Novel upcycling technique of recycling of cement paste powder by a two-step carbonation process

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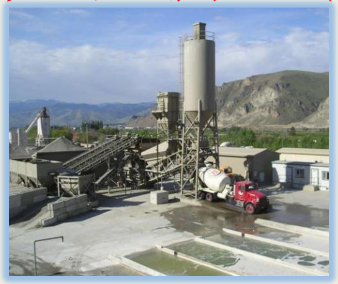
Research at PolyU

Turning wastes to eco-construction products

Construction and Demolition Waste

建筑和拆迁废物

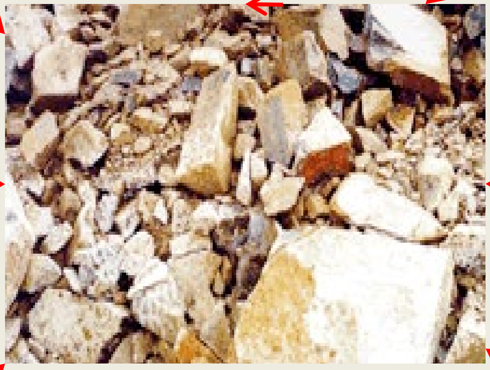
- 15 Million tonnes
  一千五百万吨



Batching plants
混凝土搅拌站

Road Work 公路

Excavation 挖掘



C&D Waste

Demolition 拆迁

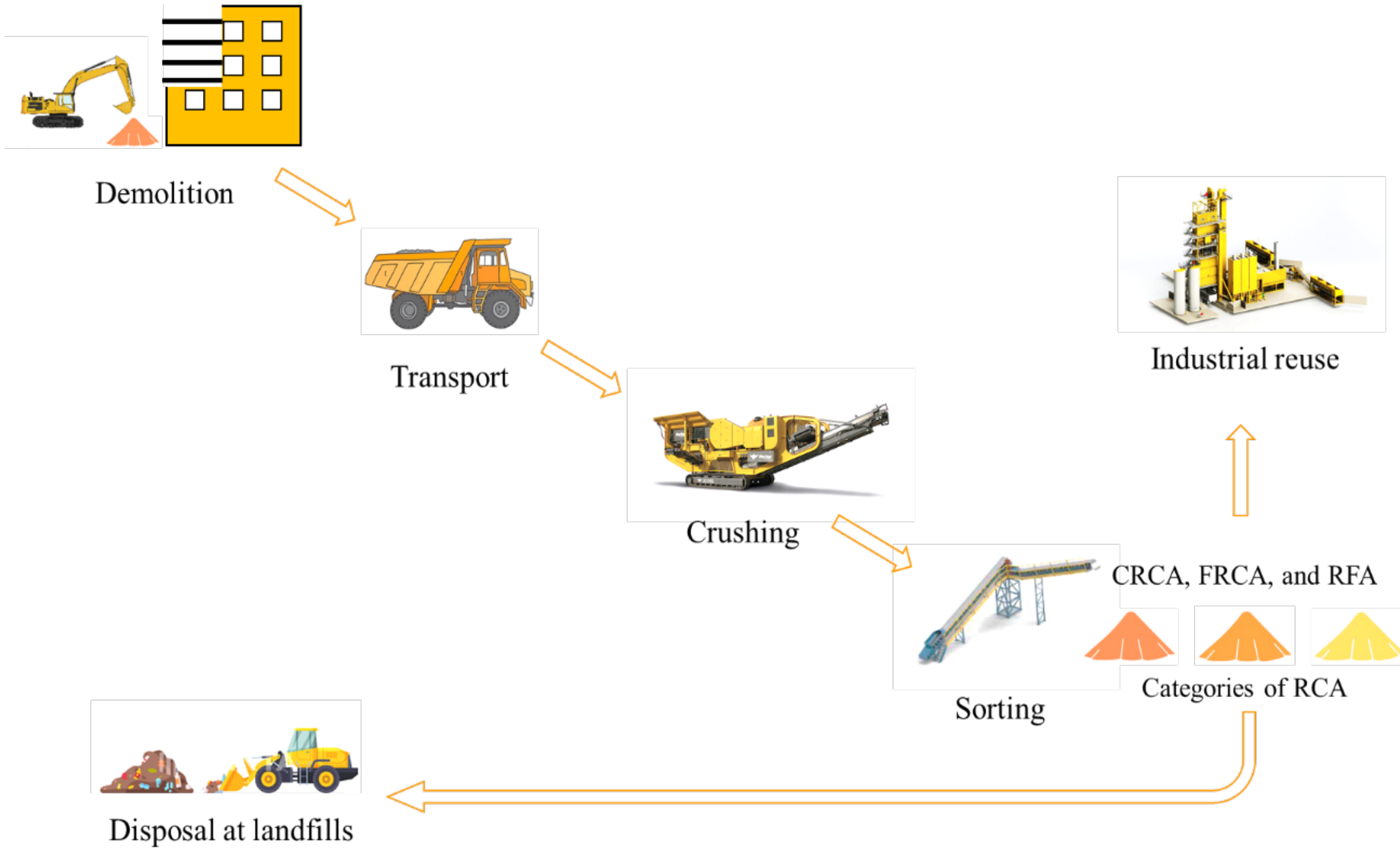
Construction 建筑

Renovation 装修

Refurbishment
翻新,整修

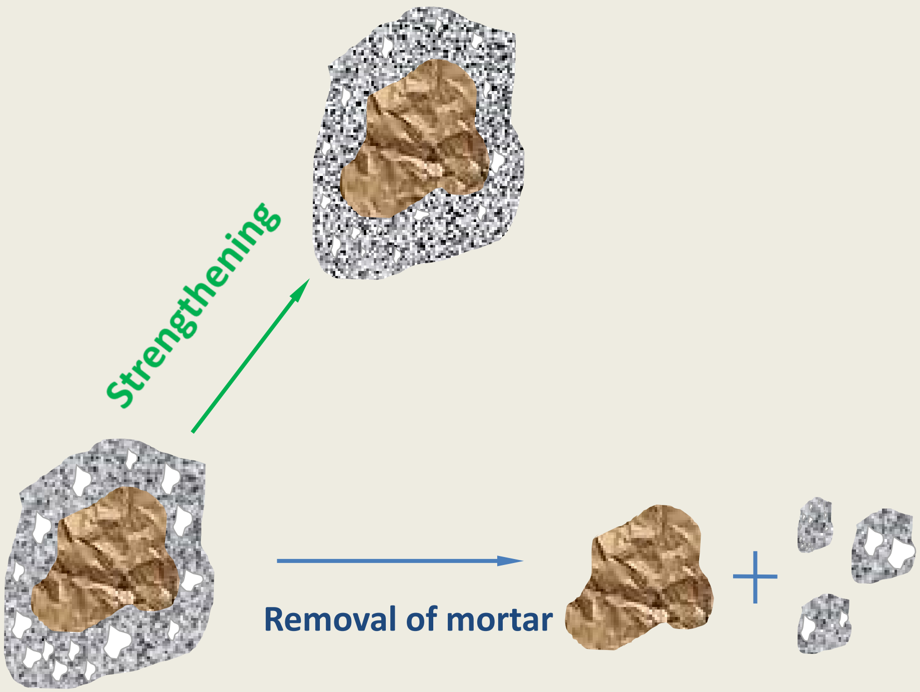
Recycled Aggregates Derived from Sorting Facility
筛选设备分选出再生骨料

Material Flow of Demolition of Concrete Structures



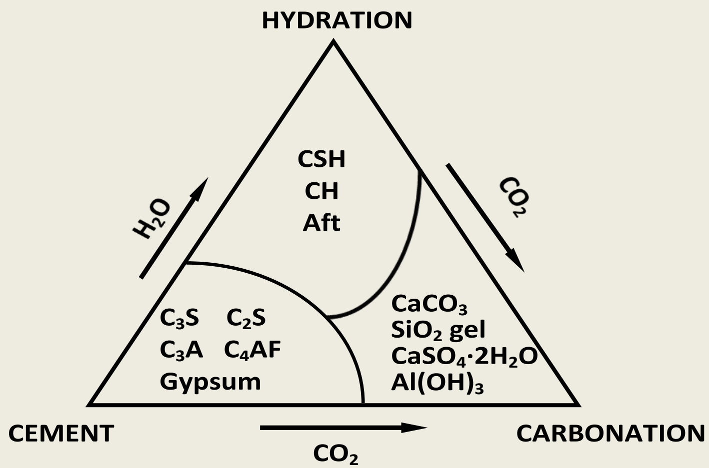
CRCA-coarse recycled aggregate (> 5mm)
FRCA- fine recycled aggregate (0.15 – 5 mm)
RFA- recycled fine powder (0.15 mm)

