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

Marco Bassani(1), ***Luca Tefa***(1), *Paola Palmero*(2)

(1) Department of Environment, Land and Infrastructures Engineering
(2) Department of Applied Science and Technology,

The Cultural Center former Ursuline School - Naxos, Greece
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Introduction

<u>CONSTRUCTION AND DEMOLITION WASTE (CDW)</u>

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)

Natural aggregates

Concrete

Bricks and tiles

Asphalt

<u>Production and recycling</u>

EU-28 (2014):

868 million of tons of CDW per year

(**1/3 of total waste generated in EU**)

→ Average recycling rate: **46 %**

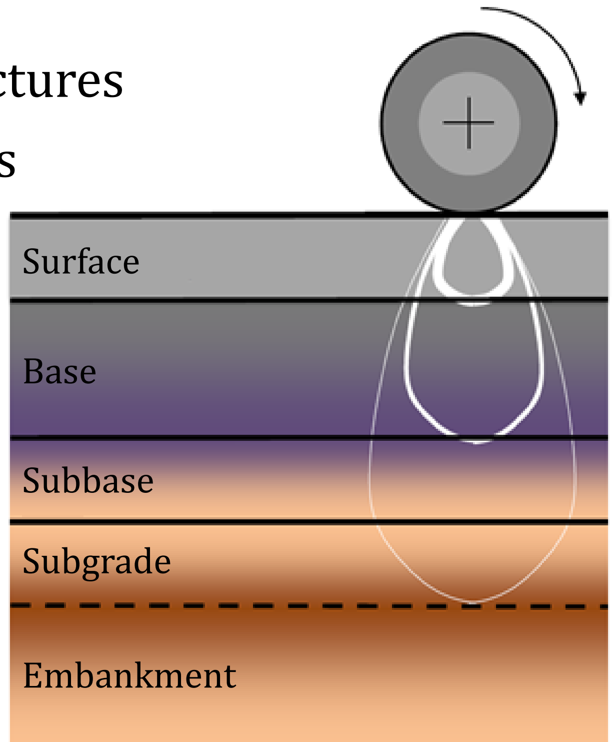
(European waste statistics)

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

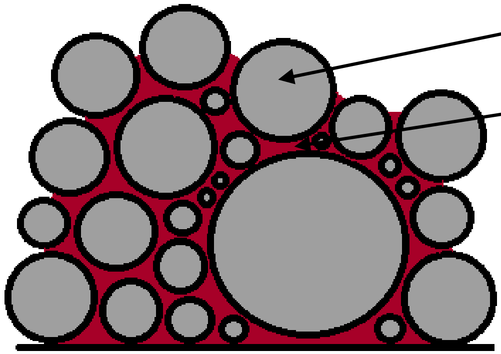


Improving performances in terms of strength, stiffness, and durability

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**:

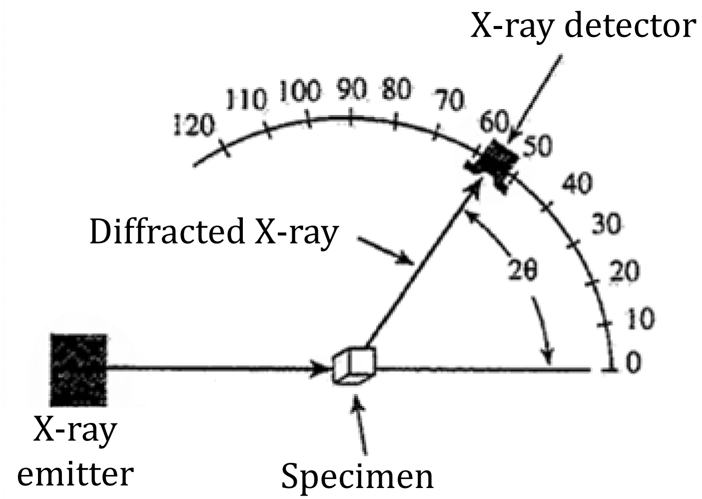
- **RC** (recycled concrete)
- **RA** (recycled asphalt)
- **BT** (bricks and tiles)
- **NA** (natural aggregates)

