluble phases in salicylic acid and methanol dissolution *(Zhao et al., 2013, Journal of Sustainable Cement-Based Materials* ***2****,186-203)*



Quartz, Dolomite, Calcite
Insoluble in salicylic acid

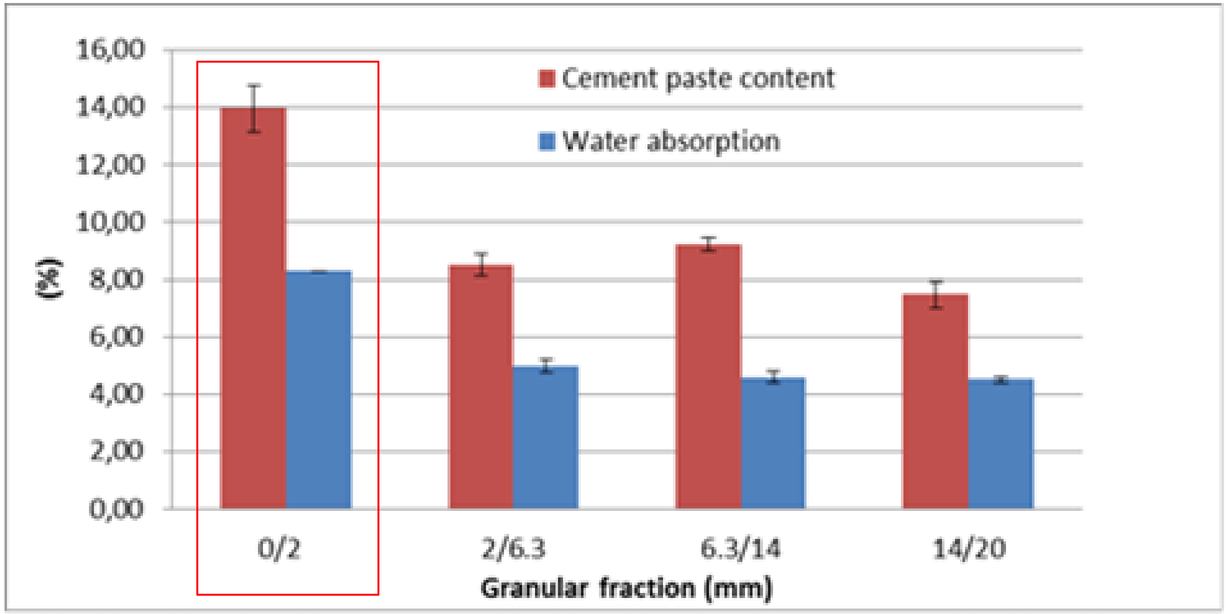


C_2S, C_3S, $Ca(OH)_2$, C-S-H, Ettringite
Soluble in salicylic acid

Insoluble in salicylic acid
C_4AF, AFm → CEM I
Calcite, Slag… → CEM II, III

Properties of RCA

- Water absorption W_A (EN 1097-6)



  - CPC and W_A of 0/2mm fraction larger than three coarse fractions
  - Recycled sand presents higher CPC and W_A than CRCA

UEE
Urban & Environmental Engineering

Materials

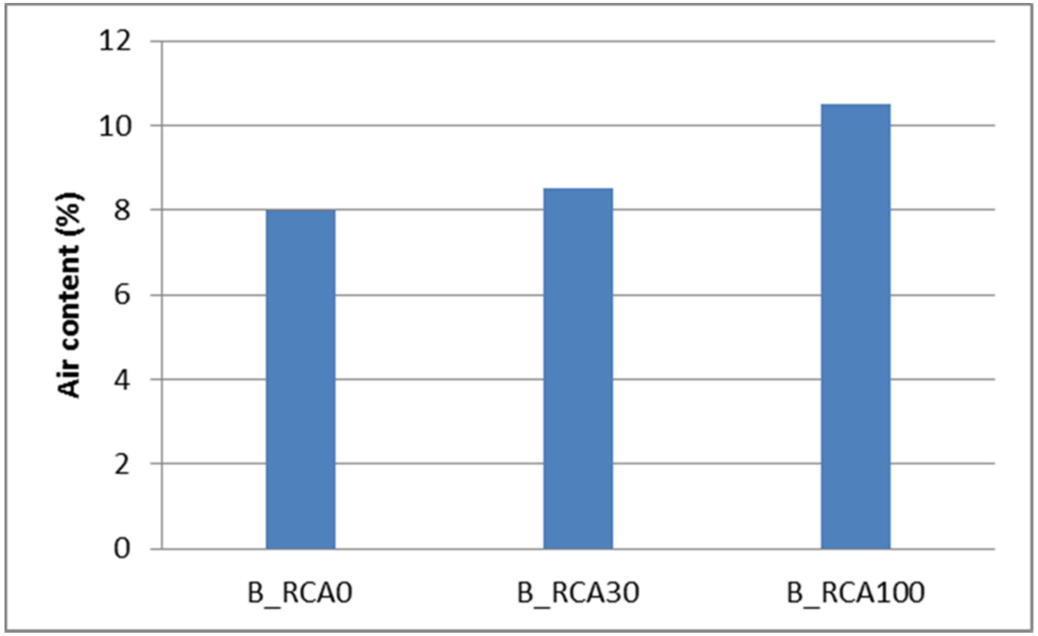
▶ Mix design

	B_RCA0	*B_RCA30*	*B_RCA100*
NA 2/7 (kg)	1080	754	0
RCA 2/6.3 (kg)	0	302	1008
NS 0/2 (kg)	825	825	825
Cement (kg)	150	150	150
Efficient water (kg)	105	105	105
Absorbed water (kg)	13.12	26.00	56.20
W_{eff}/C	0.70	0.70	0.70

