Recovered Cement Fines as a Supplementary Cementitious Material

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Outline

- Background
- Supplementary Cementitious Materials
- Construction and Demolition Waste
- Degree of Hydration & Residual Cement
- Conclusions

Background & Motivation

Global cement production has reached 4 billion tons per year, with a projection to achieve 4.8 billion tons in 2030.

Today the total CO_2 emissions worldwide of the cement Industry is 3.5 billion ton per year

To attain the decarbonization of the cement industry, identifying new sources of supplementary cementitious materials (SCMs) is crucial.

SCMs: Supplementary Cementitious Materials

- Pozzolanic materials, which are typically low-Ca aluminosilicates, chemically react with calcium hydroxide (CH) and water to form cementitious hydrates. Most latent hydraulic materials used as SCMs with Portland cement still consume some CH in their reaction, which is generally supplied by the hydration of the Portland cement. In most SCMs, the reactive components are the amorphous phases.

Cement Hydration Process

$$OPC + H_2O \text{ -----------------------------------> } CSH + CH$$

Pozzolanic Reaction Process

$$AS_2 + CH \xrightarrow{H_2O} C_2ASH_8 + CSH$$

SCMs - PCA

- Fly ash, the most commonly used pozzolan in concrete, is a by-product of thermal power generating stations. Commercially available fly ash is a finely divided residue that results from the combustion of pulverized coal and is carried from the combustion chamber of the furnace by exhaust gases.

- Slag Cement, formerly referred to as ground, granulated blast-furnace slag, is a glassy, granular material formed when molten, iron blast-furnace slag is rapidly chilled - typically by water sprays or immersion in water - and subsequently ground to cement fineness. Slag cement is hydraulic and can be added to cement as an SCM.

- Silica fume, also called condensed silica fume or micro silica, is a finely divided residue resulting from the production of elemental silicon or ferro-silicon alloys that is carried from the furnace by the exhaust gases. Silica fume, with or without fly ash or slag, is often used to make high-strength concrete.

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Other Common SCMs

- Limestone, the most common filler material, is not entirely inert as it reacts with aluminate from clinker or from other SCMs to form carboaluminate phase. At higher clinker replacement levels (>20 %), cements incorporating inert fillers typically show significantly reduced strength and durability.
- Natural pozzolans are a category of SCMs that encompasses naturally occurring, quarried materials that may require some minor processing, such as grinding and/or calcination. They are generally not industrial byproducts. Metakaolin is a natural pozzolan that is commonly known and used in the cement and concrete industry. More precisely, it is categorized as a calcined natural pozzolan, because of the high temperatures (650–850 °C) needed to break down the crystal structure of kaolinite clay.

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SCMs from recycled concrete

Construction and Demolition Waste C&DW

Fresh concrete waste from ready-mixed concrete plants* → No curing

Low-quality recycled aggregate	High-quality recycled aggregate	Hydrated cement paste or mortar
Base and sub-bases in roads	Replacement of natural aggregate in recycled concrete	?

- ✓ Only partially hydrated
- ✓ source of unhydrated cement
- ✓ potential for recovery

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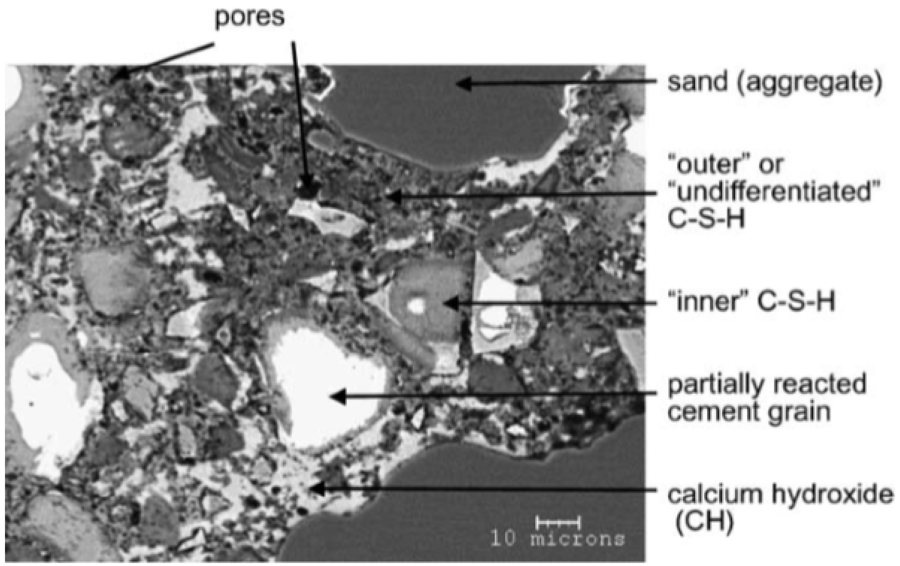
Scientific Background – residual unhydrated cement

