Benchmarking of materials composition and transportation influences on Life Cycle Assessment of Recycled Aggregate Concrete

S. Braymand, A. Feraille, N. Serres, F. Feugeas

ATHENS 2017
5th International Conference on Sustainable Solid Waste Management
21-24 June 2017, Athens, Greece
LCA METHODOLOGY

Allows to quantify the damage of a product or a structure on the environment

### Environmental impacts

<table>
<thead>
<tr>
<th>Impact indicator</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic depletion</td>
<td>kg Sb eq</td>
</tr>
<tr>
<td>Consumption of energetic resources</td>
<td>MJ</td>
</tr>
<tr>
<td>Acidification of soils and water</td>
<td>kg SO₂ eq</td>
</tr>
<tr>
<td>Ozone layer depletion</td>
<td>kg CFC-11 eq</td>
</tr>
<tr>
<td>Global warming</td>
<td>kg CO₂ eq</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg PO₄³⁻ eq</td>
</tr>
<tr>
<td>Photochemical oxidation</td>
<td>kg C₂H₄ eq</td>
</tr>
</tbody>
</table>

### Waste categories

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous waste disposed</td>
<td>kg</td>
</tr>
<tr>
<td>Non-hazardous waste disposed</td>
<td>kg</td>
</tr>
<tr>
<td>Radioactive waste disposed</td>
<td>kg</td>
</tr>
</tbody>
</table>

### Resource use

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total use of renewable primary energy resources</td>
<td>MJ</td>
</tr>
<tr>
<td>Total use of non-renewable primary energy resources</td>
<td>MJ</td>
</tr>
</tbody>
</table>
Aim of the study

LCA comparison of 1 m³ of concrete produced from natural or recycled aggregates (RA). These concretes make it possible to ensure the same function, the compositions are variable.

Cement dosage: 270 – 326 kg/m³
Limestone filler
Admixtures

Recycled sand
0% (mass) of sand is recycled

Strength class

Recycled gravel
30% of aggregates are recycled

Sensitivity to the transport of concretes of equal volume composition (1 m³)

Influence of substitution rate in RA

<table>
<thead>
<tr>
<th></th>
<th>0% RA</th>
<th>10% RA</th>
<th>30% RA</th>
<th>100% RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (kg)</td>
<td>182</td>
<td>192</td>
<td>213</td>
<td>284</td>
</tr>
<tr>
<td>Cement (kg) (CEM I)</td>
<td>260</td>
<td>260</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>Natural aggregate (NA) (kg)</td>
<td>1906</td>
<td>1715</td>
<td>1334</td>
<td>-</td>
</tr>
<tr>
<td>Recycled aggregate (RA) (kg)</td>
<td>-</td>
<td>153</td>
<td>458</td>
<td>1527</td>
</tr>
<tr>
<td>Superplasticizer (kg)</td>
<td>1.92</td>
<td>1.95</td>
<td>2.08</td>
<td>2.34</td>
</tr>
</tbody>
</table>

Study of experimental construction sites

Inventory data

- Cement: ATILH data
- Aggregates: UNPG data
  - Solid rock (gravel)
  - Loose rock (sand)
  - Recycled (gravel + sand)
- Admixtures: SYNAD data
  - Plasticizer
  - Air entrainment agent
- Data used to create the "Mix" process
  - Mixer capacity: 2 m³
  - Mixing time: 55 s
  - Power: 220 kW
  - Energy consumed: 14.4 MJ/m³
- Transport
  - European emission standards EURO 4
Environment assessment of recycled aggregate concretes

- Concrete containing RA globally more impacting than sample with NA because the formulations are made with increasing cement rate as a function of the percentage of RA.
- The magnitude of the deviations depends on the software: methods and associated databases.

Need for transport sensitivity study

Environment assessment of recycled aggregate concretes

- Study of the sensitivity to transport of LCA
- LCA study on experimental construction site

**Eco-friendly nature of recycled aggregate concrete:**
Non-storage of waste
+ Non-depletion of natural aggregate resources

Sensitivity/transport

**Routing Circuits**
- Current Practice

**Distances between places (km)**
- Average / 3 more close
- As the crow flies

**Different possibilities of conveying aggregates**

Sensitivity study of transport

- **Parametrical study**
  
  2 factors:
  - RA % (quantitative): 0, 10, 30 and 100
  - City (qualitative): Lille, Lyon, Strasbourg and Bordeaux

⇒ Control values for each RA %: without circuit & not including city

**Selected concrete compositions: at constant volume of constituents**
Same dosage for cement, efficient water, aggregate volumes.
- Same strength class thanks to admixtures
  \[ R_{c28} = 32.3 \pm 2.5 \text{ MPa} \]
- Differences between compositions: admixture %, total water, aggregate mass (\( \rho \))

- **Preliminary analyse in t.km**
  - Sensitivity to transport

\[
t.Km = M_{RA} \times D_{RA} + M_{NA} \times D_{NA} + M_{\text{concrete}} \\
\times D_{\text{concrete}}
\]
Control concrete LCA

• Moderate deviation: ± 10%
• Impact Indicator gap between aggregates is moderate and the impact of cement remains predominant
**LCA sensitivity study**

To what extent are the differences in t.km influencing the environmental impact indicators?

