Circular Concrete

10 MAY, 2023

Dr. Dipl.-Eng. M.V.A. Florea, I.E. Teune M.Sc., Dr. Dipl.-Min. K. Schollbach, Prof. dr. ir. H.J.H. (Jos) Brouwers

Department of the Built Environment

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Context The Netherlands

- About 25% of generated waste is C&D waste (Bossink and Brouwers, 1996)
- Landfill ban was introduced in 1997
- In 1985 about 50% was “re-used”, now close to 100%
- Landfill ban has stimulated separation of waste streams at C&D source
- Resulting in mono-streams (e.g. cardboard, <u>metals</u>, plastics, wood, glass, <u>stone</u>)
- Stone fraction is processed (crushed, washed, sieved etc.) on 65 stationary sites/installations, 65 mobile installations
- Resulting in 2 streams: “concrete aggregates” and “mixed aggregates” (mostly mixed brickwork and concrete)
- Clean concrete partly applied as aggregate in new concrete, large part still ends up as aggregate replacement in low-end applications (e.g. as road base material)
- For high-end application and circularity: separation of concrete in original constituents is needed: first aggregate and paste, the latter being separated into unhydrated and hydrated cement

Selective demolition

Stripped steel-reinforced concrete structure

Separation steel/concrete

Stone processing (Amsterdam), 700 ton/hour

Clearing debris after natural disasters: mobile kits

Concrete recycling

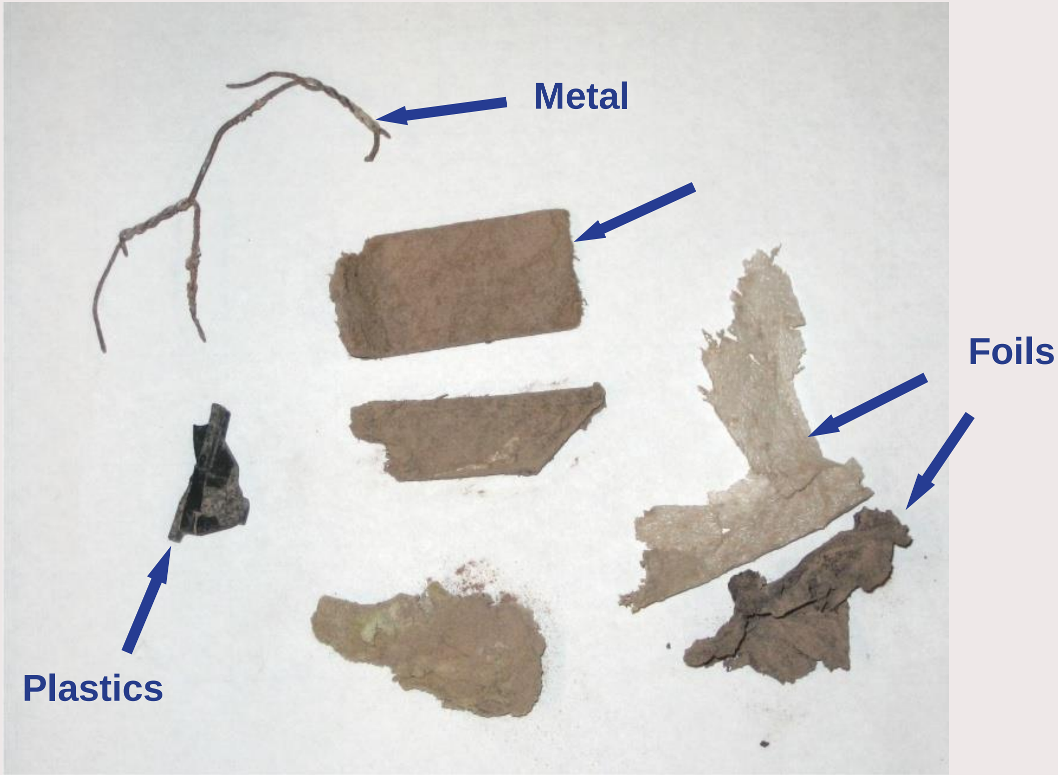
Aggregates in the Netherlands are mainly composed of α-quartz

- High water absorption
- Lower density
- Fractured or broken
- Impurities/contamination
- Reduced fresh concrete properties
- Reduced mechanical strength

RCF = cement paste + α-quartz (SiO_2)

Recycled concrete aggregates

Impurities recycled concrete



Application Method

Recycled Concrete Aggregates (RCA)

