Valorization integrated solutions for Construction Demolitions Wastes flows: transborder approach for circular economy (2016-2020)

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Luc COURARD, Romania, Iasi, September 6, 2017
Design and properties of self-compacting concrete based on fine recycled particles

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Supervisors: Prof. Luc COURARD, Prof. Sébastien REMOND
1. Introduction: context

- Environment: think globally, act locally
- Concrete: the most used construction material in the world
- Construction sector → 40-50% of natural resources

Goal: valorization of 70% construction and demolition waste (CDW) by 2020
1. Introduction: valorization/objective

Construction and demolition wastes are inert wastes and vary according to their origin.

Objective: Use the fine recycled particles from CDW in the design of self-compacting concrete (SCC)
1. Introduction: self-compacting concrete (SCC)

- **Properties of SCC**
  - Be able to consolidate under its own weight
  - Contains between 500 and 600 kg/m³ of fine particles (cement + limestone fillers)

- **Specifications**
  - Good workability
  - Good resistance to segregation
  - Need to use superplasticizers

- **Advantages**
  - No need to use any vibrator
  - Easily cast in complicated formwork and in presence of dense reinforcement
  - Mechanical properties similar to conventional concrete

- **Disadvantages**
  - Higher cost than conventional concrete
2. Methodology

- SCC
- SCC mortar
  - Crushed recycled sand
    - Rheological properties
    - Mechanical properties
  - Recycled sand
    - Rheological properties
    - Mechanical properties
3. Self-compacting concrete/mortar composition

<table>
<thead>
<tr>
<th>Materiel</th>
<th>SCC mix design (kg/m³)</th>
<th>Mortar mx design (kg/m³)</th>
<th>SCC rheological properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 52.5N</td>
<td>311</td>
<td>448</td>
<td>Slump (mm) 700</td>
</tr>
<tr>
<td>Limestone filler</td>
<td>207</td>
<td>298</td>
<td>Time of slump (s) 4.5</td>
</tr>
<tr>
<td>Sand 0/2</td>
<td>918</td>
<td>1323</td>
<td>Slump after 60 minutes (mm) 565</td>
</tr>
<tr>
<td>Aggregate 2/7</td>
<td>295</td>
<td>/</td>
<td>U-box (mm) 334</td>
</tr>
<tr>
<td>Aggregate 7/14</td>
<td>554</td>
<td>/</td>
<td>Time of U-box (s) 9.9</td>
</tr>
<tr>
<td>Water</td>
<td>165</td>
<td>238</td>
<td>V-funnel (s) 14.3</td>
</tr>
<tr>
<td>SP (% cement)</td>
<td>2.1</td>
<td>2.1</td>
<td>% air 2.5</td>
</tr>
<tr>
<td>W/C</td>
<td>0.53</td>
<td>0.53</td>
<td></td>
</tr>
</tbody>
</table>

Substitution of natural sand by recycled sand (RS) : 20%, 40%, 60%, 80% and 100%

Substitution of limestone filler by crushed recycled sand (CRS) : 20%, 40%, 60%, 80% and 100%
3. Characterization: recycled sand/natural sand

<table>
<thead>
<tr>
<th></th>
<th>Recycled sand</th>
<th>Natural sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent particle density (g/cm³)</td>
<td>2.456 0.033</td>
<td>2.606 0.019</td>
</tr>
<tr>
<td>Particle density on an oven-dried basis (g/cm³)</td>
<td>2.238 0.028</td>
<td>2.514 0.018</td>
</tr>
<tr>
<td>Particle density on a saturated and surface-dried basis (g/cm³)</td>
<td>2.327 0.029</td>
<td>2.549 0.018</td>
</tr>
<tr>
<td>Helium apparente density (g/cm³)</td>
<td>2.64 0.004</td>
<td>2.66 0.003</td>
</tr>
<tr>
<td>Accessible porosity (%)</td>
<td>9.7 0.13</td>
<td>4 0.03</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>3.95 0.19</td>
<td>1.41 0.33</td>
</tr>
</tbody>
</table>

Opening sieve (µm)

Cumulative passing %
3. Characterization: Crushed Recycled Sand/limestone filler (powder)

- **Crushed Recycled Sand (CRS)**
  - Density (g/cm³): 2.69
  - Blaine Specific Surface area (cm²/g): 3360
  - BET Specific Surface area (m²/g): 2.771
  - βp: 0.3052

- **Limestone (LP)**
  - Density (g/cm³): 2.71
  - Blaine Specific Surface area (cm²/g): 3180
  - BET Specific Surface area (m²/g): 0.772
  - βp: 0.2738

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**Graphs:**

- **Cumulative passing % vs. Sieve diameter (mm)**
  - CRS and LP curves are plotted with cumulative passing % on the y-axis and sieve diameter (mm) on the x-axis.