→ ▪ **UND** (undivided CDW)

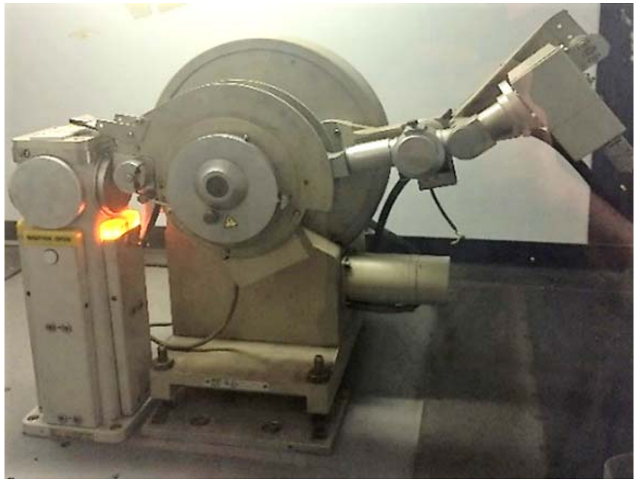
Fines characterization

Physical characterization	Particle size distribution, density
Chemical analysis	X-ray diffraction

POWDERS

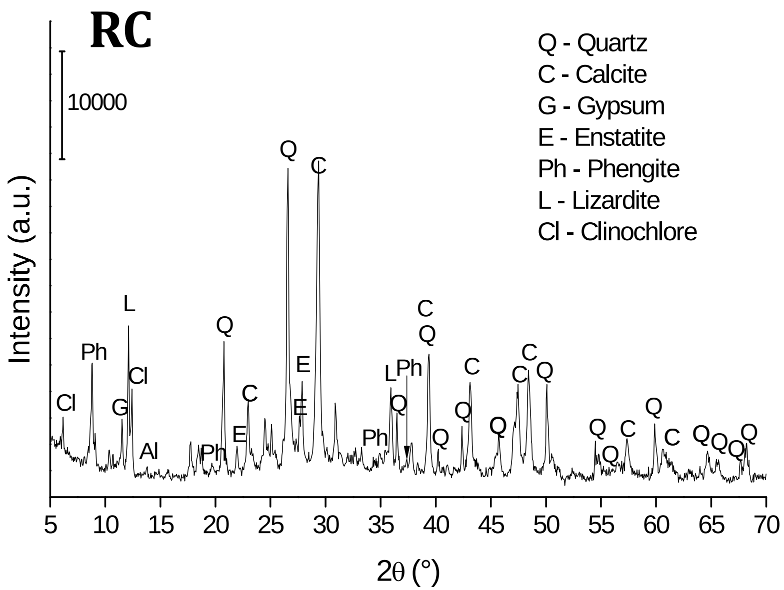


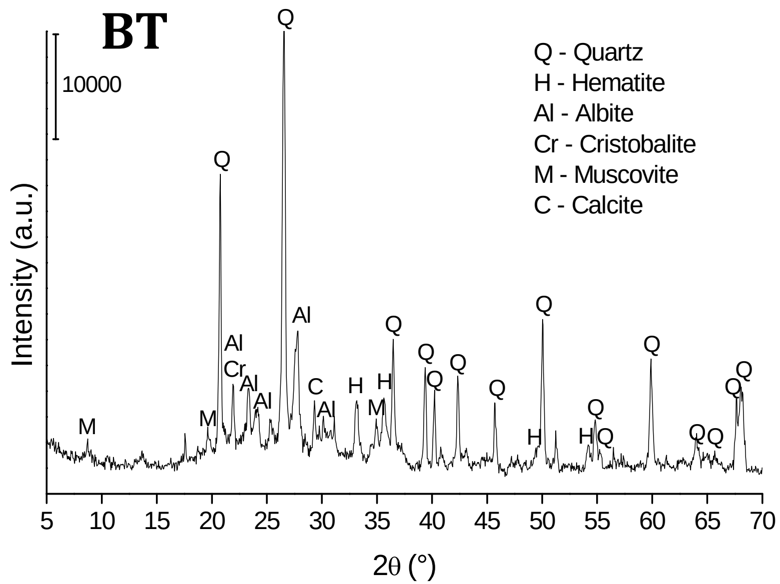
Smith (1993). *Foundations of materials science and engineering*. McGraw-Hill.