Characteristics of RCA



Presoaking RCA in acid solution

Technical background



C_3S: $3CaO \cdot SiO_2$ (s); C_2S: $3CaO \cdot SiO_2$ (s); C_3A: $3CaO \cdot Al_2O_3$(s)

C_4AF: $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$; Gypsum: $CaSO_4 \cdot 2H_2O$; CH: $Ca(OH)_2$

C-S-H: $xCaO \cdot ySiO_2.zH_2O$ gel; Aft: $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$

$$C_3S + 3CO_2 + nH_2O \rightarrow 3CaCO_3 + SiO_2 \cdot nH2O \quad (1)$$

$$C_xS_yH_z + xCO_2 \rightarrow xCaCO_3 + ySiO_2 \cdot tH_2O + (z-t)\ H_2O \quad (2)$$

$$Ca\ (OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (3)$$

$$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + 3CO_2 \rightarrow 3CaCO_3 + 2Al(OH)_3 + 3CaSO_4 \cdot 2H_2O + 23H_2O \quad (4)$$

11.8% increase in solid volume

Accelerated CO_2 Curing Technique

- Carbonation of cement hydration products: CH and CSH are predominant components to react with carbon dioxide in cement paste during carbonation.

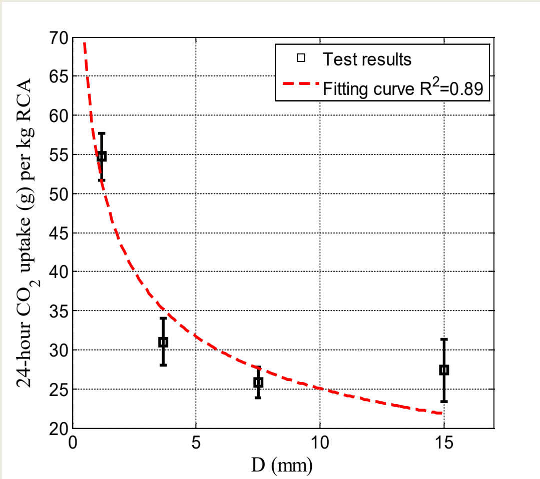
$$CSH_{(s)} + CO_{2(g)} \rightarrow CaCO_{3(s)} + silica + H_2O_{(l)}$$

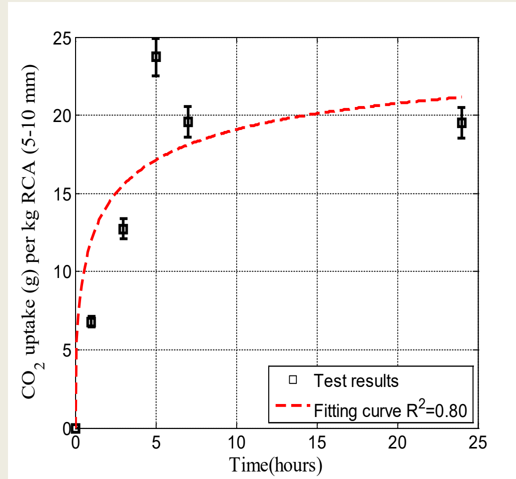
$$Ca(OH)_{2\,(s)} + CO_{2(g)} \rightarrow CaCO_{3(s)} + H_2O_{(l)}$$