**Share of aggregate and concrete transport on penalizing circuit**

<table>
<thead>
<tr>
<th></th>
<th>Hazardous waste</th>
<th>Non-hazardous waste</th>
<th>Inert waste</th>
<th>Radioactive waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,00%</td>
<td>28,31%</td>
<td>6,24%</td>
<td>31%</td>
<td>0,38%</td>
</tr>
<tr>
<td>10,00%</td>
<td>29,41%</td>
<td>6,52%</td>
<td>33%</td>
<td>0,40%</td>
</tr>
<tr>
<td>30,00%</td>
<td>31,53%</td>
<td>6,94%</td>
<td>35%</td>
<td>0,44%</td>
</tr>
<tr>
<td>100,00%</td>
<td>38,46%</td>
<td>8,63%</td>
<td>42%</td>
<td>0,59%</td>
</tr>
</tbody>
</table>

**Strasbourg circuit**

- **depletion of...**
- **acidification...**
- **eutrophication**
- **climate change**
- **stratospheric...**

LCA sensitivity study

To what extent are the differences in t.km influencing the environmental impact indicators?

Share of aggregate and concrete transport on penalizing circuit

<table>
<thead>
<tr>
<th>Lille circuit</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Hazardous waste</th>
<th>Non-hazardous waste</th>
<th>Inert waste</th>
<th>Radioactive waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,00%</td>
<td>47,92%</td>
<td>13,79%</td>
<td>53%</td>
<td>0,81%</td>
</tr>
<tr>
<td>10,00%</td>
<td>46,55%</td>
<td>13,02%</td>
<td>51%</td>
<td>0,77%</td>
</tr>
<tr>
<td>30,00%</td>
<td>43,51%</td>
<td>11,29%</td>
<td>48%</td>
<td>0,69%</td>
</tr>
<tr>
<td>100,00%</td>
<td>28,43%</td>
<td>5,59%</td>
<td>31%</td>
<td>0,39%</td>
</tr>
</tbody>
</table>

LCA sensitivity study

Impact study: influence of composition and transport parameters

**Experimental construction sites**

**Chaponost (slab):**

**Site ground plan**

<table>
<thead>
<tr>
<th>Components (kg/m³)</th>
<th>D1</th>
<th>D4</th>
<th>D2</th>
<th>D3</th>
<th>D5</th>
<th>D6+conv.</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF</td>
<td>1796</td>
<td>1467</td>
<td>1437</td>
<td>1151</td>
<td>772</td>
<td>1005–100A</td>
</tr>
<tr>
<td>Natural aggregate</td>
<td>302</td>
<td>306</td>
<td>305</td>
<td>308</td>
<td>346</td>
<td>390</td>
</tr>
<tr>
<td>Recycled aggregate</td>
<td>2.57</td>
<td>3.65</td>
<td>2.60</td>
<td>2.62</td>
<td>2.94</td>
<td>3.32</td>
</tr>
<tr>
<td>Cement</td>
<td>1.54</td>
<td>0.88</td>
<td>1.54</td>
<td>1.04</td>
<td>1.95</td>
<td></td>
</tr>
<tr>
<td>Plasticizer</td>
<td>173</td>
<td>188</td>
<td>178</td>
<td>205</td>
<td>205</td>
<td>260</td>
</tr>
</tbody>
</table>

Experimental construction sites

Comparison of experimental site and simulated construction site (100% natural aggregates)
Conclusion: environmental performances

How to measure them?
How to compare them?

How?
Standardized framework (LCA)
or
Targeted impact study + Avoidance study
Ex: depletion of aggregates and waste storage

On what?
Reference materials (for a defined function)
Or
Comparison (influence of a substitution NA/RA)

BUT
Dilution effects if different compositions

Functional unit and reference flows

How far?
What transport
1 study → 1 circuit
Several circuits → Study of sensitivity, influence of territorialisation
System boundaries
Thank you for your attention

Nicolas Serres
Associate Professor
INSA Strasbourg
24 Bd de la Victoire, 67000 Strasbourg, France

nicolas.serres@insa-strasbourg.fr