Increasing properties of concrete with recycled construction and demolition wastes

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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 activity 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
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: enu_waspen)
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)

Global context

► We produce wastes
  ▪ construction area is producing more or less than 40% of CO₂
  ▪ 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
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)
Figure 2: 2015 National Production in Tonnes per Capita

Figure 2: National Production per country in Tonnes per Capita
Global context

► We are living in a limited world
  ➢ Energy
  ➢ Raw materials
  ➢ Space
  ➢ Maximum capacity of resilience of nature

► Ascertainment → behaviour

► Deposit ↔ market
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)
Properties of concrete made with fine recycled concrete aggregates
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

<table>
<thead>
<tr>
<th></th>
<th>B.FRCA0</th>
<th>B.FRCA30</th>
<th>B.FRCA100</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA 6/14 (kg)</td>
<td>550.0</td>
<td>550.0</td>
<td>550.0</td>
</tr>
<tr>
<td>NA 2/7 (kg)</td>
<td>775.0</td>
<td>775.0</td>
<td>775.0</td>
</tr>
<tr>
<td>NS 0/2 (kg)</td>
<td>600.0</td>
<td>420.0</td>
<td>0.0</td>
</tr>
<tr>
<td>FRCA 0/2 (kg)</td>
<td>0.0</td>
<td>168.0</td>
<td>559.2</td>
</tr>
<tr>
<td>Cement (kg)</td>
<td>320.0</td>
<td>320.0</td>
<td>320.0</td>
</tr>
<tr>
<td>Efficient water (kg)</td>
<td>160.0</td>
<td>160.0</td>
<td>160.0</td>
</tr>
<tr>
<td>Absorbed water (kg)</td>
<td>11.2</td>
<td>24.7</td>
<td>56.2</td>
</tr>
<tr>
<td>Superplasticizer (kg)</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>$W_{eff}/C$</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- 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/m²/h^(0.5) (0.11 and 0.14 kg/m²/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).
Properties of concrete blocks made with recycled concrete aggregates: from block wastes to new blocks
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$_2$S, C$_3$S, Ca(OH)$_2$, C-S-H, Ettringite
Soluble in salicylic acid

Insoluble in salicylic acid
C$_4$AF, 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
Materials

Mix design

<table>
<thead>
<tr>
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<th>B = RCA0</th>
<th>B = RCA30</th>
<th>B = RCA100</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA 2/7 (kg)</td>
<td>1080</td>
<td>754</td>
<td>0</td>
</tr>
<tr>
<td>RCA 2/6.3 (kg)</td>
<td>0</td>
<td>302</td>
<td>1008</td>
</tr>
<tr>
<td>NS 0/2 (kg)</td>
<td>825</td>
<td>825</td>
<td>825</td>
</tr>
<tr>
<td>Cement (kg)</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Efficient water (kg)</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>Absorbed water (kg)</td>
<td>13.12</td>
<td>26.00</td>
<td>56.20</td>
</tr>
<tr>
<td>W_{eff}/C</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
</tr>
</tbody>
</table>

- 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

► 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