Coarse

- Higher water demand/Internal curing
- Prevention of autogenous shrinkage due to internal water source
- “Lightweight”

Fines

- Cement replacement (SCM)
- Filler replacement
- Thermal treatment (optional)
- Carbonation treatment (optional)
- Mutual activation of the mineral oxides and the cementitious binders

Vision of total recycling of concrete

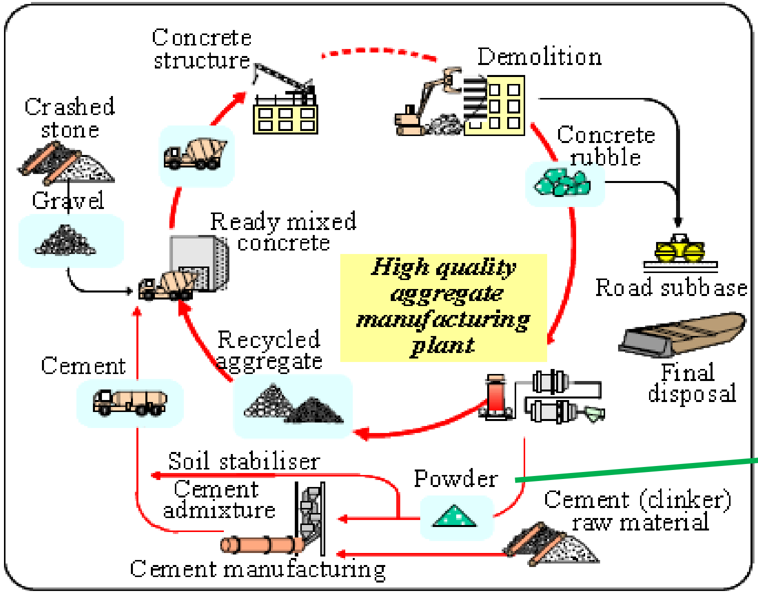


Fig. 1 Schematic flow of concrete recycling system.

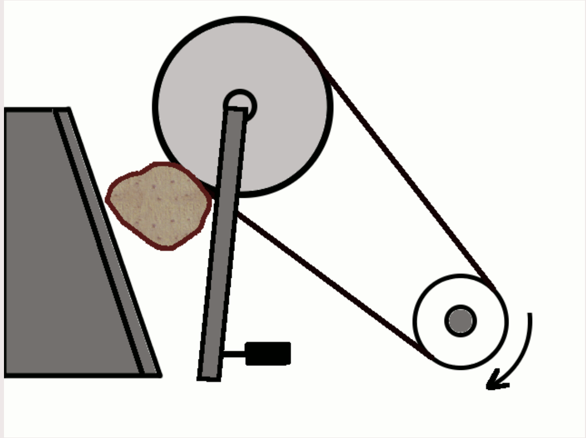
?