- **βp measurement**
  - Linear regression equations for CRS and LP:
    - CRS: \( y = 0.0143x + 0.3052 \) with \( R^2 = 0.9277 \)
    - LP: \( y = 0.0131x + 0.2738 \) with \( R^2 = 0.9406 \)

- **W/P vs. Slump**
  - CRS and LP data points are plotted with W/P on the y-axis and slump on the x-axis.
## 5. Compactness

<table>
<thead>
<tr>
<th></th>
<th>Cement</th>
<th>LF</th>
<th>CRS</th>
<th>SP</th>
<th>W with SP</th>
<th>W without SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 1</td>
<td>284</td>
<td>188</td>
<td>0</td>
<td>0 or 5.96</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Mix 2</td>
<td>287</td>
<td>0</td>
<td>185</td>
<td>0 or 6.03</td>
<td>80</td>
<td>132</td>
</tr>
</tbody>
</table>

\[ C_{\text{exp}} = \frac{1000}{1000 + M_{v}^{*} \frac{M_{e}}{M_{p}}} \]

With superplasticizer: CRS+C higher packing density than LF+C
Without superplasticizer: LF+C higher packing density than CRS+C
6. Rheological test: slump

Workability of mortar increases with the increase of substitution of NS by RS
Workability of mortar decreases as the substitution of LF by CRS increases
6. Rheological test: time of slump

Slump of mortar made with recycled sand kept unchanged after 1 hour
7. Mechanical properties

Effect of CRS and RS on the mechanical properties

Significant difference in compressive strength at 7 and 28 days compared to the reference mortar
8. Conclusions

**Crushed recycled sand**
- Worse workability
- Significant difference in mechanical strength

**Recycled sand**
- Better workability
- Significant difference in mechanical strength
9. Perspectives

- Simulation of packing density by Compressible Stacking Method (CSM)
- Understand the rheology of mortar/concrete based on recycled material
- Formulation of SCC based on recycled material with CSM
- Validation of the scientific approach with different recycled materials from different companies
- Study the influence of sulfate contents on the rheological properties of mortar
Gypsum residues in recycled materials
Effects on microstructural and mechanical properties of cementitious mixes

Charlotte Colman
Supervisors: Prof. Luc Courard, Prof. David Bulteel
Problem definition: fine particles

The incorporation of fine recycled particles into new concrete has a negative influence on its strength and durability properties.

Construction and Demolition Waste is contaminated with materials from the construction site.

Even with a careful ‘deconstruction’ instead of a demolition, a lot of contaminants still end up in the recycled waste.
Problem definition: sulfate attack

Gypsum (CaSO$_4$.2H$_2$O) contamination in fine recycled particles may complicate, enhance, accelerate the effects of sulfate attack.

Sulfate attack is a deteriorating process for concrete, causing the expansive formation of sulfate containing minerals such as ettringite.

The formation of this secondary ettringite leads to expansive behaviour:

$$(\text{CaO})_3(\text{Al}_2\text{O}_3).6\text{H}_2\text{O}+(\text{CaSO}_4)_3.2\text{H}_2\text{O}+26\text{H}_2\text{O} \rightarrow (\text{CaO})_3(\text{Al}_2\text{O}_3)(\text{CaSO}_4)_3.32\text{H}_2\text{O}$$
Problem definition: research objectives

Which proportion of residual gypsum contamination from demolition waste is acceptable for designing new concretes?

Understand the effects of sulfate attack on various properties of concrete based materials derived from demolition waste

Establish the relation between pore fluid chemistry and volumetric deformation
Methodology

1. Characterization of recycled sand
Fine recycled materials, obtained from construction, recycling or demolition companies are analyzed chemically, physically, mineralogically.

2. Swelling measurements
Mortar parameters are varied to assess their influence on the swelling process (cement type, gypsum content, humidity, temperature, ...). Swelling is measured in the classical way, but also with oedometers.

3. Following the development of sulfate attack
With different analytical techniques (SEM, nano indentation, petrography, ...), different stages of sulfate attack are researched in hardening pastes.

4. Development of a quantitative relation
The gypsum content of a material is directly related to its volumetric deformation
Characterization results show a large variation between different sources, even between different batches of the same source.
Characterization results

Water soluble sulfates

Acid soluble sulfates
Characterization results

Thermogravimetric analysis for source B and C is similar. Sand from source A is fully carbonated!
Characterization results

XRD: a very large quartz peak may be hiding information about ettringite.
Characterization results

XRF: larger fractions are more rich in C and Ca, and less in Si
Thank you for your attention
Questions?