X-ray diffraction test (XRD)

XRD patterns





Semi-quantitative phase analysis

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

→ 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_2SiO_3 + 61% H_2O)

3 concentrations:

- 100% → *AAS_100%*
- 75% → *AAS_75%*
- 50% → *AAS_50%*

15 combinations of mixtures

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

Mixing

(Prisms 20x20x80 mm)

Casting

Curing

- room temperature
- 3, 7, 28 days

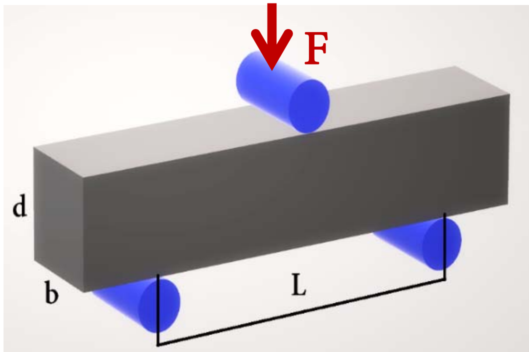
Characterization of mixtures

Properties of fresh mixtures	Viscosity	
		MIXTURES
Mechanical properties	Strengths of hardened products	

<u>Brookfield viscometer</u>

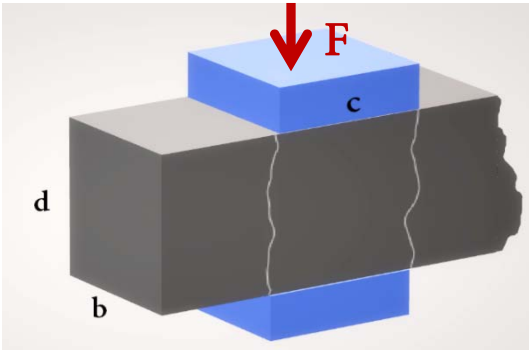
<u>3-point flexural tests</u>

$b = d = 20\ mm$
$L = 60\ mm$

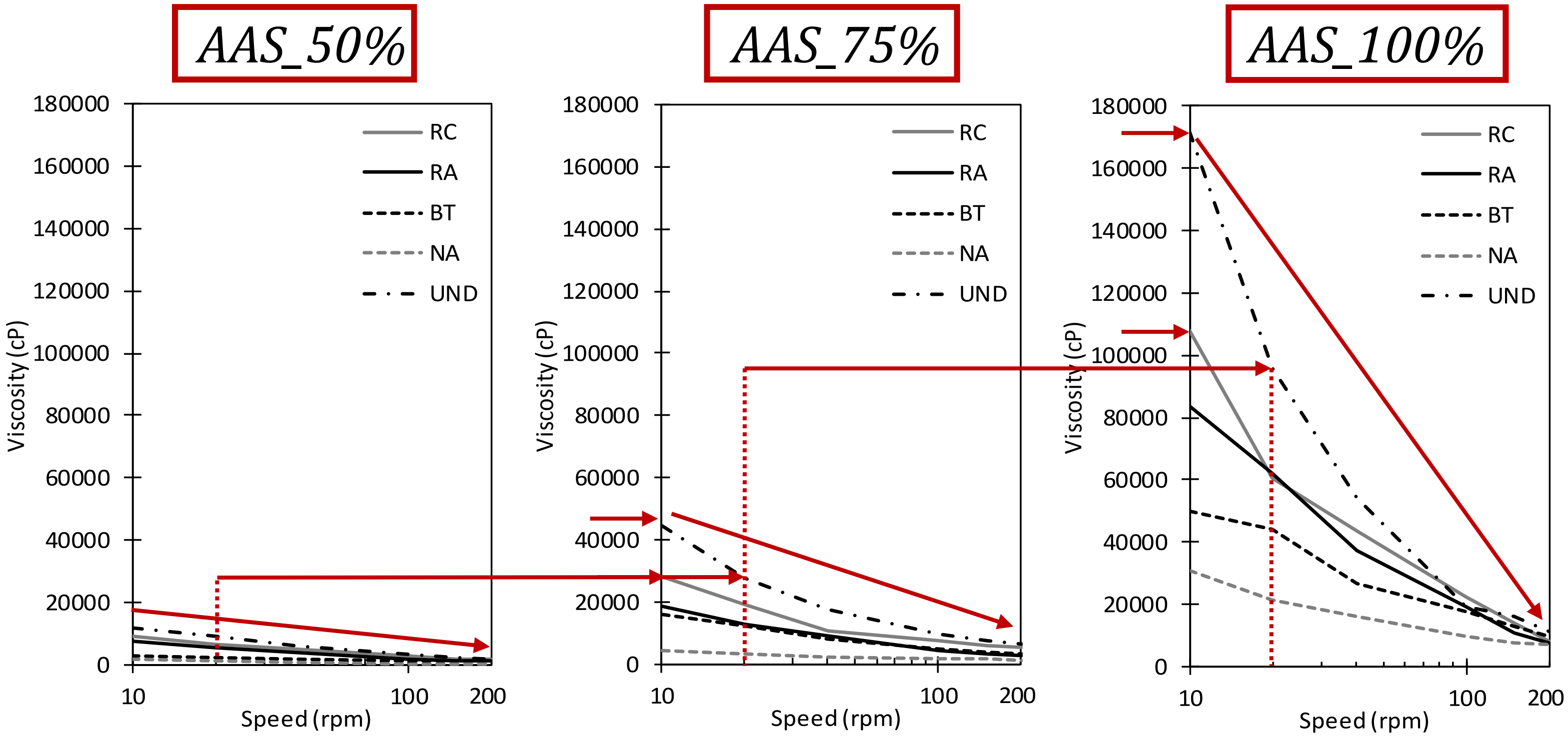


<u>Compressive tests</u>

$b = c = d = 20\ mm$



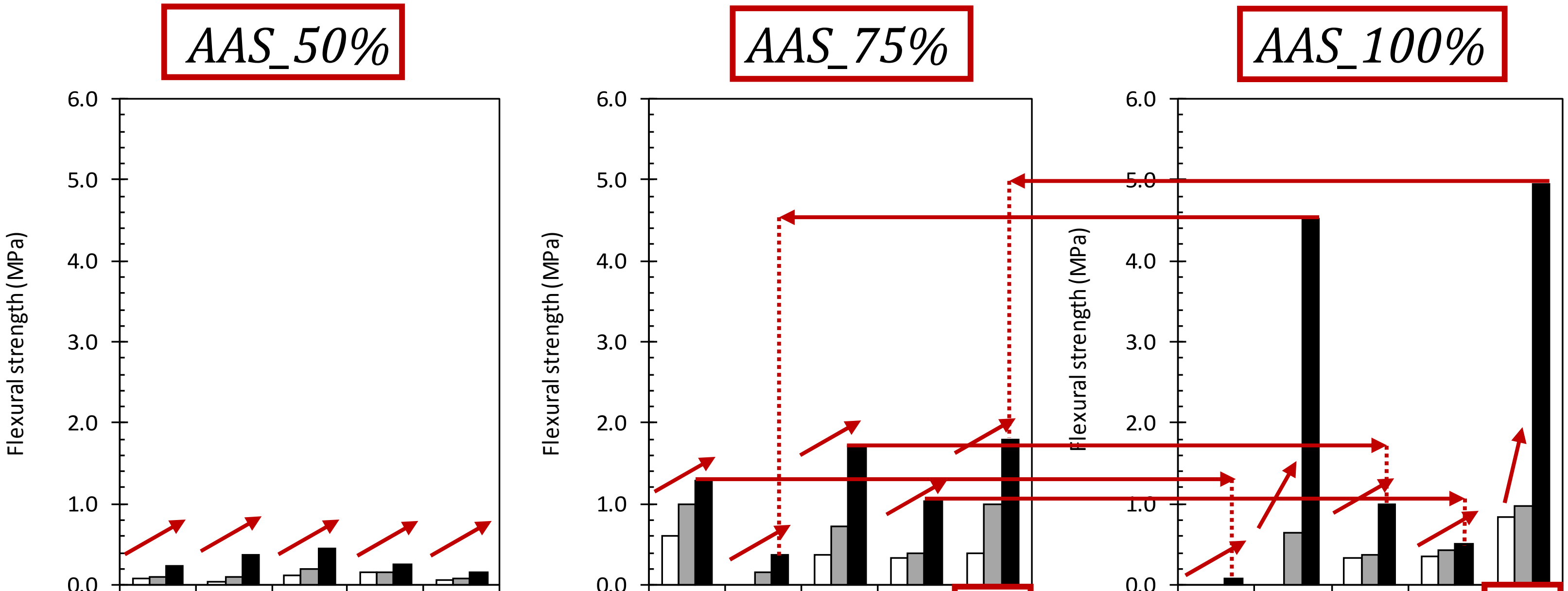
Viscosity of fresh mixtures



- viscosity decreases with revolution speed (non-Newtonian)
- viscosity increases with AAS concentration
- different viscosity for each components
- highest values for UND and RC, lowest one for NA

Workability during compaction

Flexural strength



AAS_50%

	RC	RA	BT	NA	UND
3 days	0.07	0.05	0.12	0.15	0.06
7 days	0.11	0.09	0.20	0.16	0.08
28 days	0.23	0.37	0.46	0.26	0.15

