Recycling of construction and demolition waste – Status and new utilisation methods

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20. CODATA
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1. Sustainable development in construction industry

2. Classification and properties of recycled construction materials from CDW

3. Closed loop of materials from concrete CDW

4. Utilization of masonry CDW as raw material

5. Summary and prospects
CDW is the umbrella term for very wide range of materials which are generated by all construction activities.
Amount of CDW per inhabitant in Europe

European countries

<table>
<thead>
<tr>
<th>Population density [Capita/km²]</th>
<th>Spec. amount of CDW [t/a*Capita]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0.4</td>
</tr>
<tr>
<td>200</td>
<td>0.8</td>
</tr>
<tr>
<td>300</td>
<td>1.2</td>
</tr>
<tr>
<td>400</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Others

<table>
<thead>
<tr>
<th>Pop. density [C/km²]</th>
<th>Spec. amount of CDW [t/a*Capita]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.4</td>
</tr>
<tr>
<td>333</td>
<td>0.8</td>
</tr>
<tr>
<td>6126</td>
<td>1.2</td>
</tr>
</tbody>
</table>

- USA
- Japan
- Hong Kong
Composition of CDW in Europe

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>2…39 %</td>
</tr>
<tr>
<td>Asphalt</td>
<td>6…21 %</td>
</tr>
<tr>
<td>Masonry CDW</td>
<td>42…92 %</td>
</tr>
<tr>
<td>Mixed rubble</td>
<td>2…11 %</td>
</tr>
</tbody>
</table>

Substitution of natural materials by recycled materials

Ref.: F.I.R. Interforum 2005
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Features for classification

Composition

- Division in at least three main groups
  - Concrete + mortar + natural aggregates
  - All kinds of brick + ceramics
  - Asphalt

Bulk density (water absorption)

- Division in at least two groups
  - $> 2,0$ (OD) / $2,2$ (SSD) $\text{kg/m}^3$
  - $> 1,5$ (OD) / $1,8$ (SSD) $\text{kg/m}^3$

Content of leachable substances

- Division in at least two groups
  - Material without contaminations
  - Material with contaminations lower than certain, defined threshold values
## German standard on recycled aggregates DIN 4226-100

<table>
<thead>
<tr>
<th>Constituents [% by mass]</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN 4226-100: Recycled aggregates</td>
<td>Concrete chippings + crusher sand</td>
<td>Construction chippings + c. sand</td>
<td>Masonry chippings + c. sand</td>
<td>Mixed chippings + c. sand</td>
</tr>
<tr>
<td>Concrete and natural aggregates</td>
<td>≥ 90</td>
<td>≥ 70</td>
<td>≤ 20</td>
<td>≥ 80</td>
</tr>
<tr>
<td>Clinker, non-pored bricks</td>
<td>≤ 10</td>
<td>≤ 30</td>
<td>≥ 80</td>
<td>≤ 5</td>
</tr>
<tr>
<td>Sand-lime bricks</td>
<td>≤ 10</td>
<td>≤ 30</td>
<td>≥ 80</td>
<td>≤ 5</td>
</tr>
<tr>
<td>Other mineral bricks (i.e. pored brick, lightweight concrete, no-fines concrete, plaster, mortar, porous slag, pumice stone)</td>
<td>≤ 2</td>
<td>≤ 3</td>
<td>≤ 5</td>
<td>≤ 20</td>
</tr>
<tr>
<td>Asphalt</td>
<td>≤ 1</td>
<td>≤ 1</td>
<td>≤ 1</td>
<td></td>
</tr>
<tr>
<td>Foreign substances (i.e. glass, non ferrous metal slag, lump gypsum, plastic, metal, wood, plant residue, paper, others)</td>
<td>≤ 0.2</td>
<td>≤ 0.5</td>
<td>≤ 0.5</td>
<td>≤ 1</td>
</tr>
<tr>
<td>OD density/oven dry [kg/m³]</td>
<td>≥ 2000</td>
<td>≥ 2000</td>
<td>≥ 1800</td>
<td>≥ 1500</td>
</tr>
</tbody>
</table>
Properties of real concrete CDW