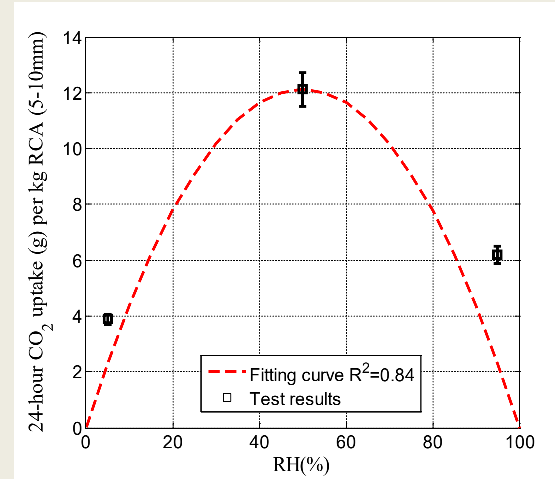
33.0 ml/mol 36.9ml/mol

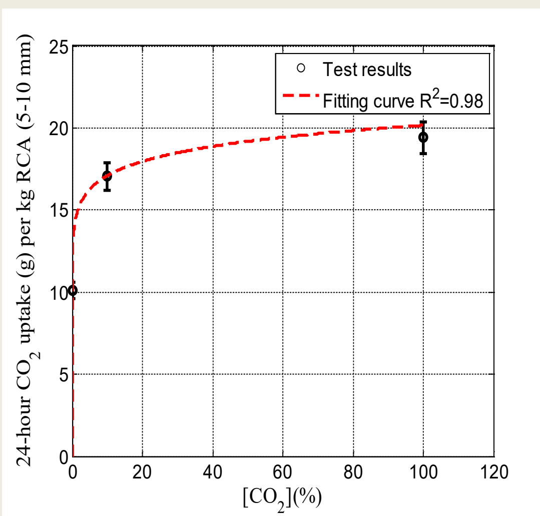
11.8% increase in solid volume

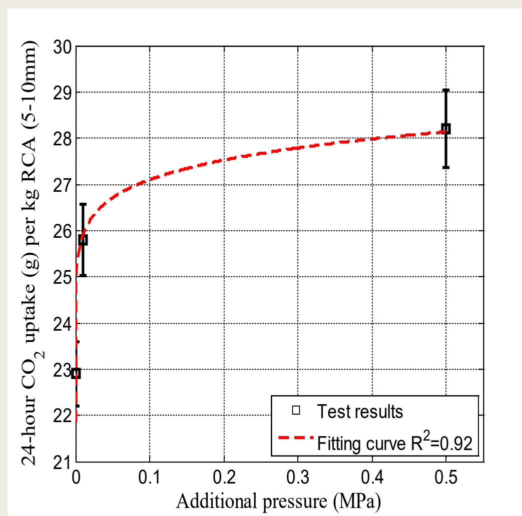
CO_2 sequestration by RCAs

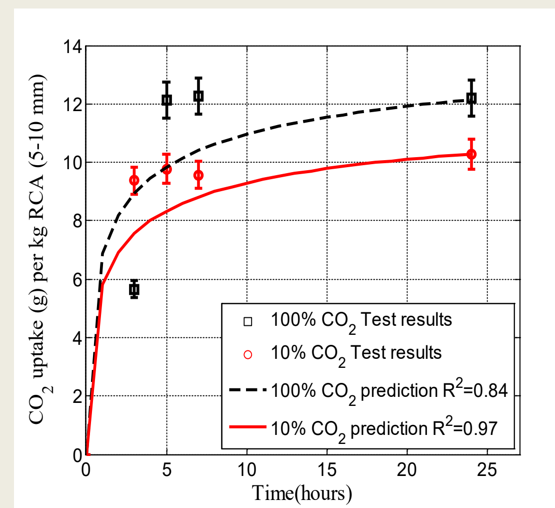






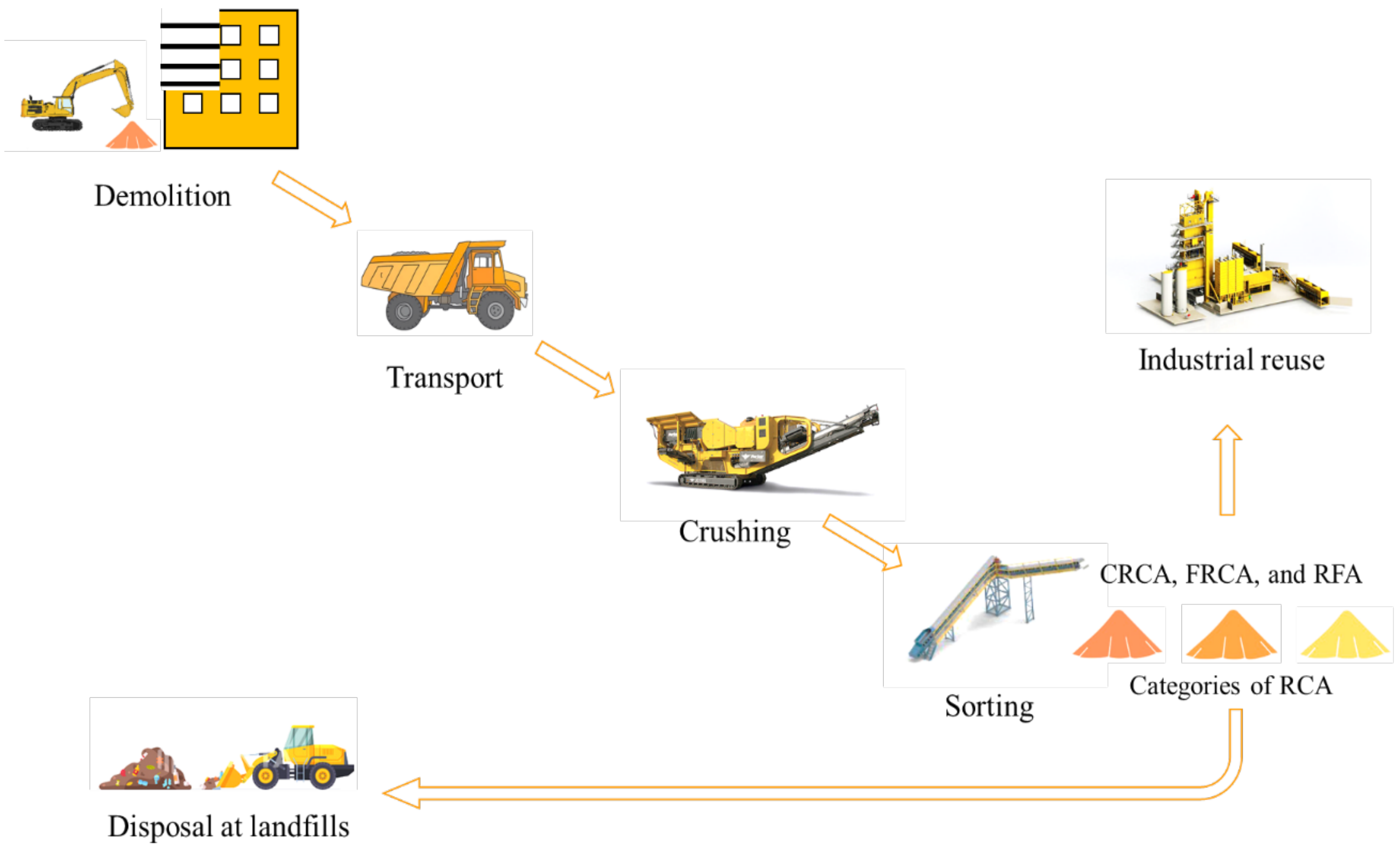






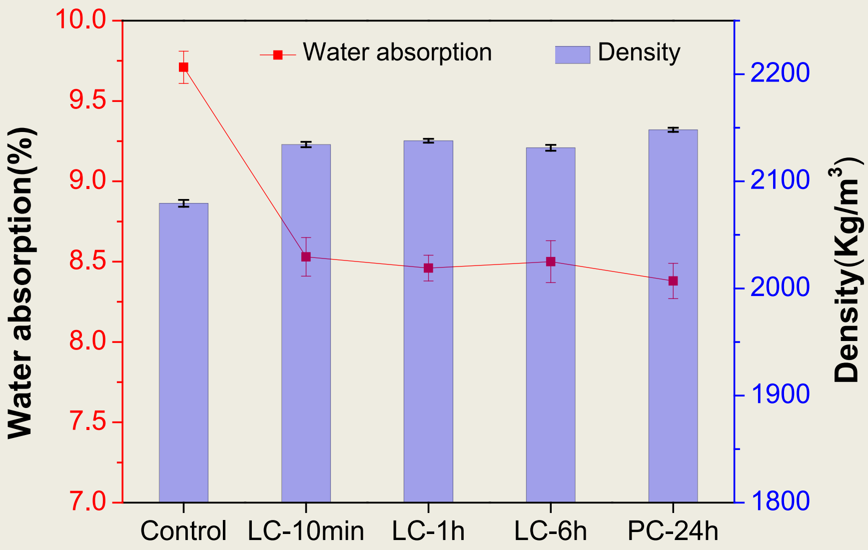
X. Fang, D. Xuan, **C.S. Poon**, (2017). Materials and Structures, 50(4): 200.

Material Flow of Demolition of Concrete Structures

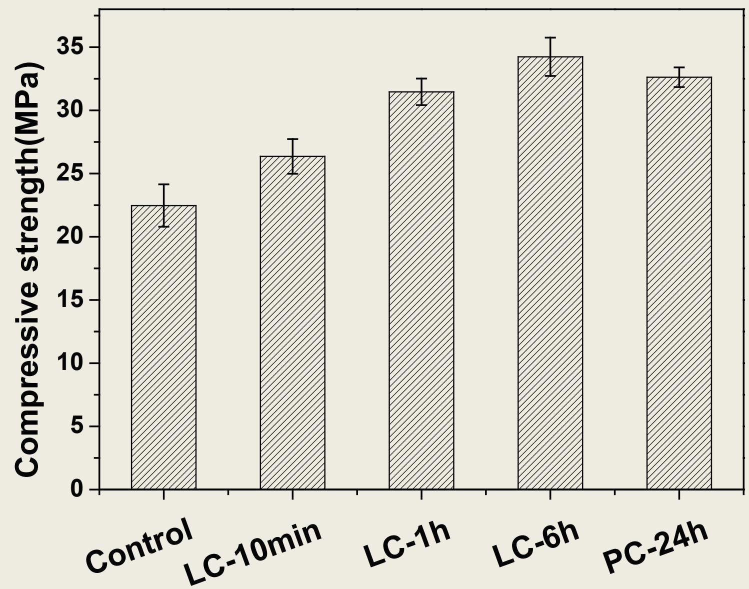


CRCA-coarse recycled aggregate
FRCA- fine recycled aggregate
RFA- recycled fine powder

Properties of carbonated RCAs and RAC (1)



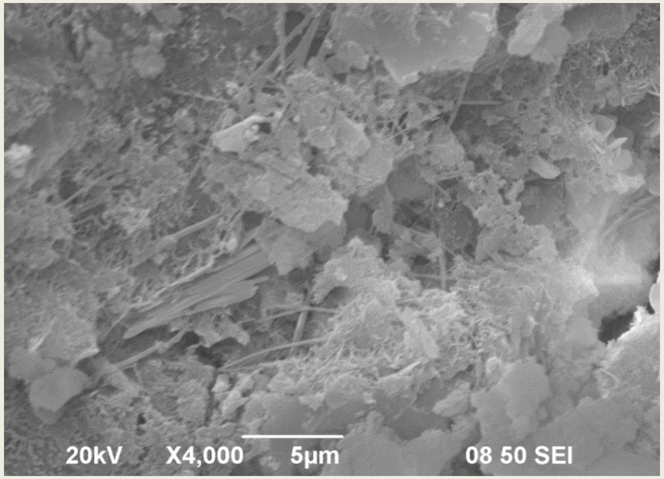
Water absorption and density of CMA before and after liquid-solid and gas-solid pressurized carbonation



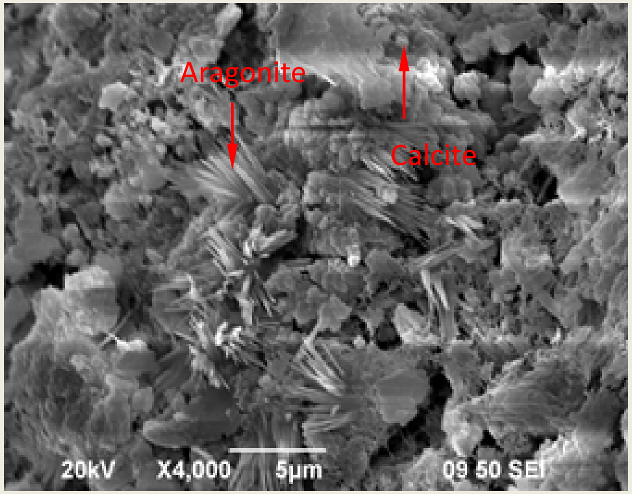
Compressive strength of RAC incorporated with carbonated CMA at 28 days