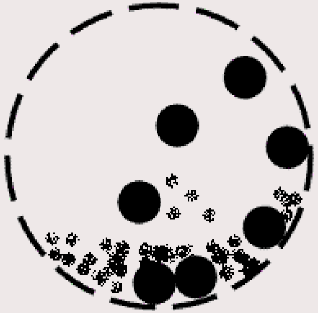
Use as binder material

Hardened cement paste
+ α-quartz

Recycled concrete: smart crushing

Lab jaw crusher;
dimensions and process
parameters adjustable



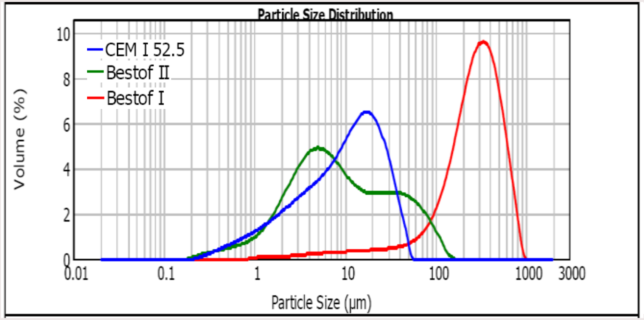


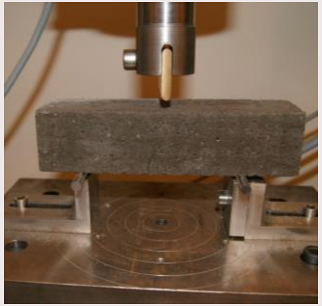
Ball mill

TU/e

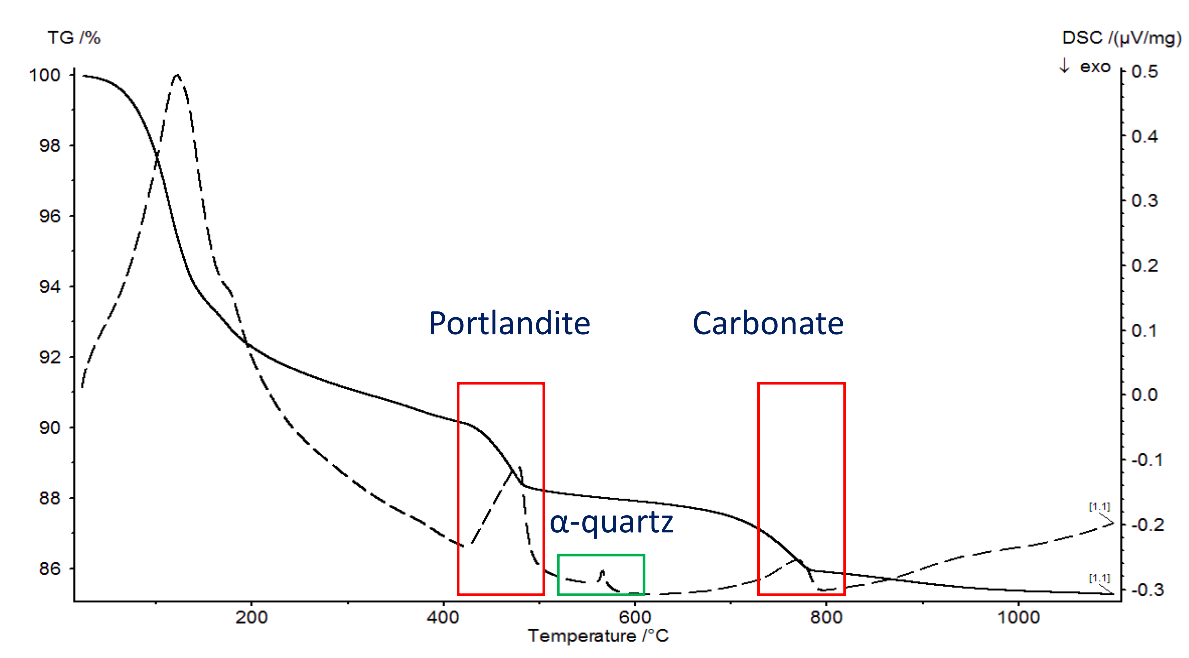
Mechanical and analytical techniques

- Particle size distribution analysis
- Thermogravimetric analysis
- X-Ray fluorescence and/or diffraction
- Water demand and slump flow tests
- Flexural and compressive strength determinations