Composition of processed concrete from one recycling plant

Ref: SERGIO CIRELLI ANGULO 2005
Bulk density of processed concrete from one recycling plant

- Nat. aggregate: Mean: 2.20 g/cm³, Variation coefficient: 4.4%
- Cement paste: Mean: 2.20 g/cm³, Variation coefficient: 4.4%

Ref: SERGIO CIRELLI ANGULO 2005
Composition of processed masonry from several recycling plants

Brick and ceramics

Mean: 48.3 %
Variation coefficient: 21.3 %

Ref.: WINKLER 2001
Bulk density of processed masonry from several recycling plants

Ref.: WINKLER 2001

Fraction < 10 mm
Mean: 1.74 g/cm³
Variation coefficient: 8.5%

Fraction > 10 mm
Mean: 1.91 g/cm³
Variation coefficient: 5.3%
Conclusion: Considerable fluctuations in composition and density

Concrete CDW: Caused by composite nature of concrete more than by composition

Masonry CDW: Caused by composition

Consequences for reuse in closed loops

High-grade applications not realizable so far due to unstable quality of processed CDW

Technologies for quality improvement and homogenization have to be developed
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Coarse recycled concrete aggregates:
Composites of cement paste and natural aggregate

Consequences of the composite nature on properties of secondary concretes

- Fresh concrete: Increase of water absorption and loss of workability caused by additional porosity of the adhered cement paste.

- Hardened concrete: Loss of compressive strength caused by increased porosity.

- Hardened concrete: Loss of modulus of elasticity as a result of higher porosity and higher content of CSH phases.

- Further effects on shrinkage, creep and durability.
Mechanical properties vs. portion of recycled aggregates

Replacement of coarse and fine aggregates
Δ Strength → 32 %
Δ E-modulus → 39 %

Replacement of coarse aggregates only
Δ Strength → 16 %
Δ E-modulus → 20 %
Consequences for quality improvement of coarse recycled aggregates

Generation of cement paste free aggregates with suitable techniques for liberation and separation

Mechanical or thermal liberation

Separation by particle size or density
## Removal of adhering cement paste by abrasion stress

### External cylinder:
- Ø 720 mm; height 800 mm
- Rotor: Ø 720 mm; height 800 mm; 500 U/min
- Eccentricity: 11.7 mm

### Operating mode

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Operating mode</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

### Material parameter

<table>
<thead>
<tr>
<th></th>
<th>Virgin aggregates</th>
<th>Secondary aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (ρ)</td>
<td>ρ = 2.62 g/cm³</td>
<td>ρ = 2.5...2.61 g/cm³</td>
</tr>
<tr>
<td>Water Absorption (WA)</td>
<td>WA → 0</td>
<td>WA = 1.2...3.6 %</td>
</tr>
<tr>
<td></td>
<td>ρ = 2.52 g/cm³</td>
<td>ρ = 2.4...2.53 g/cm³</td>
</tr>
<tr>
<td></td>
<td>WA = 3.0 %</td>
<td>WA = 1.8...5.4 %</td>
</tr>
</tbody>
</table>
Applying of thermal stress

![Diagram of thermal stress process]

700 °C

Vibrating screen

Coarse aggregates

Flow cavitation chamber

with specimen (1)

Degree of separation between 46 und 90 %

Applying of cavitation stress

Mass balance

1 t Concrete waste

450 kg gravel

350 kg sand

water 60 kg

CEM

dehyd. CEM < 150 µm 130 kg

reinforcement 10 kg

Ref.: MULDER 2002

Ref.: MOMBER 2004
Applying of high performance sonic impulses (HPSI)

Electrical energy

Disruptive electrical discharge under water

Shock wave
- Pressure amplitudes up to 100 MPa
- Rise time < 5 µs

Reflexions at interfaces of different density

Generation of pressure and tensile stresses

Failure at the interfaces

Ref.: LINSZ 2004
Concrete B 25: 300 kg/m³ CEM I 32,5 R + 180 kg/m³ water + 1902 kg/m³ quartz sand and gravel AB 16
Comp. strength: 36 N/mm²
Modulus of elasticity: 33 kN/mm²

Degree of liberation versus ratio of size reduction

Ratio of mean particle sizes [-]

Degree of liberationchem; 4/8 mm [%]

< 10 J/g
10-20 J/g
25-40 J/g
> 40 J/g

Ratio = \( \frac{x_{m, \text{original aggregate}}}{x_{m, \text{crushed product}}} \)
Concrete B 25 with varying maximum particle size of aggregates: 8 mm; 16 mm; 32 mm.