Liu S.Shen P.Xuan D.Li L.Sojobi A.Zhan B. Poon C.S. **A comparison of liquid-solid and gas-solid accelerated carbonation for enhancement of recycled concrete aggregate,** ***Cement and Concrete Composites*** Volume 118, April 2021 Article number 103988

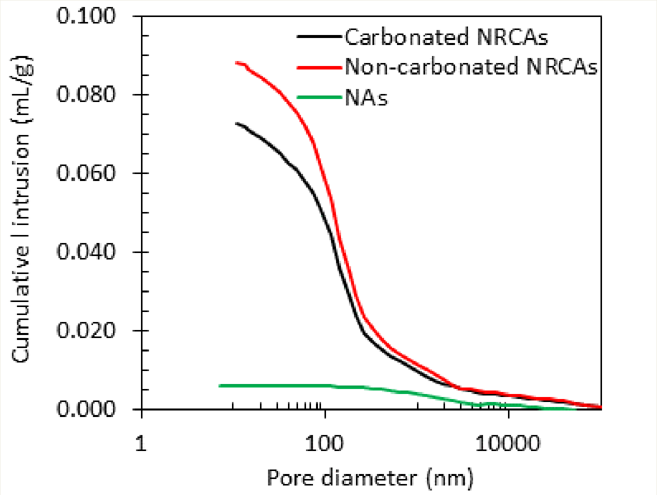
Properties of carbonated RCAs and RAC (2)



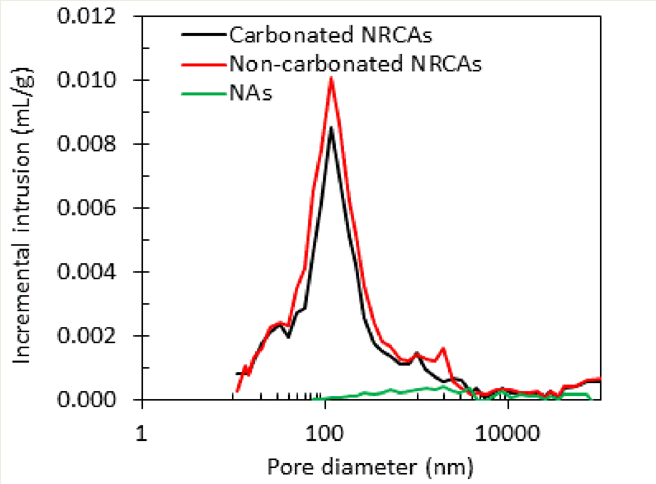
(a) Non-carbonated NRCAs



(b) Carbonated NRCAs



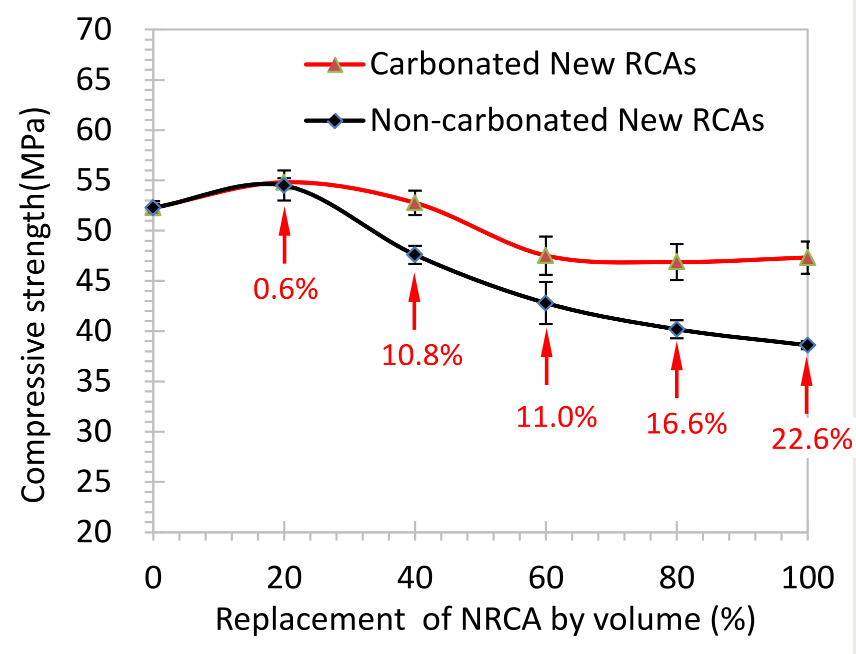
(a) Cumulative intrusion

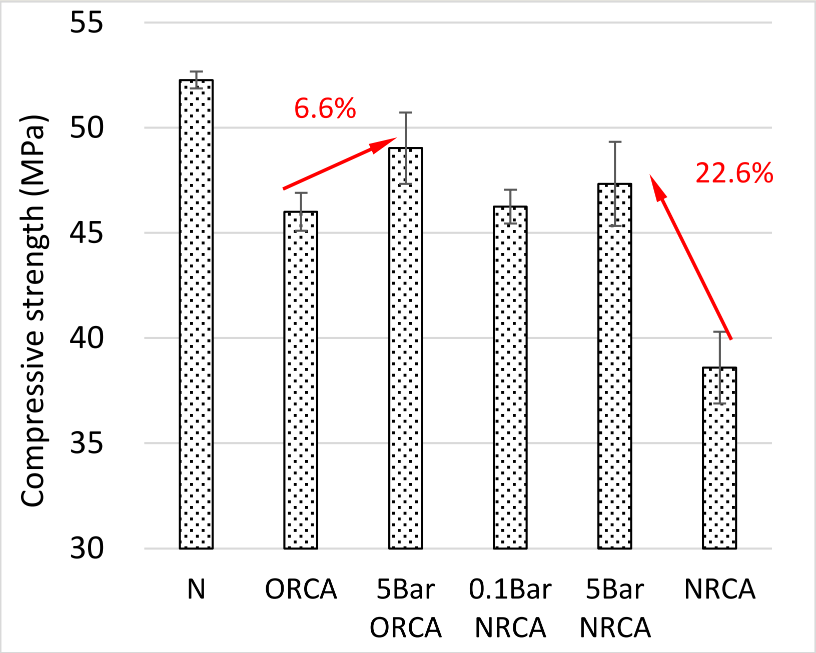


(b) Incremental intrusion

Properties of carbonated RCAs and RAC (3)

