The alkali-activation of construction and demolition waste (CDW) components for stabilization purposes

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Introduction

CONSTRUCTION AND DEMOLITION WASTE (CDW)
Waste material produced in the process of construction, renovation, or demolition of buildings and infrastructures.
(US EPA, United States Environmental Protection Agency)

- concrete
- bricks and tiles
- asphalt
- natural aggregates and excavated soil
- impurities (metals, wood, glass, plastic)

Production and recycling
EU-28 (2014):
868 million of tons of CDW per year
(1/3 of total waste generated in EU)
Average recycling rate: 46 %
(European waste statistics)
Motivation and interest

- recycling and re-using policies of Europe
- increasing demand for sustainable infrastructures
- reduction of exploitation of natural resources
- environmental and economic benefits

From waste to resource...

CDW AGGREGATE USES

Improving performances in terms of strength, stiffness, and durability

Stabilization techniques

- addition of cementitious binders
- no addition of binders

Alkali-activation
Research objective

Coarse particles d>0.125 mm
Fine particles d<0.125 mm
Binding attitude exhibited by the most reactive phase

Alkali-activation of CDW fines

CDW aggregates in 4 components:
- RC (recycled concrete)
- RA (recycled asphalt)
- BT (bricks and tiles)
- NA (natural aggregates)

UND (undivided CDW)
Fines characterization

Physical characterization
- Particle size distribution, density

Chemical analysis
- X-ray diffraction

X-ray diffraction test (XRD)

**XRD patterns**

<table>
<thead>
<tr>
<th>Mineral phases</th>
<th>RC</th>
<th>RA</th>
<th>BT</th>
<th>NA</th>
<th>UND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminosilicates (%)</td>
<td>23.3</td>
<td>29.7</td>
<td>63.6</td>
<td>30.1</td>
<td>56.8</td>
</tr>
<tr>
<td>Minerals from mica group (%)</td>
<td>15.2</td>
<td>11.9</td>
<td>30.3</td>
<td>n.a.</td>
<td>22.7</td>
</tr>
<tr>
<td>Carbonates (%)</td>
<td>26.0</td>
<td>13.9</td>
<td>6.1</td>
<td>17.2</td>
<td>11.8</td>
</tr>
<tr>
<td>Quartz (%)</td>
<td>9.1</td>
<td>9.9</td>
<td>22.2</td>
<td>8.5</td>
<td>14.7</td>
</tr>
</tbody>
</table>

Semi-quantitative phase analysis

Aluminosilicates in all components (especially BT and UND) essential for alkali-activation process.
Alkali-activation of fines

CDW fines
- RC, RA, BT, NA
- UND

2 size fractions:
- d < 0.063 mm
- 0.063 mm ≤ d < 0.125 mm

Activating alkaline solution (AAS)
(10% NaOH + 29% Na$_2$SiO$_3$ + 61% H$_2$O)

3 concentrations:
- 100% → AAS$_{100\%}$
- 75% → AAS$_{75\%}$
- 50% → AAS$_{50\%}$

$\frac{\text{liquid}}{\text{solid}} = 0.4$

Mixing

Casting (Prisms 20x20x80 mm)

Curing
- room temperature
- 3, 7, 28 days
Characterization of mixtures

Properties of fresh mixtures

Viscosity

MIXTURES

Mechanical properties

Strengths of hardened products

Brookfield viscometer

3-point flexural tests

Compressive tests

\[ b = d = 20 \text{ mm} \]
\[ L = 60 \text{ mm} \]

\[ b = c = d = 20 \text{ mm} \]
Viscosity of fresh mixtures

- Viscosity decreases with revolution speed (non-Newtonian)
- Viscosity increases with AAS concentration
- Different viscosity for each component
- Highest values for UND and RC, lowest one for NA

Workability during compaction

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Luca Tefa
6th International Conference on Sustainable Solid Waste Management, Naxos, Greece - 2018
Flexural strength

- improvement of flexural strength ($\sigma_f$) with curing time
- $\sigma_f$ strongly influenced by the AAS concentration and the component of CDW
- $\sigma_f$ of RC, BT, NA higher with AAS_75%; RA, UND more active with AAS_100%
- UND shows the highest $\sigma_f$ (for different curing time) $\Rightarrow$ 5.0 MPa
Compressive strength