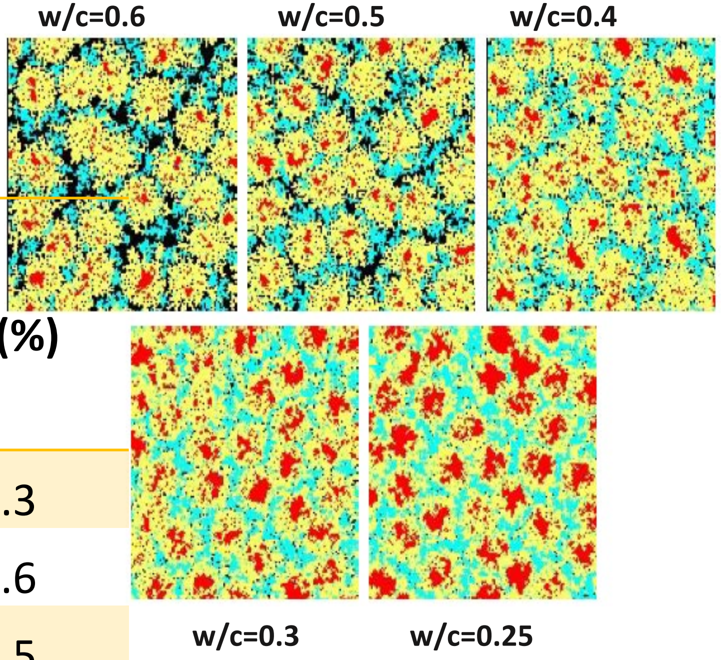
An appreciable amount of unhydrated clinker grains may be found in the microstructure of hydrated cement pastes even after long hydration times, which means that cement pastes do not always achieve complete hydration.

This may be due to several parameters:

- Cement particle size
- Water amount necessary for complete hydration
- Lack of space for hydration
- Curing duration and conditions



Mathematical Assessment of the Unreacted Cement Portion



Constant Cement Particle Size (21 µm)

w/c	Maximum hydration (%)	Remaining porosity (%)	Remaining cement (%)	C-S-H (%)	CH (%)
0.60	85	25.9	4.9	50.9	18.3
0.50	83	19.5	6.2	54.7	19.6
0.40	79	9.2	9.2	60	21.5
0.30	67	2.7	16.5	59.4	21.3
0.25*	59	1	22.9	56.1	20.1

*Lower allowed value in the model

Color code:

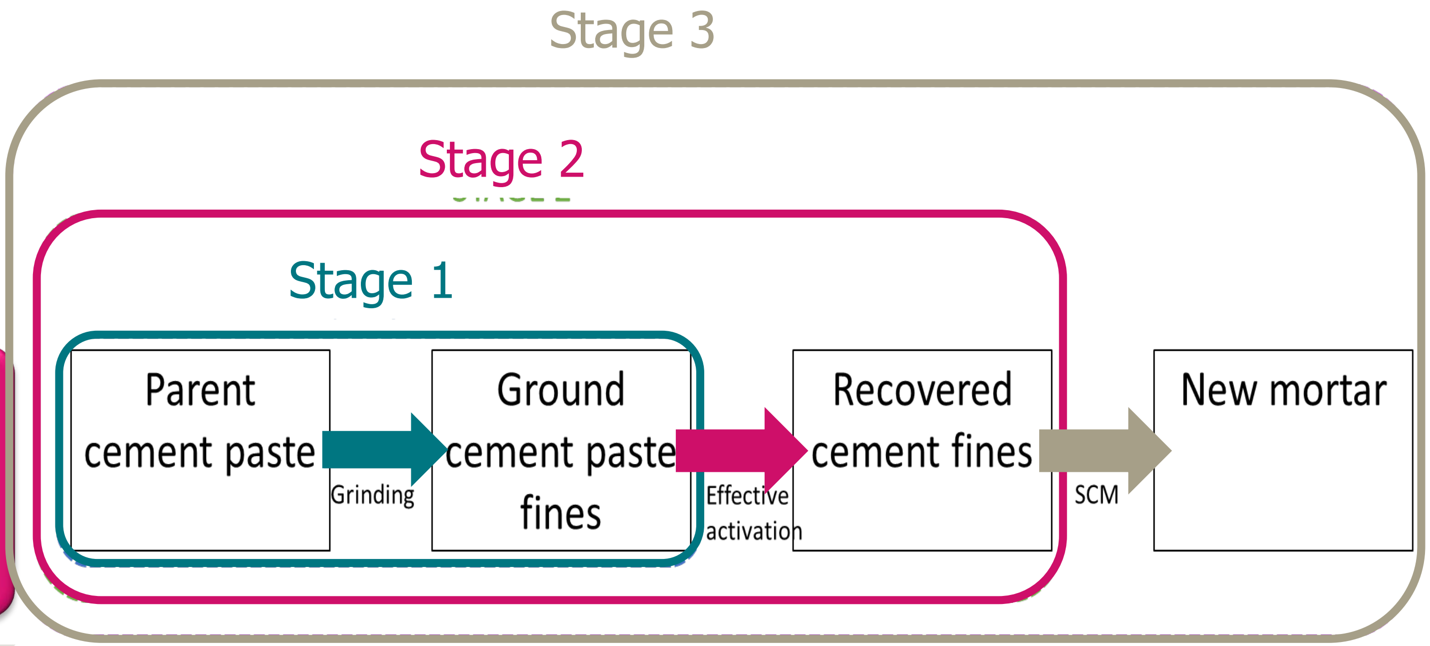
porosity (black) ;cement (red), C-S-H (yellow) CH(cyan)