AAS_75%

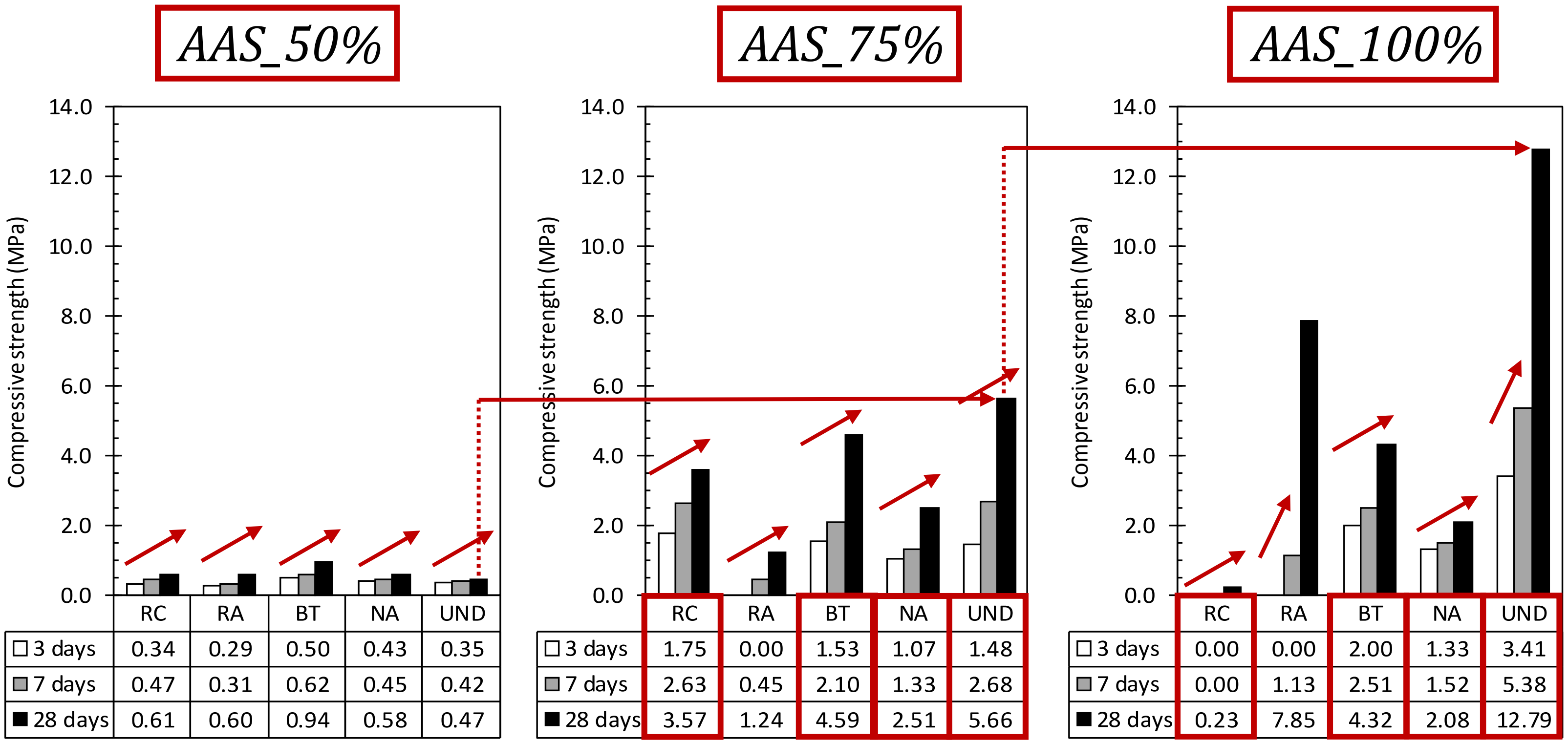
	RC	RA	BT	NA	UND
3 days	0.60	0.00	0.38	0.33	0.40
7 days	1.00	0.15	0.72	0.40	0.99
28 days	1.30	0.37	1.72	1.04	1.80

AAS_100%

	RC	RA	BT	NA	UND
3 days	0.00	0.00	0.33	0.35	0.83
7 days	0.00	0.63	0.38	0.42	0.98
28 days	0.09	4.52	0.99	0.51	4.96

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

Compressive strength



AAS_50%

	RC	RA	BT	NA	UND
3 days	0.34	0.29	0.50	0.43	0.35
7 days	0.47	0.31	0.62	0.45	0.42
28 days	0.61	0.60	0.94	0.58	0.47

AAS_75%

	RC	RA	BT	NA	UND
3 days	1.75	0.00	1.53	1.07	1.48
7 days	2.63	0.45	2.10	1.33	2.68
28 days	3.57	1.24	4.59	2.51	5.66

AAS_100%

	RC	RA	BT	NA	UND
3 days	0.00	0.00	2.00	1.33	3.41
7 days	0.00	1.13	2.51	1.52	5.38
28 days	0.23	7.85	4.32	2.08	12.79

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

Conclusions

Chemical analysis	Presence of aluminosilicate phases in all components (RC, RA, BT, NA, UND) potentially reactive in alkaline environment
Mechanical properties	Key role of concentration of AAS both in workability of fresh mixtures and in strength development

Huge variability in mechanical behavior

- σ_c and σ_f increase with curing time
- better performances for BT and UND (aluminosilicate and mica-group phases)

Best mechanical strengths for UND component (calcium-reach and alumina-silicate phases → geopolymers and C-S-H)