➢ Effects of carbonated RA on compressive strength of concrete

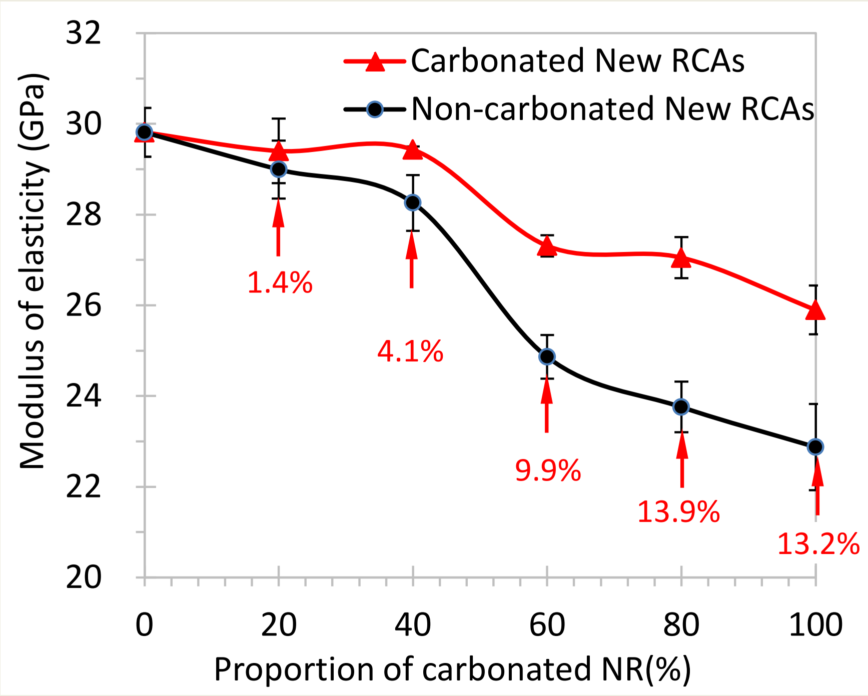


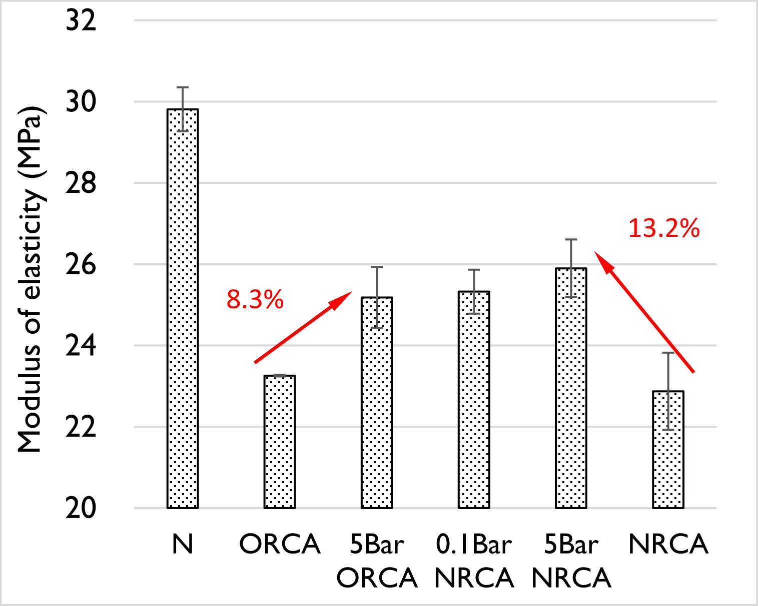


D. Xuan, B. Zhan, **C.S. Poon**, (2016). Cement and Concrete Composites, 65: 67-74.

Properties of carbonated RCAs and RAC (4)

➢ Effects of carbonated RA on elastic modulus of concrete

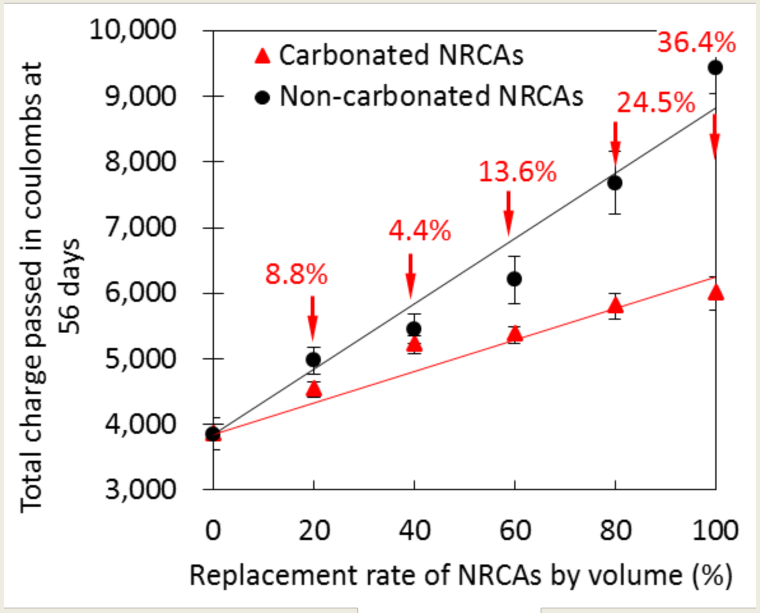




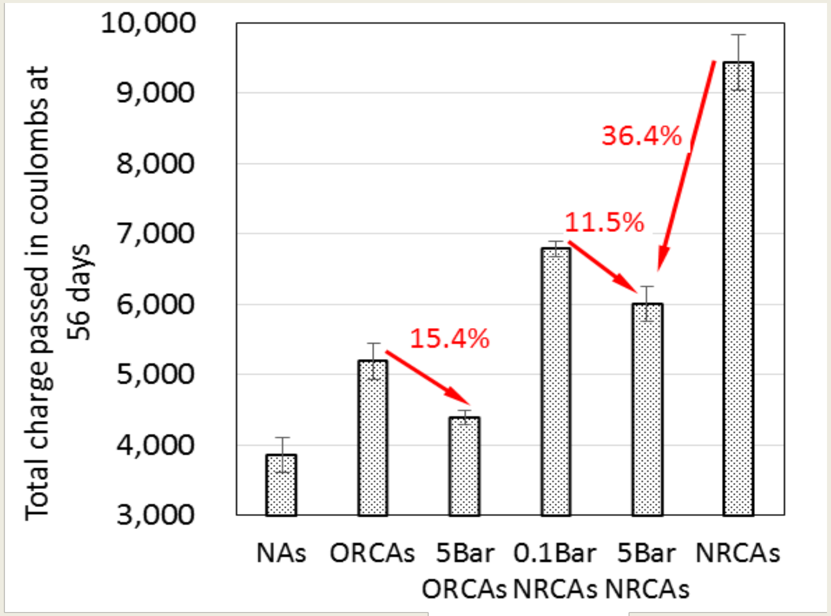
D. Xuan, B. Zhan, **C.S. Poon**, (2016). Cement and Concrete Composites, 65: 67-74.

Properties of carbonated RCAs and RAC (5)

➢ Effects of carbonated RCAs on passed in coulombs of RAC



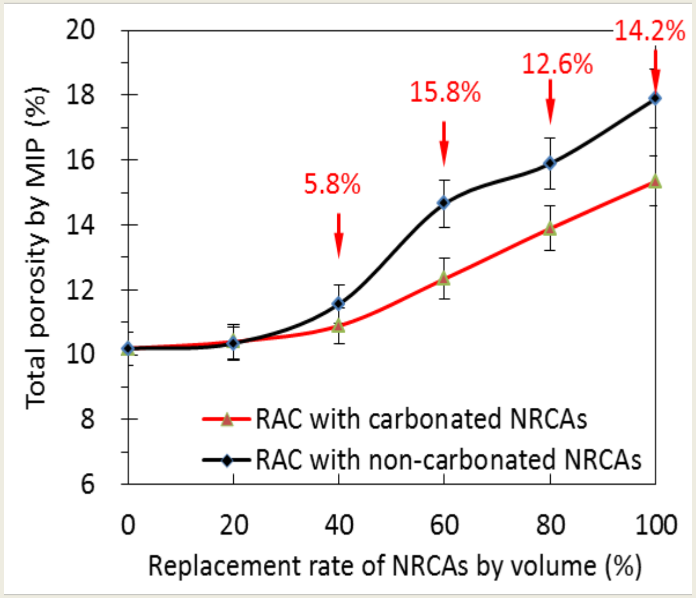
(a)



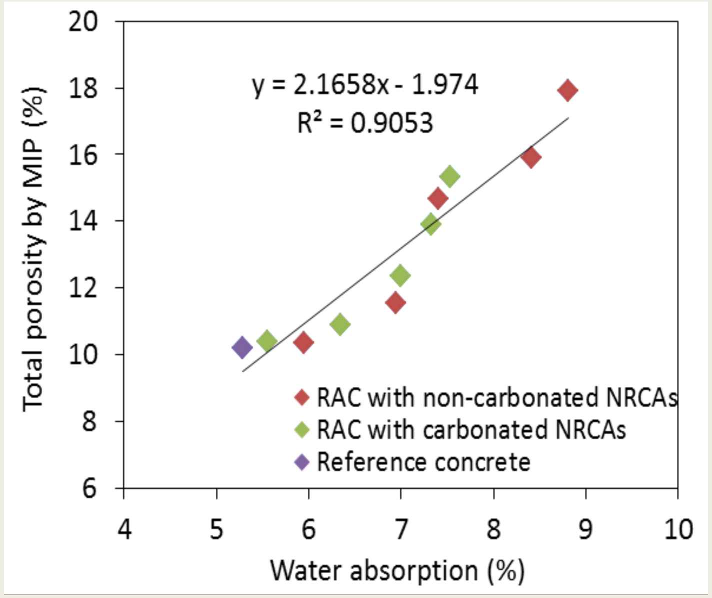
(b)