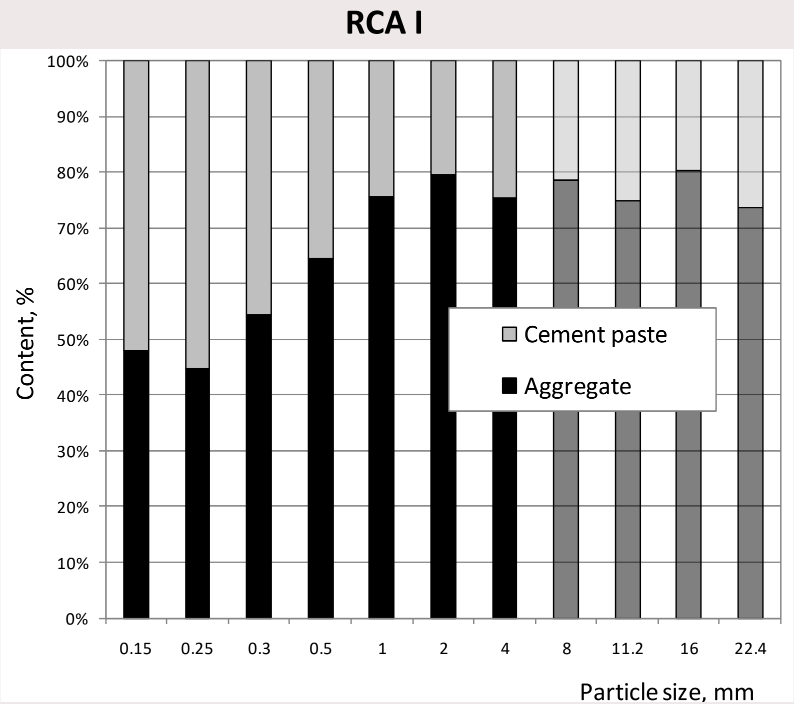
TG-DSC analysis

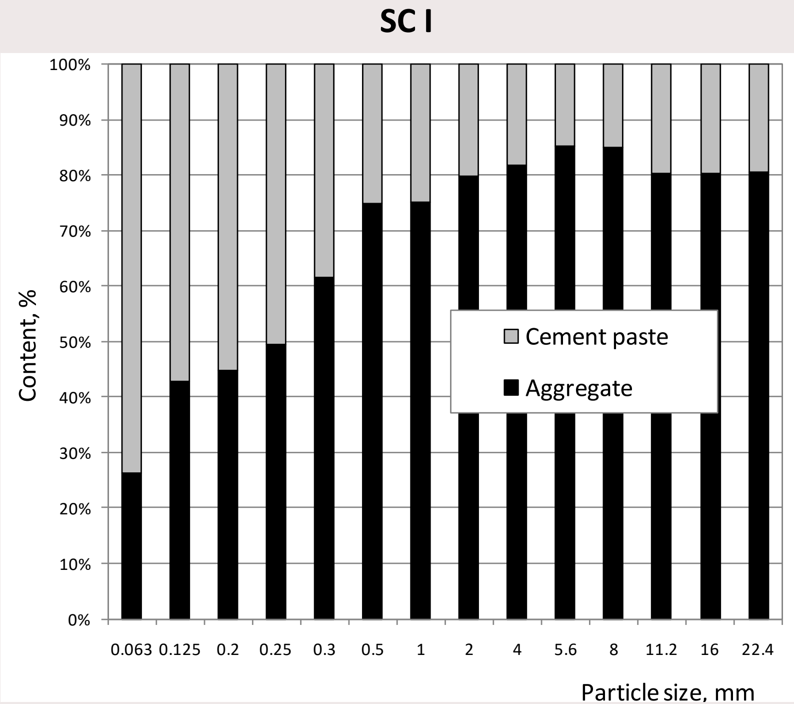


TG-DSC analysis of recycled concrete fines

TU/e

α-quartz content

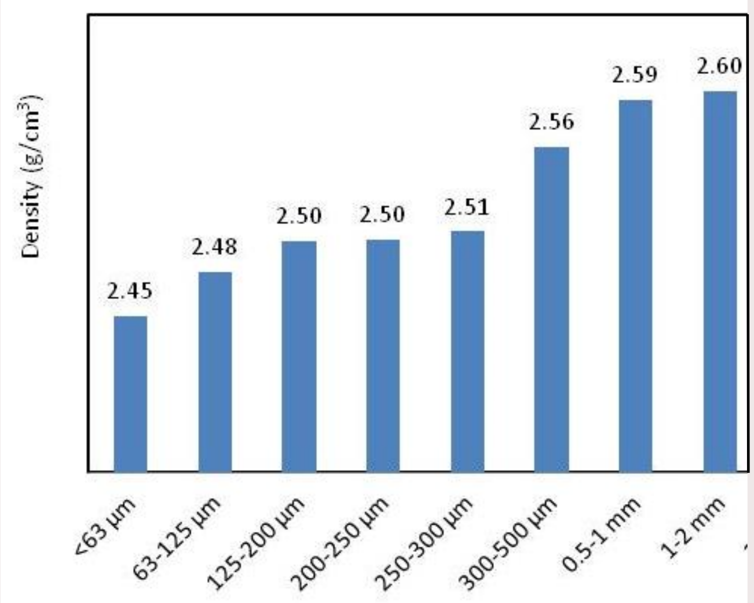




Results validated by X-ray fluorescence (XRF)