Research Program

Stage 1: Quantification of residual unhydrated cement in old cement paste

Stage 2: Activation of unhydrated cement core by grinding

Stage 3: Recovery of hydrated cement paste in new mortar as SCM



Materials and Methods – Quantification stage

Parent cement paste production → Curing in water at 20±1 °C for 28/7 days → Oven drying at 105°C + vacuum desiccator/ low humidity room → Compressive strength testing → Grinding

w/c = 0.2, 0.3, 0.6

jaw crusher + vibratory mill

Content of residual cement

PSD	TGA	XRD	CEMHYD3D

Materials and Methods – Quantification, Activation, Recovery stage

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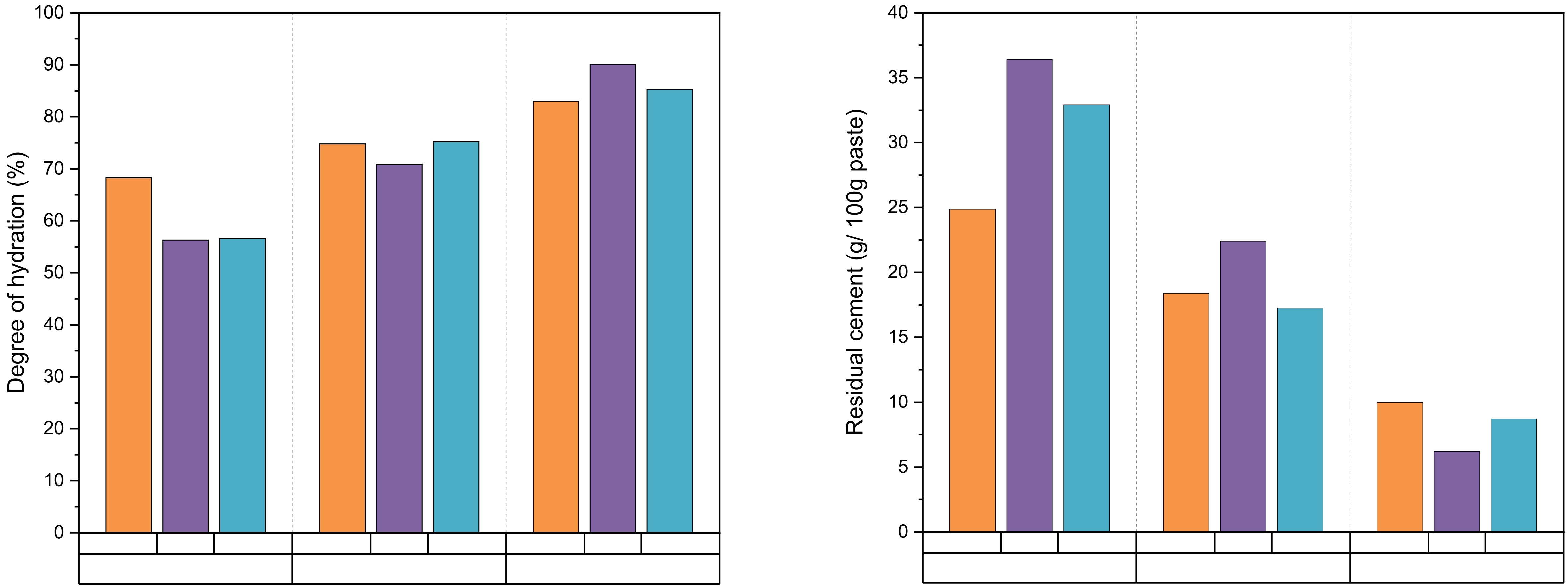
jaw crusher + Milling:
- 4 grinding methods
- 3 grinding times
- 3 GAs concentrations
- 3 requested particle sizes