D. Xuan, B. Zhan, **C.S. Poon**, (2017). Cement and Concrete Composites, 84: 214-221.

Properties of carbonated RCAs and RAC (7)



(a)

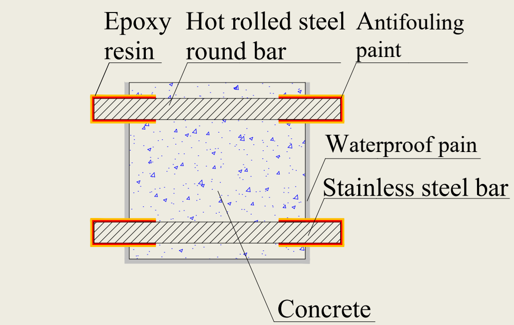


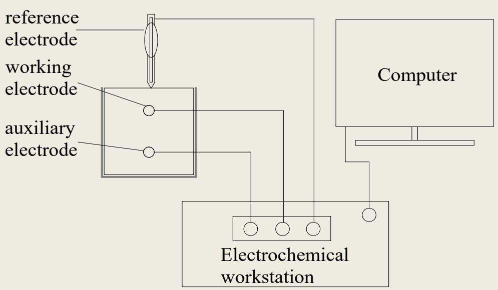
(b)

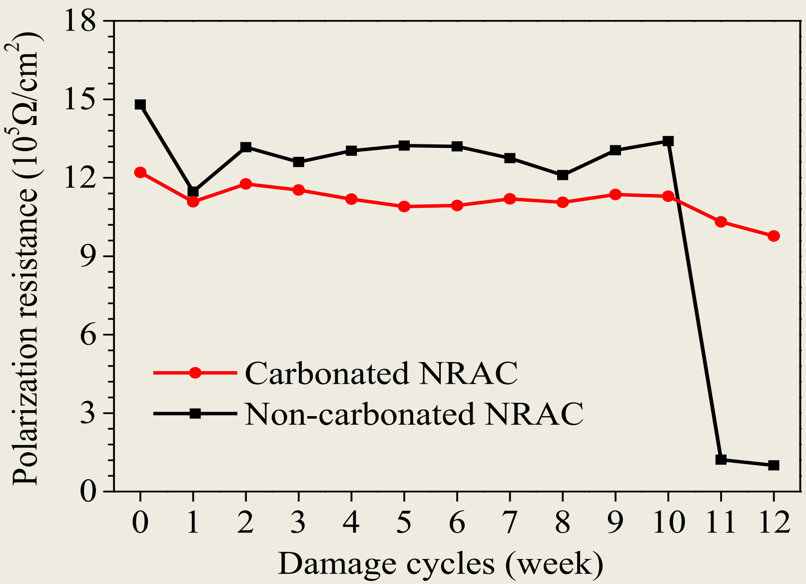
- The water absorption values of RAC may be used as a criterion to indicate the durability of RAC.

Properties of carbonated RCAs and RAC (11)

➢ Effects of carbonated RA on resistance to corrosion of RAC



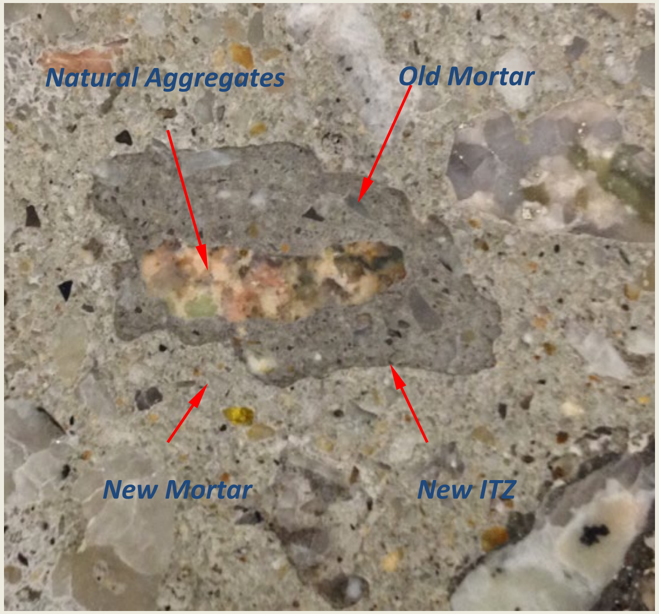


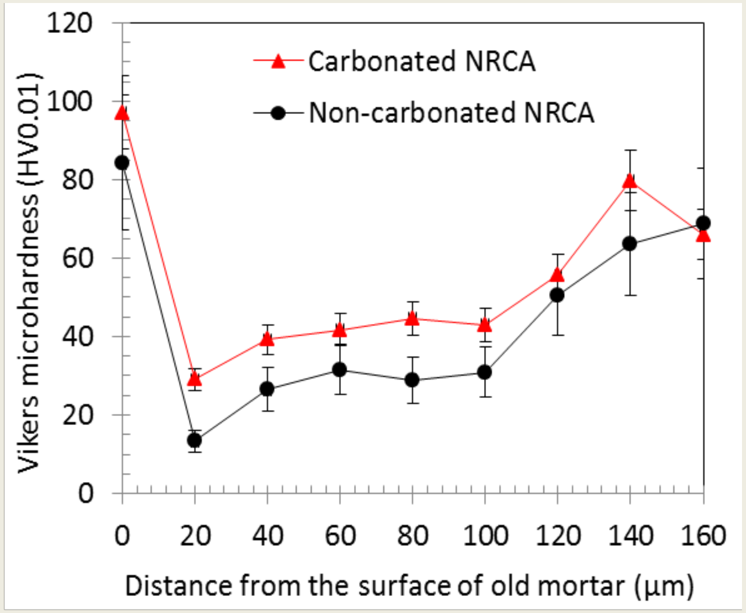


- Polarization resistance of non-carbonated NRAC rapidly decreased at the 11th damage cycle, indicating that the steel in non-carbonated NRAC was corroded.

Zeng W., Zhao Y., Zheng H., Poon C.S., *Cement and Concrete Composites* Volume 106, February 2020, Article number 103476

Properties of carbonated RCAs and RAC (8)