Material characterization

Relation silica content and density



Density of recycled aggregates

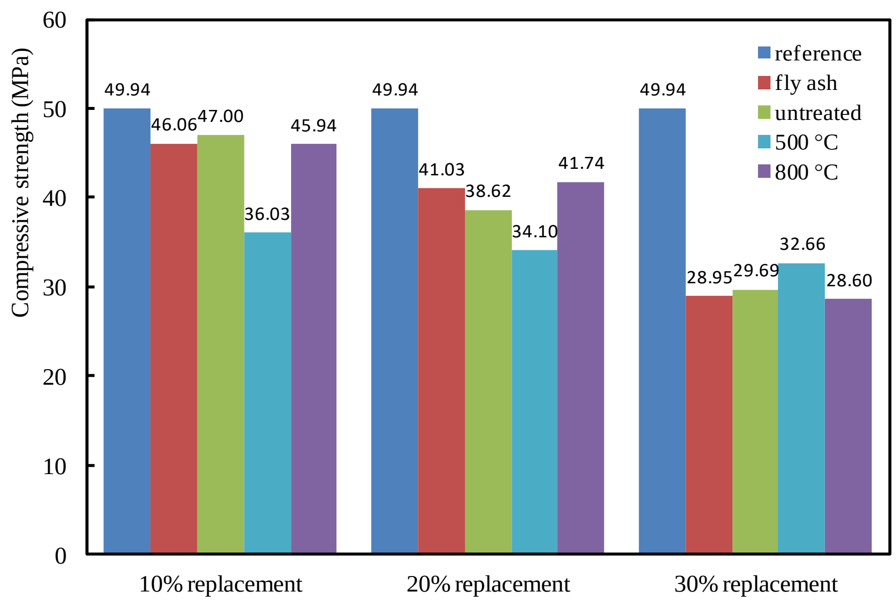
Material characterization

Chemical composition of binders and RC Fines

Oxide	CEM I	RCA I	SC I	PFA
Al_2O_3	5.3	3.2	3.8	24.4
SiO_2	21.5	55.4	44	60
SO_3	2.7	0.8	1.8	1.6
CaO	67	38.4	44	4.8
Fe_2O_3	3.5	2.2	2.8	9.2

Mortar Test Result

(Thermally treated) RCF, compared to fly ash, replacement in OPC

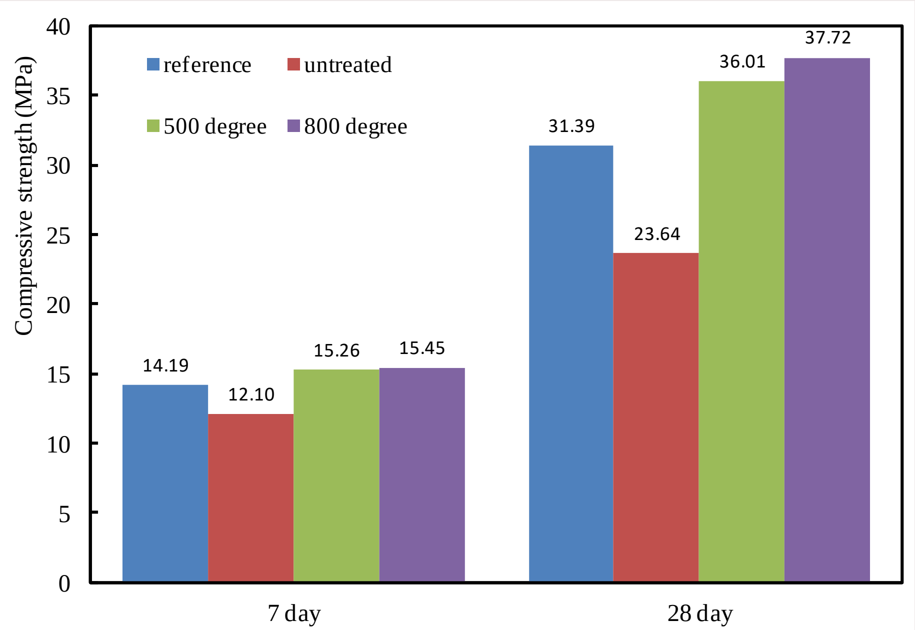


28-day compressive strength comparing to fly ash

Equivalent strength when comparing to commercial fly ash, main difference is water demand and workability.

Mortar Test Result

(Thermally treated) RCF replacement of clinker in slag cement



30% OPC versus 20% OPC/10% RCF

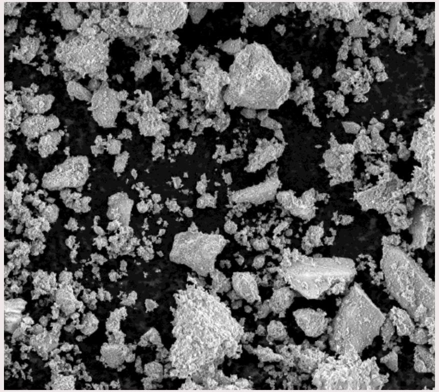
Thermally treated fines have good activator effect on slag
14.7% and 20.1% increase!