- Different substitution rates of NA 2/7 by the same volume RCA 2/6.3 (0, 30, 100%)
- Same W_{eff}/C ratio - cement CEM III/A 42.5
- Pre-saturation of aggregates in the mixer **5 min** before the addition of cement by half of total water

Properties

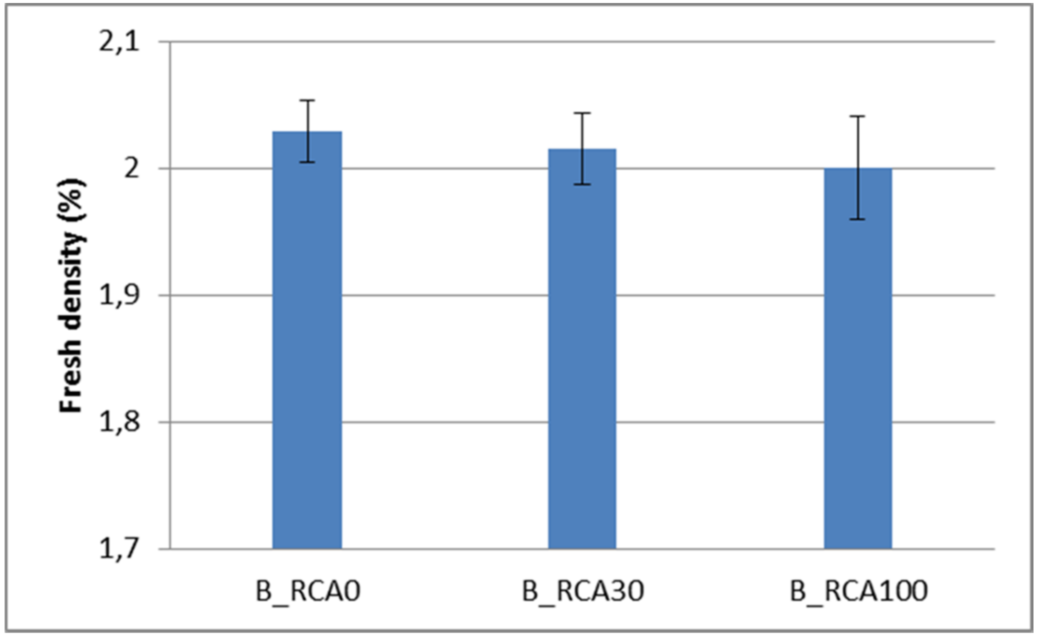
► Fresh properties of concrete (zero slump)



- The air content of concrete increases when the substitution of recycled aggregates increases

Properties

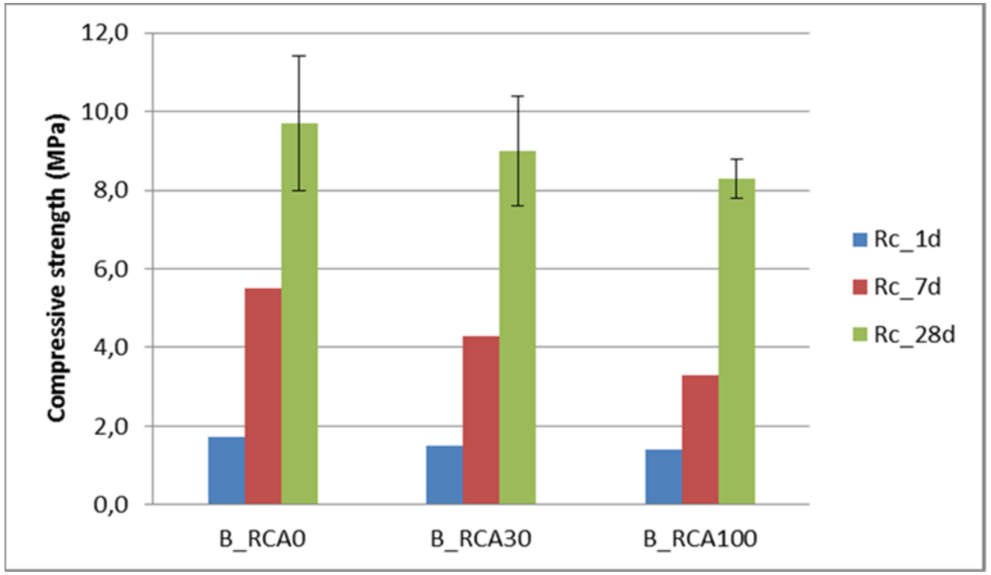
- Fresh density



  - The fresh density of concrete slightly decreases when the substitution of RCA increases

Properties

- Compressive strength



- Compressive strengths of concretes with RCA are slightly lower than those of concrete with natural aggregate
- Compressive strength of concrete made with 100% RCA at 28 days is 8 MPa (14.4% decrease)

Conclusions

- Feasibility of using RCA obtained from old concrete block wastes in the new concrete blocks
  - Recycled sand possesses significantly higher cement paste content and higher water absorption than coarse RCA
  - Compressive strength of concrete blocks slightly decreases as the substitution of RCA increases; Rc of B_RCA100 could reach 8 MPa after 28 days without increasing the cement content of the concrete mix

Acknowledgment

- VALDEM INTERREG FWVL research project
  - "Solutions intégrées de valorisation des flux « matériaux » issus de la démolition. Approche transfrontalière vers une économie circulaire" - *http://www.valdem-interreg.eu*
- SeRaMCo INTERREG NWE research project
  - "Secondary Raw Materials for Concrete Precast Products (introducing new products, applying the circular economy)" - *http://www.nweurope.eu/seramco*
- PREFER Company

MOOC recycling

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