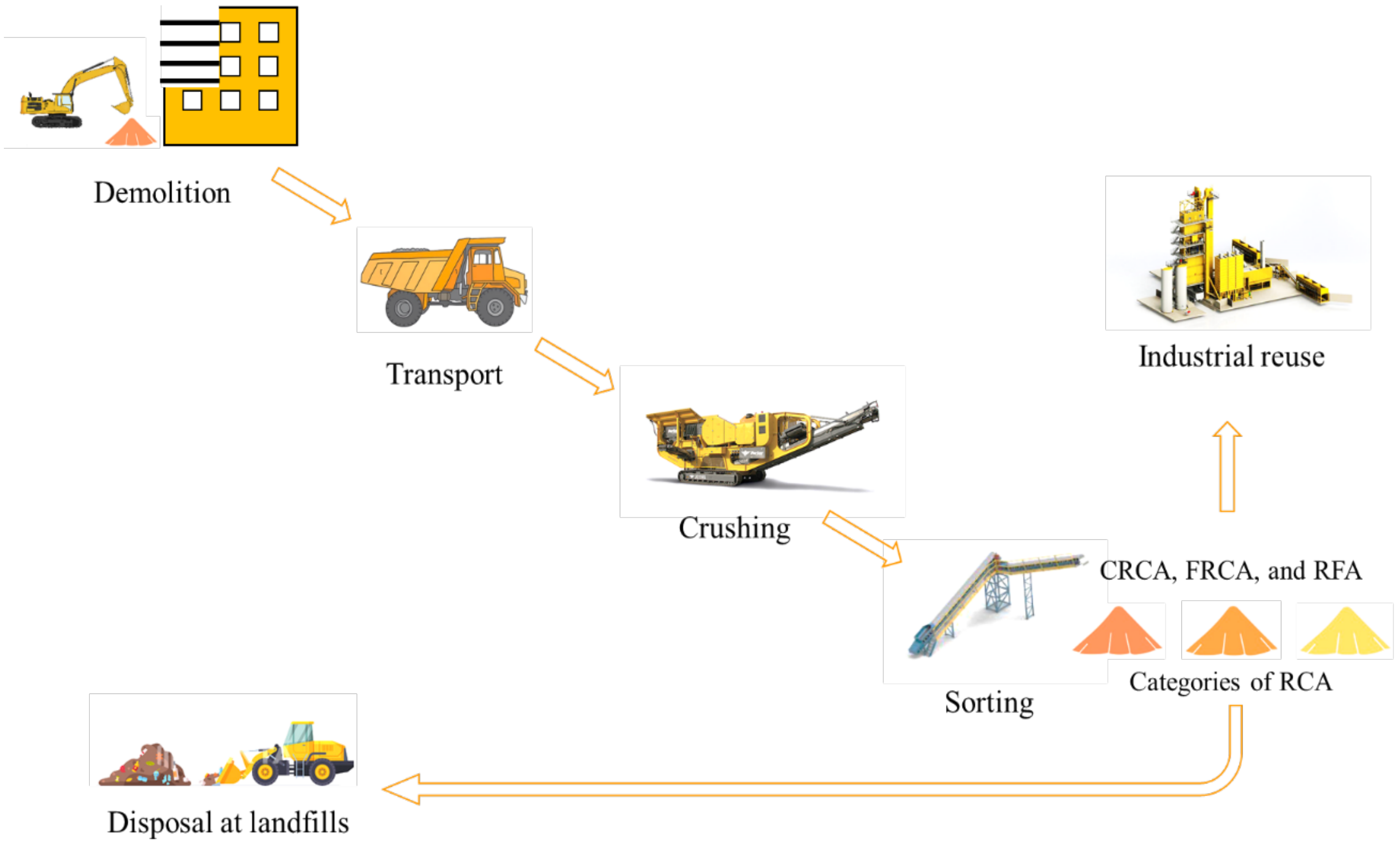




The microhardness of the cement paste in the old mortar of NRCAs was enhanced after the carbonation treatment. Moreover, the microhardness on the new ITZ around the carbonated NRCAs had higher values than that around the non-carbonated NRCAs.

D. Xuan, B. Zhan, **C.S. Poon**, (2016). Cement and Concrete Composites, 65: 67-74.

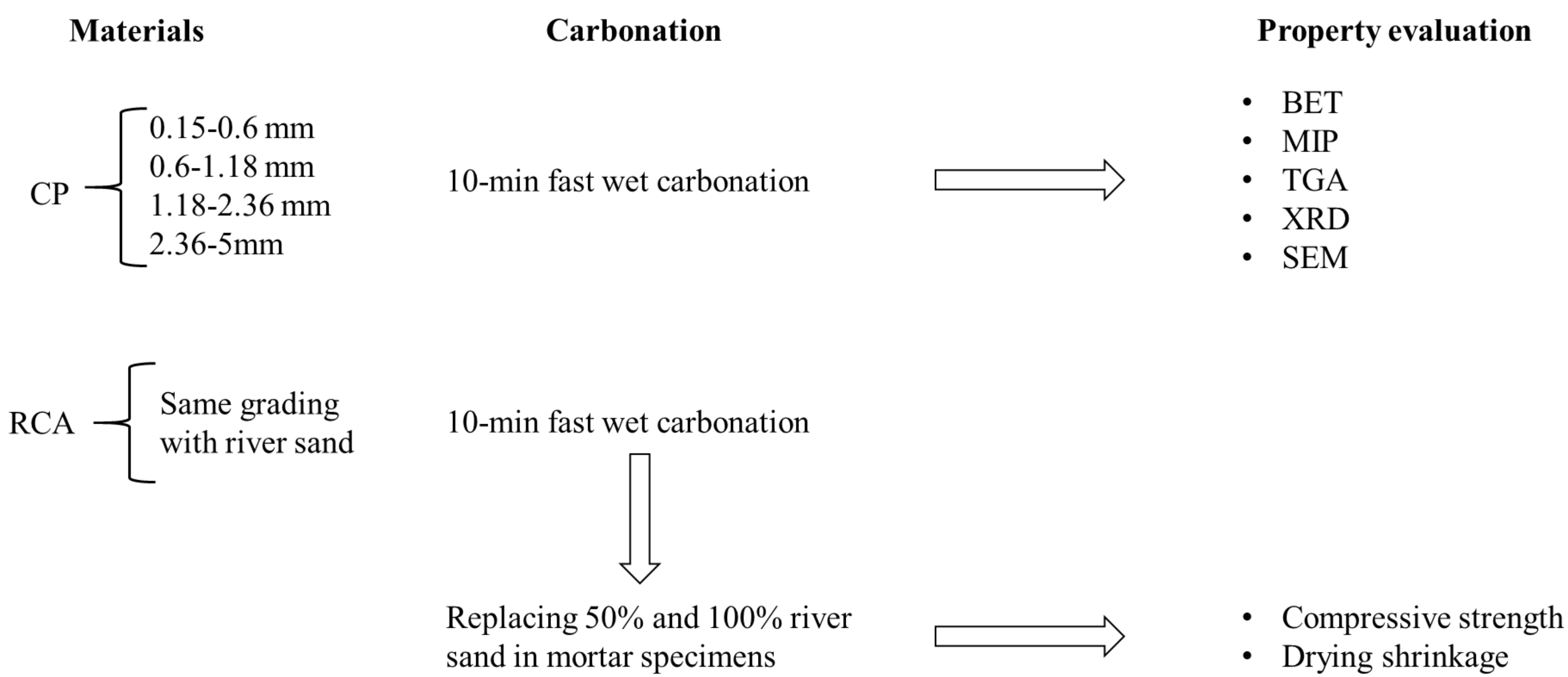
Material Flow of Demolition of Concrete Structures



CRCA-coarse recycled aggregate
FRCA- fine recycled aggregate
RFA- recycled fine powder

Fast wet carbonation for FRCA particles from 0.15-5 mm

Schematic illustration

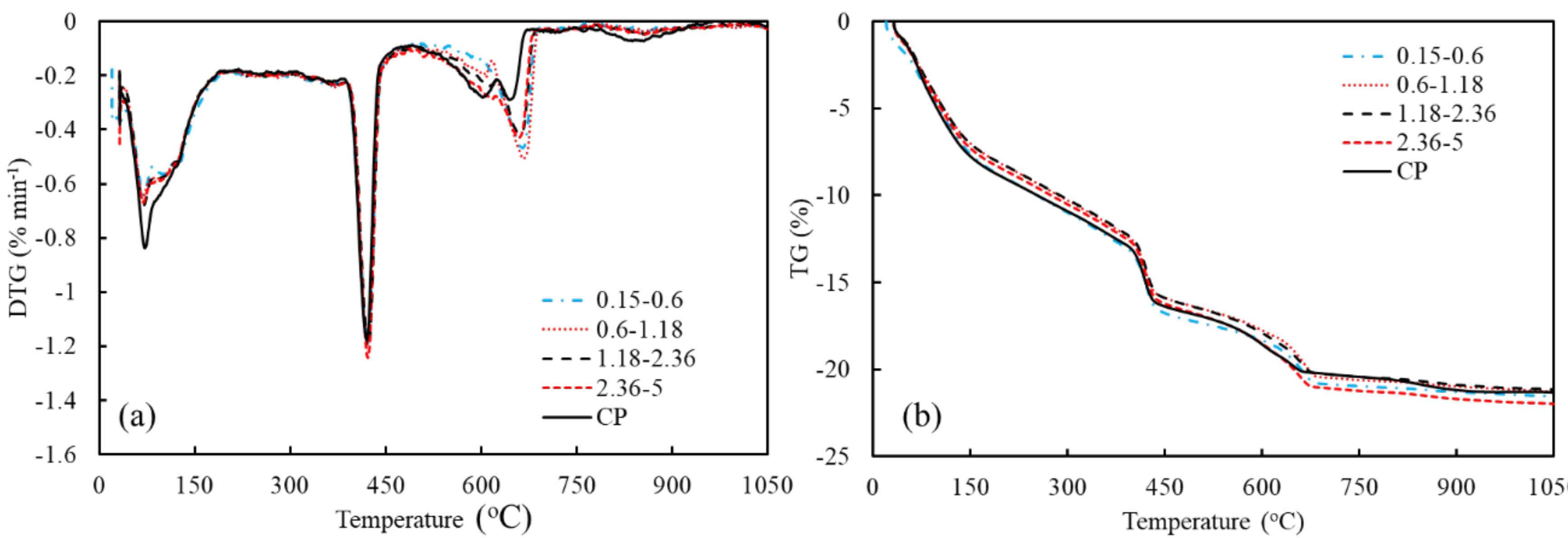


Fang, X.L., Xuan, D.X., Shen, P.L., & Poon, C.S. **Fast enhancement of recycled fine aggregates properties by wet carbonation,** ***Journal of Cleaner Production***, Volume 3131 September 2021 Article number 127867