- similar behavior of flexural strength results ($\sigma_c \approx 3 \sigma_f$)
- $\sigma_c$ of samples with AAS_75% and AAS_100% >> AAS_50%
- $\sigma_c$ of RC and NA higher with AAS_75% than AAS_100%
- BT and UND → rich of aluminosilicates → highest $\sigma_c$
Conclusions

<table>
<thead>
<tr>
<th>Chemical analysis</th>
<th>Presence of aluminosilicate phases in all components (RC, RA, BT, NA, UND) potentially reactive in alkaline environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical properties</td>
<td>Key role of concentration of AAS both in workability of fresh mixtures and in strength development</td>
</tr>
</tbody>
</table>
|                    | • $\sigma_c$ and $\sigma_f$ increase with curing time  
|                    | • better performances for BT and UND (aluminosilicate and mica-group phases) |
|                    | Huge variability in mechanical behavior  
|                    | Best mechanical strengths for UND component (calcium-reach and alumina-silicate phases $\rightarrow$ geopolymers and C-S-H) |

**AAS+CDW powders** (d<0.125 mm) increase strengths without any thermal treatment and binder addition
Future perspectives

From mixtures of fine particles...

... to stabilized CDW aggregates

- lab scale
- full scale application
Thank you!

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Additional information (I)

- Particle size distribution

![Particle size distribution graphs]

\[d < 0.063 \text{ mm}\]

\[0.063 \text{ mm} \leq d < 0.125 \text{ mm}\]
Additional information (II)

- Density

<table>
<thead>
<tr>
<th>Component</th>
<th>Particle size [μm]</th>
<th>Particle density $\rho_p$ [Mg/m³]</th>
<th>Bulk density $\rho_b$ [Mg/m³]</th>
<th>Rigden porosity $\nu$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>&lt;63</td>
<td>2.580</td>
<td>1.945</td>
<td>24.6</td>
</tr>
<tr>
<td></td>
<td>63 ÷ 125</td>
<td>2.687</td>
<td>1.953</td>
<td>27.3</td>
</tr>
<tr>
<td>RA</td>
<td>&lt;63</td>
<td>2.424</td>
<td>1.940</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>63 ÷ 125</td>
<td>2.347</td>
<td>1.990</td>
<td>15.2</td>
</tr>
<tr>
<td>BT</td>
<td>&lt;63</td>
<td>2.763</td>
<td>2.010</td>
<td>27.3</td>
</tr>
<tr>
<td></td>
<td>63 ÷ 125</td>
<td>2.722</td>
<td>1.946</td>
<td>28.5</td>
</tr>
<tr>
<td>NA</td>
<td>&lt; 63</td>
<td>2.726</td>
<td>1.987</td>
<td>27.1</td>
</tr>
<tr>
<td></td>
<td>63 ÷ 125</td>
<td>2.710</td>
<td>2.025</td>
<td>25.3</td>
</tr>
<tr>
<td>UND</td>
<td>&lt; 63</td>
<td>2.640</td>
<td>1.963</td>
<td>25.6</td>
</tr>
<tr>
<td></td>
<td>63 ÷ 125</td>
<td>2.673</td>
<td>1.963</td>
<td>26.5</td>
</tr>
</tbody>
</table>
Additional information (III)

- X-ray diffraction output pattern

**RA**

- Q - Quartz
- C - Calcite
- At - Antigorite
- E - Enstatite
- Cd - Cordierite
- Cl - Clinohore
- M - Muscovite
- D - Diopside

**NA**

- Q - Quartz
- C - Calcite
- Cd - Cordierite
- E - Enstatite
- L - Lizardite
- Cl - Clinohore
- D - Diopside
- I - Illite

**UND**

- Q - Quartz
- C - Calcite
- Al - Albite
- G - Gladiusite
- Ph - Phengite
- Cl - Clinohore
- A - Antigorite
- D - Diopside
Additional information (IV)

- Proportion of components in the alkaline solution

**AAS_50%**
- 51% H₂O
- 29% Na₂SiO₃
- 10% NaOH
- 10% additional H₂O

**AAS_75%**
- 7.5% NaOH
- 22% Na₂SiO₃
- 38% H₂O
- 25% additional H₂O

**AAS_100%**
- 5% NaOH
- 15% Na₂SiO₃
- 40% additional H₂O
- 25% H₂O