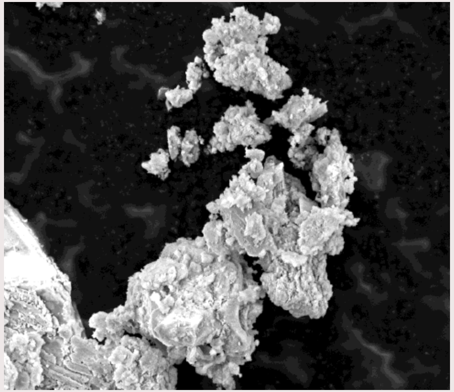
Compressive strength of clinker replacement (1/3) in combination with 70% GGBS

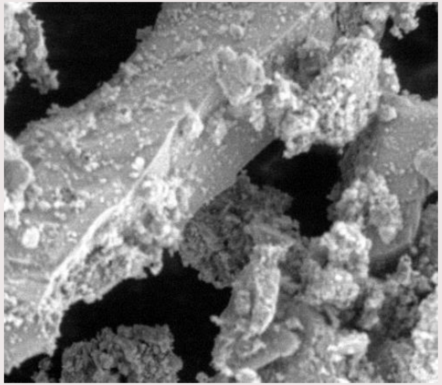
TU/e

Natural sand replacement by RC Sand of SC I

Particle size (mm)	NS (g)	RCS (g)
< 0.075	2.9	3.0
0.075-0.15	120.8	121.0
0.15-0.50	316.2	318.0
0.50-1.0	428.3	430.0
1.0-1.4	250.9	251.0
1.4-2.0	225.9	227.0
Total (g)	1345.0	1350.0