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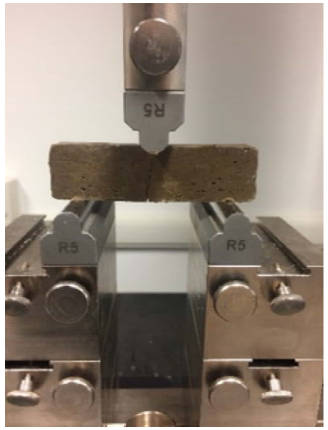
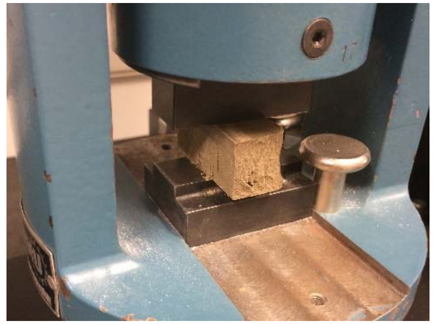
AAS+CDW powders (d<0.125 mm) increase strengths without any thermal treatment and binder addition

Future perspectives

From mixtures of fine particles…





… to stabilized CDW aggregates

- lab scale

- full scale application

Thank you!

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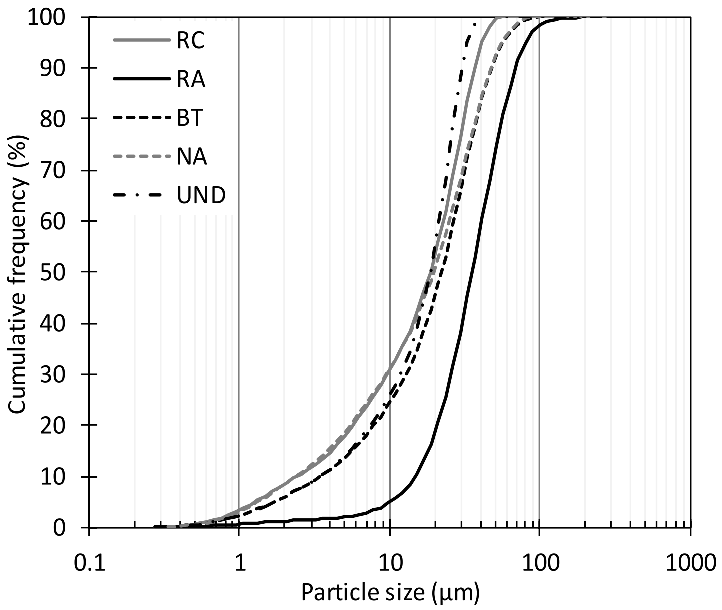
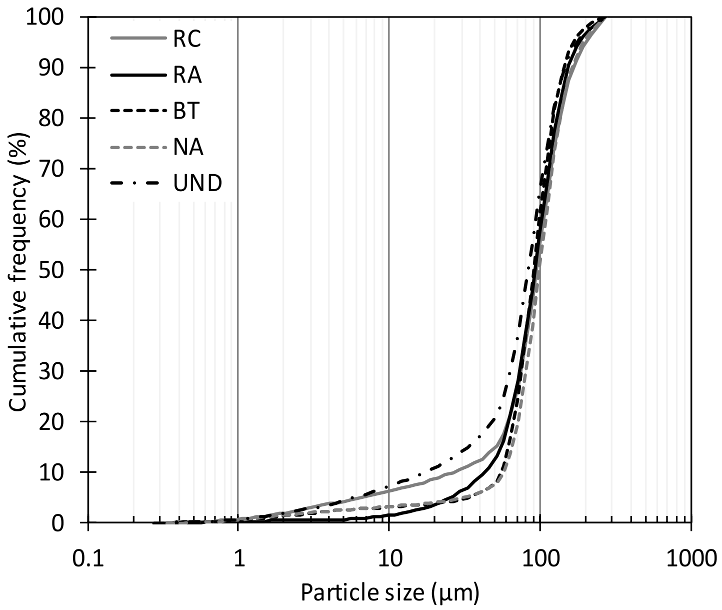
luca.tefa@polito.it

Additional information (I)