Degree of liberation after treatment in impact crusher or by HPSI:

- Specific energy consumption:
  - HPSI: $0.05 \text{ MJ/kg}$ for comminution of concrete
  - Impact crusher: $0.08 \text{ MJ/kg}$ for comminution + liberation
  - Impact crusher: $0.01$ to $0.02 \text{ MJ/kg}$ for comminution

Mean particle size [mm]

Portion of cement free (visual) particles 8/16 mm [%]

- $x_{\text{max}} = 8 \text{ mm}$
- $x_{\text{max}} = 16 \text{ mm}$
- $x_{\text{max}} = 32 \text{ mm}$
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Expanded granulates from masonry rubble

Masonry CDW as mixture of different materials

Crushing and grinding

Addition of SiC as expanding agent

Mixing and shaping

Thermal treatment

Lightweight aggregate
### Raw materials

<table>
<thead>
<tr>
<th>Masonry CDW 0/4 mm from a recycling plant as matrix material</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>63,1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aerated autoclaved concrete from AAC plant as additional material to increase the heterogeneity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>53,0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Silicium carbide waste &lt; 100 µm as expanding component</th>
</tr>
</thead>
</table>
Manufacturing process

Grindability
Masonry CDW – medium energy consumption
AAC – low energy consumption

Shaping
Easily able to granulate without additional binder

Influence of AAC
Shortening of melting range
Max. content of AAC: 50%

Burning condition
Temperature: 1180 – 1230 °C
Residence time: about 20 min
Expanding process during the thermal treatment

Green granules
$x_m = 4.8 \text{ mm}$

Burnt granules
$x_m = 7.2 \text{ mm}$

$\Delta V = 228\%$

Portion [%] vs. Passage [%] of particle size [mm] graph.
Effect of the processing on homogeneity

- Raw material < 10 mm
- Green granules
- Burnt granules with 1 % SiC

Bulk density [g/cm³]

Samples
First application tests

- Manufacturing of blocs and cubes in a precast concrete plant
- Volumetric substitution of the normally used expanded clay 4/8 mm by CDW aggregate 4/8 mm

<table>
<thead>
<tr>
<th></th>
<th>CDW aggregate</th>
<th>Expanded clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density of concrete [kg/m³]</td>
<td>1130</td>
<td>870</td>
</tr>
<tr>
<td>Com. strength [N/mm²]</td>
<td>11,90</td>
<td>6,16</td>
</tr>
<tr>
<td>Thermal conductivity [W/mK]</td>
<td>0,35</td>
<td>0,24</td>
</tr>
<tr>
<td>Freeze-thaw resistance: $E_{dyn}$ change [%]</td>
<td>- 2,6</td>
<td>- 67,9</td>
</tr>
</tbody>
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Summary

1. Construction and Demolition Waste is characterized by rather large variation range of the composition as well as the physical properties.

2. Main field of application of CDW: Unbounded systems like fills and embankments.

3. Reuse of concrete CDW as secondary aggregates requires incorporation of liberation techniques into the processing.

4. As advanced liberation technique the treatment by high performance sonic impulses results in clear quality improvement.
5. Reuse of masonry CDW in construction requires technologies which improve quality and homogeneity.

6. Own experiments show feasibility of masonry CDW as raw material for manufacturing of lightweight granulates.

7. Properties of the lightweight granulates are rather constant and at least equal to those of other mineral lightweight materials.

Further research must be aimed at
⇒ the scale up of both technologies,
⇒ examinations of product quality and uniformity and
⇒ comparative studies about the energy demand.
Thank you for your attention!

Homepage: www.uni-weimar.de/Bauing/aufber/