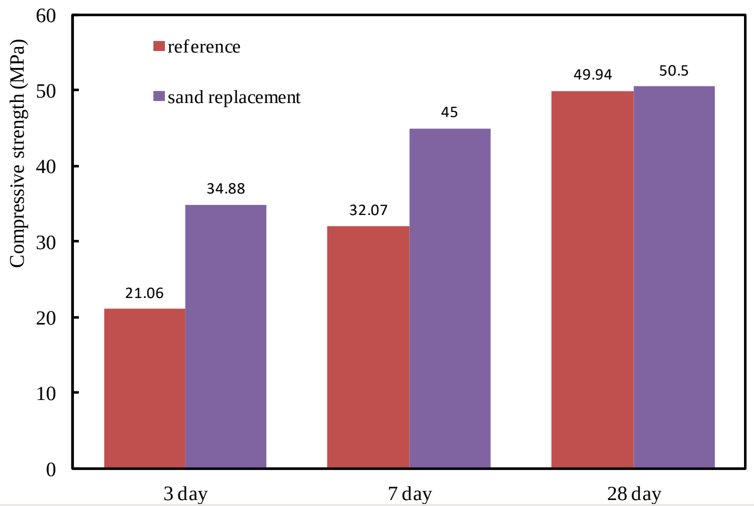


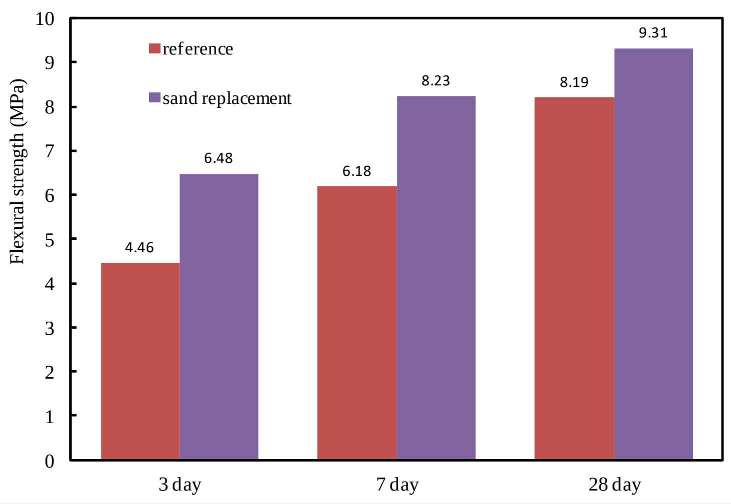




Reuse of RCS

Sand replacement by 100% result, CEM I 42.5N standard mortars





Compressive and flexural strengths

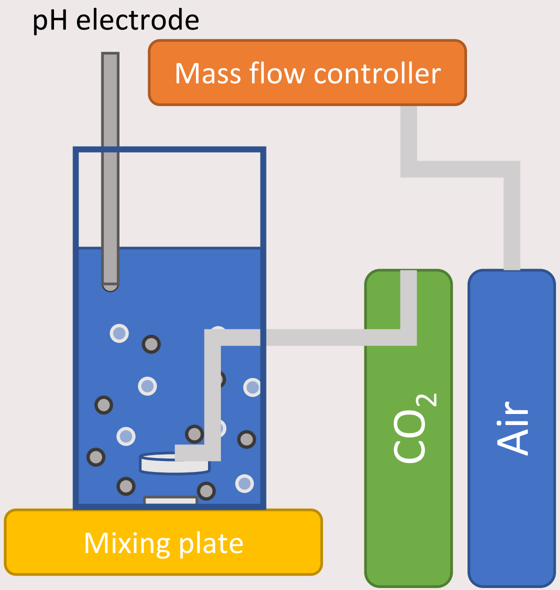
Reactivation of cement fines through carbonation

- Cement paste (C-S-H) + CO_2 → SiO_2 + $CaCO_3$ + H_2O

  Pozzolan + Limestone

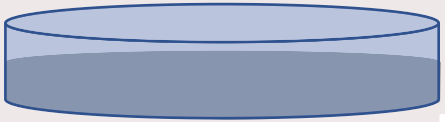
- 2 different techniques
  - Aqueous Carbonation in water or 0.1 M NaOH (AC_H and AC_{Na})
  - Dry Carbonation in climate chamber (DC)

Aqueous carbonation



Dry carbonation

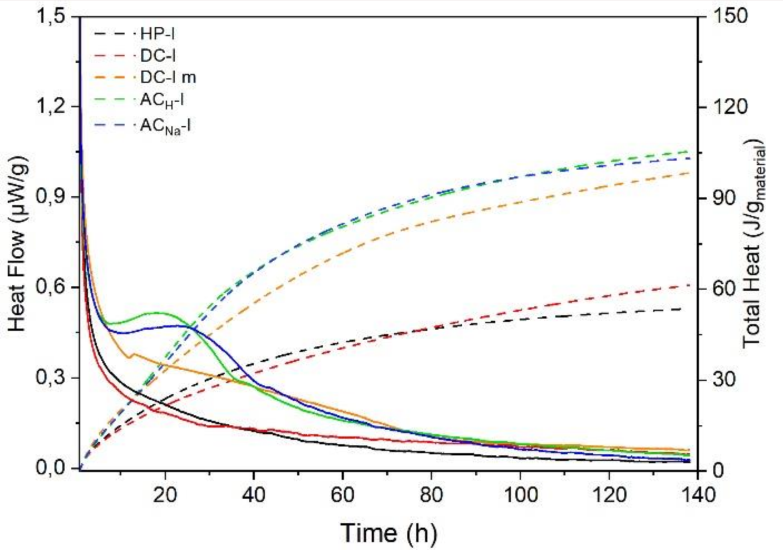
95% RH 10% CO_2



Zajac, M. *et al. Phase assemblage and microstructure of cement paste subjected to enforced, wet carbonation.*, **2020**

Reactivity

- Aqueous carbonation results in high reactivity
- Dry carbonated material can be improved by milling the material
- Faster and more complete carbonation for aqueous carbonation



TGA	HP-I	AC$_H$-I	AC$_{Na}$-I	DC-I
$Ca(OH)_2$ (wt%)	17.1	0	0	0
$CaCO_3$ (wt%)	7.3	70.0	72.5	67.6
% Ca carbonated	8.1	77.6	80.3	74.9

Conclusions

- Recycled Concrete Fines (RCF) = cement paste + α–quartz.

- The α-quartz content can be determined by a TG-DSC method, or simply by measuring the density.

- Small particles low in α-quartz and rich in cement paste.

- The recovery of the cement paste can be improved by optimized crushing

  - Larger fines volume
  - Higher paste content

Conclusions

- Recycled concrete fines and recycled sand have higher water demands than natural aggregates; 10% binder replacement will not decrease much of mortar consistency
- 100% sand replacement mortar tests demonstrate a significant increase in early strength
- Recycled concrete fines have similar compressive strength performances as commercial low calcium fly ash
- Recycled concrete fines activate GGBS
- Carbonation results in a pozzolan and a filler ($CaCO_3$)
- Wet carbonation more effective than dry.