- Particle size distribution



d < 0.063 mm



0.063 mm ≤ d < 0.125 mm

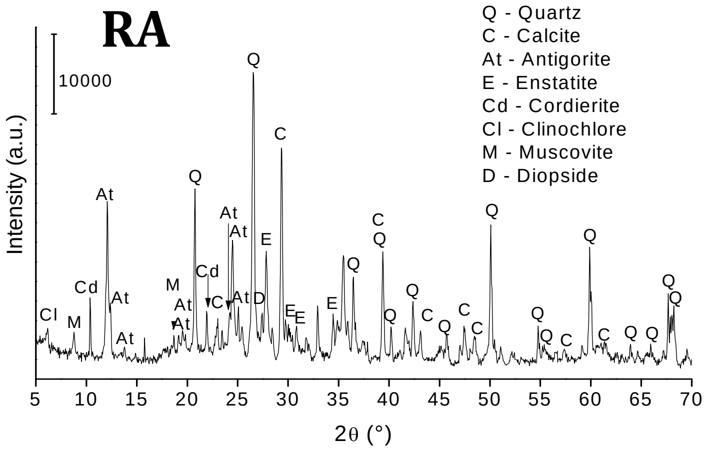
Additional information (II)

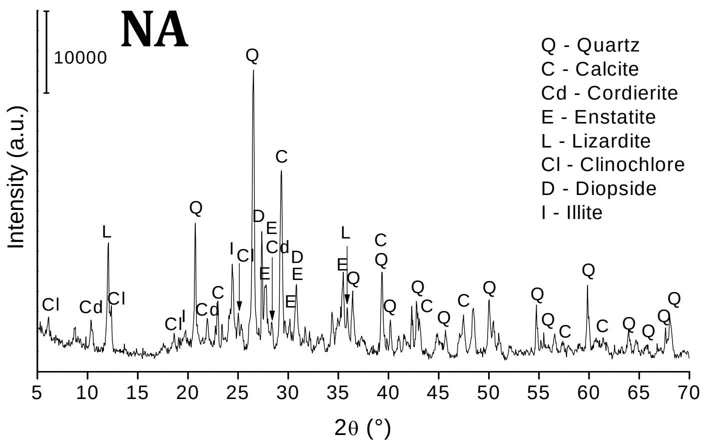
- Density

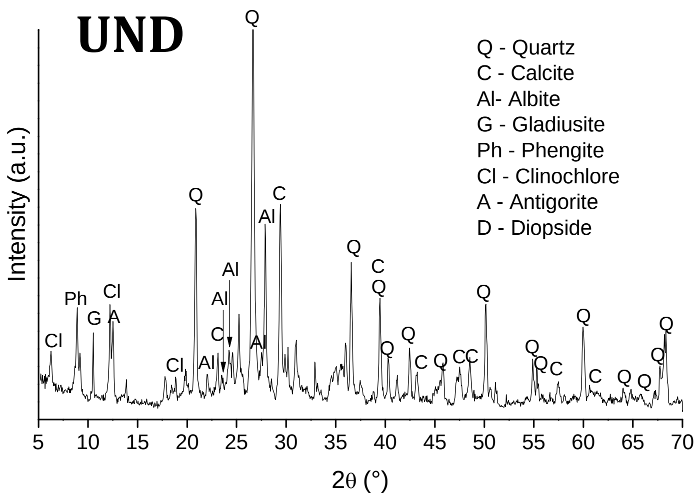
		Particle density	Bulk density	Rigden porosity
Component	Particle size [μm]	ρ_p [Mg/m^3]	ρ_b [Mg/m^3]	ν (%)
RC	<63	2.580	1.945	24.6
	63 ÷ 125	2.687	1.953	27.3
RA	<63	2.424	1.940	20.0
	63 ÷ 125	2.347	1.990	15.2
BT	<63	2.763	2.010	27.3
	63 ÷ 125	2.722	1.946	28.5
NA	< 63	2.726	1.987	27.1
	63 ÷ 125	2.710	2.025	25.3
UND	< 63	2.640	1.963	25.6
	63 ÷ 125	2.673	1.963	26.5

Additional information (III)

- X-ray diffraction output pattern







Additional information (IV)

- Proportion of components in the alkaline solution