Fines:
3 types of RCF and
2 types of inert materials

Content of Residual Cement

PSD	TGA	XRD	CEMHYD3D	Activation effect (isothermal calorimetry)

Degree of Hydration & Residual Cement



w/c ↓

Degree of Hydration ↓

Residual Cement ↑

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Partial Conclusions

The potential for recovery depends on both quantitative and qualitative factors:

- content of residual cement → Low w/c ratios → significant amounts of residual cement: 25-36 % (w/c ratio 0.2) and 17-22 % (w/c ratio 0.3). Even high w/c ratios exhibited some residual cement (6-10 %).
- composition of residual cement → Most of the residual cement is in the form of alite and belite (74-95 % of the residual cement).

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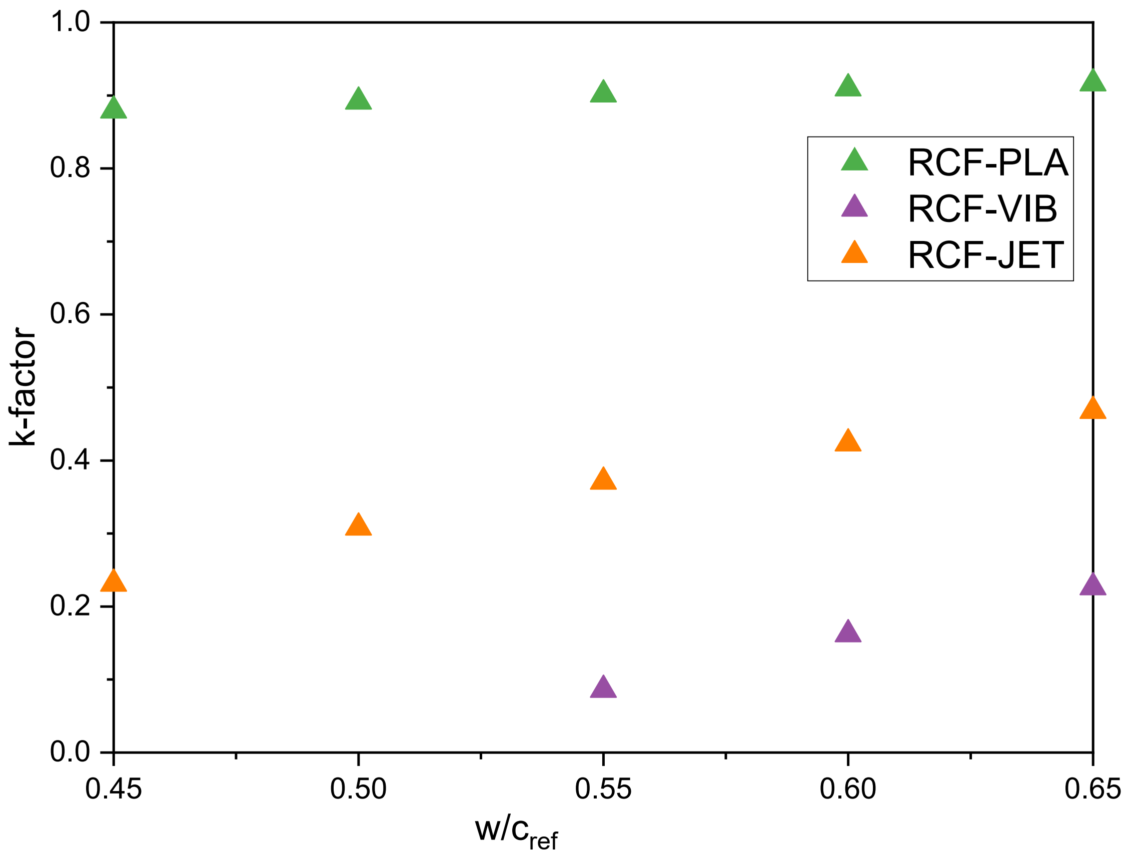
Partial Conclusions *(continued)*

- Residual cement properties of ground hydrated cement paste can be successfully recovered at a range of up to 86 %.
- From the parameters analyzed, the **grinding method** has the strongest effect on the recovery of residual unhydrated cement.
- The best efficiency for achieving the exposure and recovery of residual unhydrated cement core is found in **ball-type mills**.
- The increasing grinding time leads to finer particles, but there is no linear behavior between grinding time/grinding aids and recovery efficiency.

K-factor

- k-factor based on equal strength → **90 days**
- **C = c_a + k*a**
- **c_a** is the amount of cement of the concrete with addition
- **a** is the amount of addition



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Thank you for your attention!
Questions?