Literature

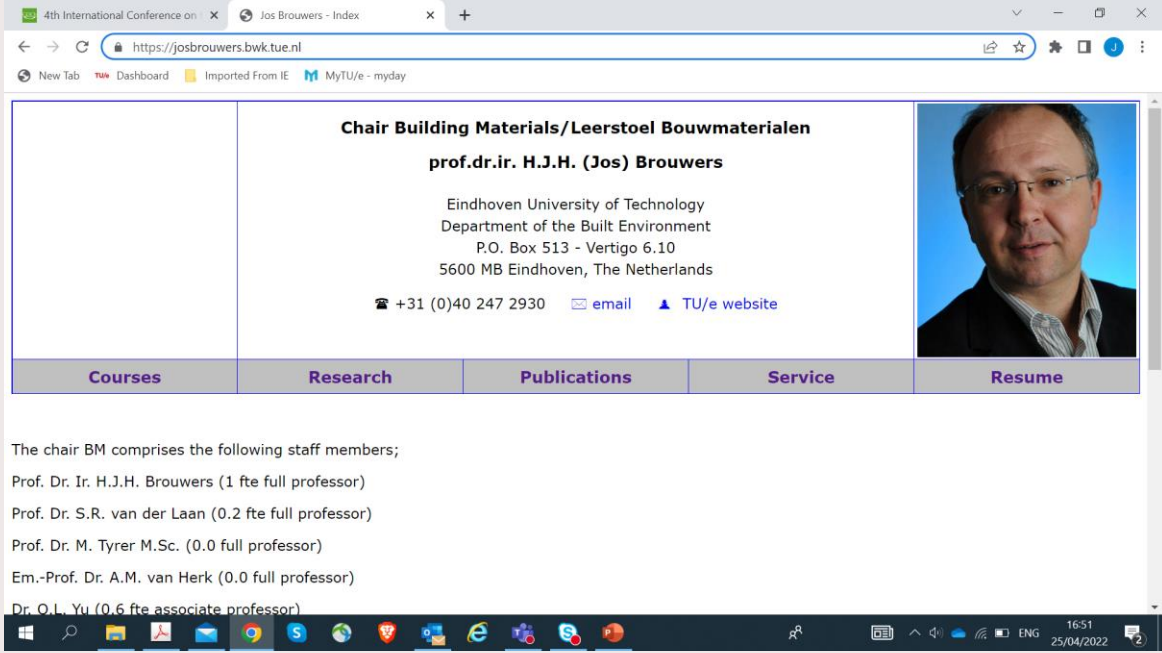
- B.A.G. Bossink, H.J.H. Brouwers, Solid waste in the construction industry, quantification and source evaluation, ASCE Journal of Construction Engineering and Management 122, 55 - 60 (1996)
- M.V.A. Florea, H.J.H. Brouwers, Properties of various size fractions of crushed concrete related to process conditions and re-use, Cement and Concrete Research 52, 11-21, Corrigendum, ibid, 53, 278 (2013).
- M.V.A. Florea, Z. Ning, H.J.H. Brouwers, Activation of liberated concrete fines and their application in mortars, Construction and Building Materials 50, 1-12 (2014).
- P. Spiesz, S. Rouvas, H.J.H. Brouwers, Utilization of waste glass in translucent and photocatalytic concrete, Construction and Building Materials 128, 436-448 (2016).
- G.C.H. Doudart de la Grée, Q.L. Yu, H.J.H. Brouwers, Upgrading and evaluation waste paper sludge ash in eco-lightweight cement composites, Journal of Materials in Civil Engineering 30, 04018021-1-04018016-11 (2018).
- G. Liu, M.V.A. Florea, H.J.H. Brouwers, Characterization and performance of high volume recycled waste glass and ground granulated blast furnace slag or fly ash blended mortars, Journal of Cleaner Production 235, 461-472 (2019).

Literature

- F. Wu, Q.L. Yu, C.W. Liu, H.J.H. Brouwers, L.F. Wang, Effect of surface treatment of apricot shell on the performance of lightweight bio-concrete, Construction and Building Materials 229, 116859 (2019).
- H. Karimi, Q.L. Yu, H.J.H. Brouwers, Valorization of waste baby diapers in concrete, Resources, Conservation & Recycling 153, 104548 (2020).
- K. Kochova, F. Gauvin, K. Schollbach, H.J.H. Brouwers, Using alternative waste coir fibres as a reinforcement in cement-fibre composites, Construction and Building Materials 231, 117121 (2020).
- P.M.F. van de Wouw, E. Loginova, M.V.A. Florea, H.J.H. Brouwers, Compositional modelling and crushing behaviour of MSWI bottom ash material classes, Waste Management 101, 268-282 (2020).

Contact

https://josbrouwers.bwk.tue.nl/



Thank you!

Summary and take-away points