Fast wet carbonation for FRCA particles from 0.15-5 mm

Changes in carbonation products after wet carbonation

Thermogravimetric analysis



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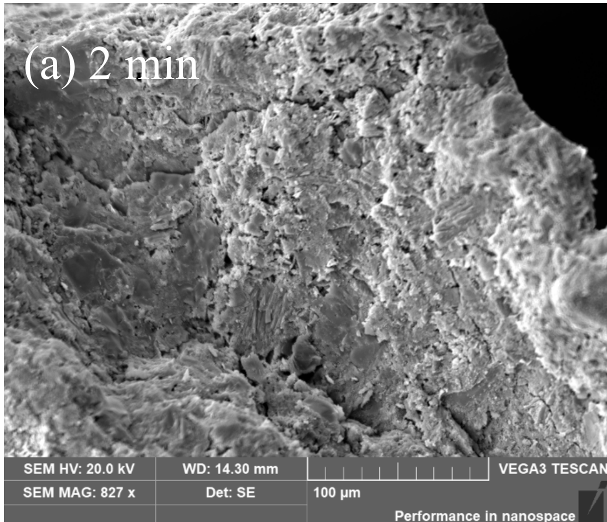
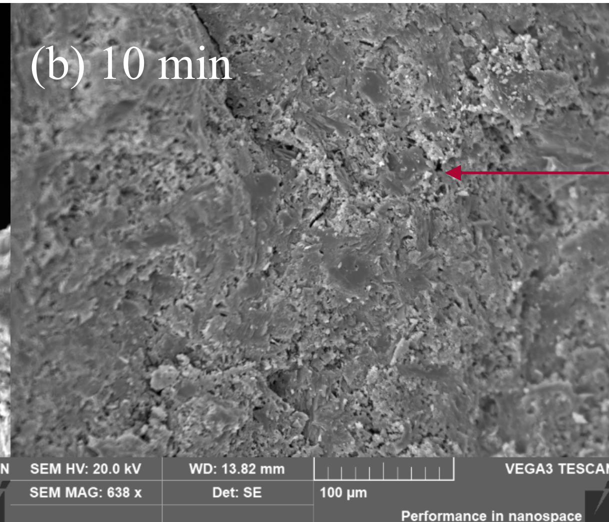
Fast wet carbonation for FRCA particles from 0.15-5 mm

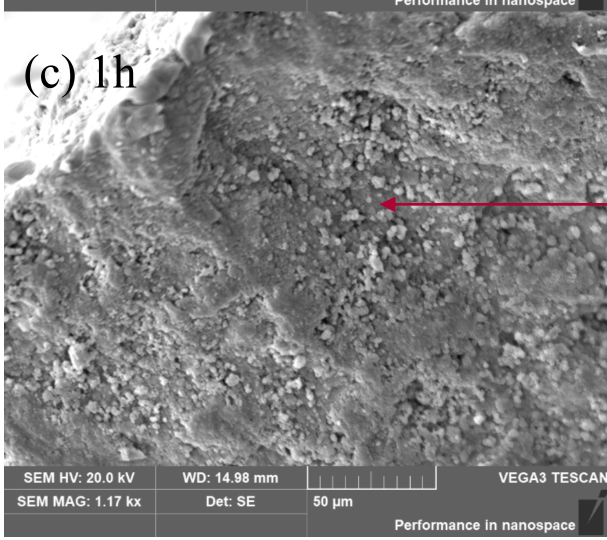
Microscopic analysis

Effect of carbonation time





some carbonation products were noticed after 10 min



After 1h, a lot of carbonation products were observed.

Fast wet carbonation for FRCA particles from 0.15-5 mm

Effect on mortar specimens

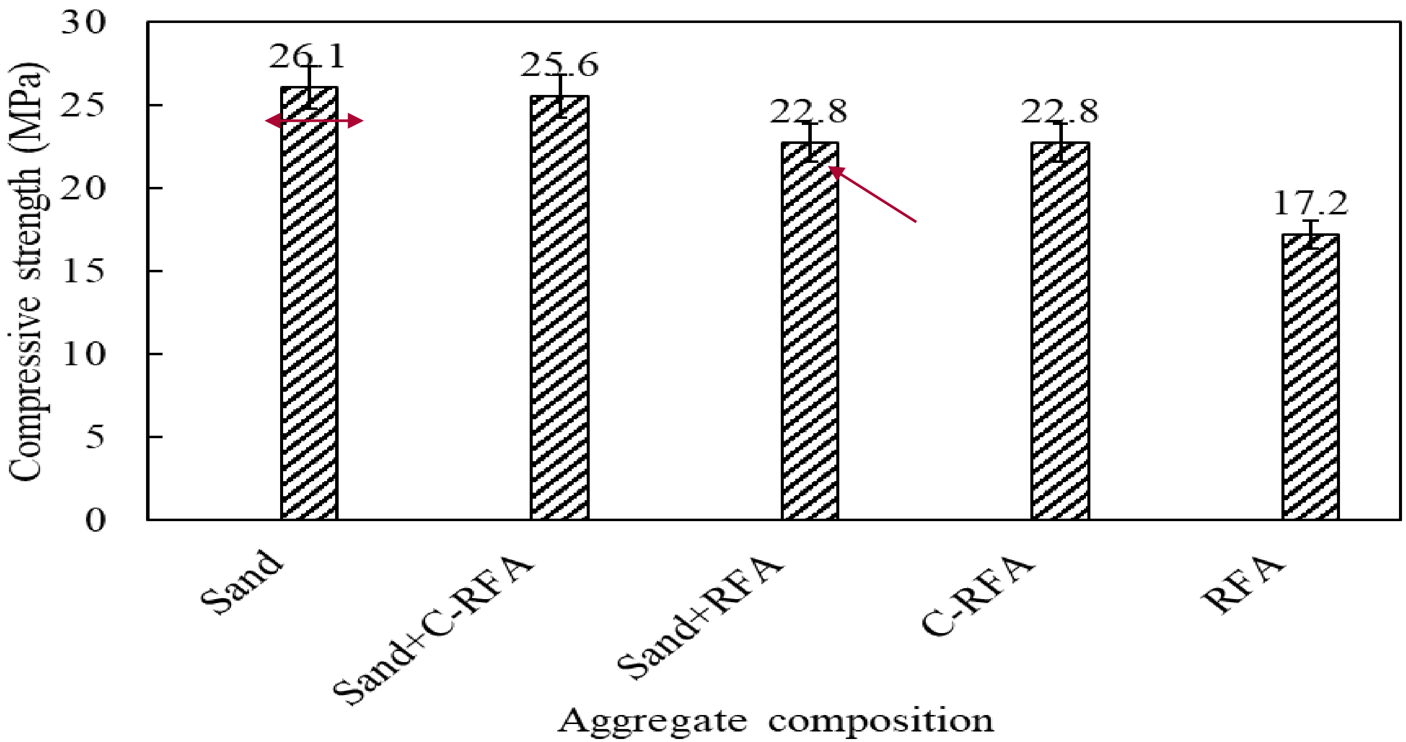
Mixture design

Replacement ratio	River sand	Carbonated RFA	Raw RFA	Water	Cement	Flowability (ASTM C1437-01, 2001)	Adjusted water
0%	1800	0		300	600		11.5
50%	900	900		300	600		69.7
50%	900		900	300	600	200±20 mm	84.1
100%	0	1800		300	600		127.8
100%	0		1800	300	600		156.6

Fast wet carbonation for FRCA particles from 0.15-5 mm

Effect on mortar specimens

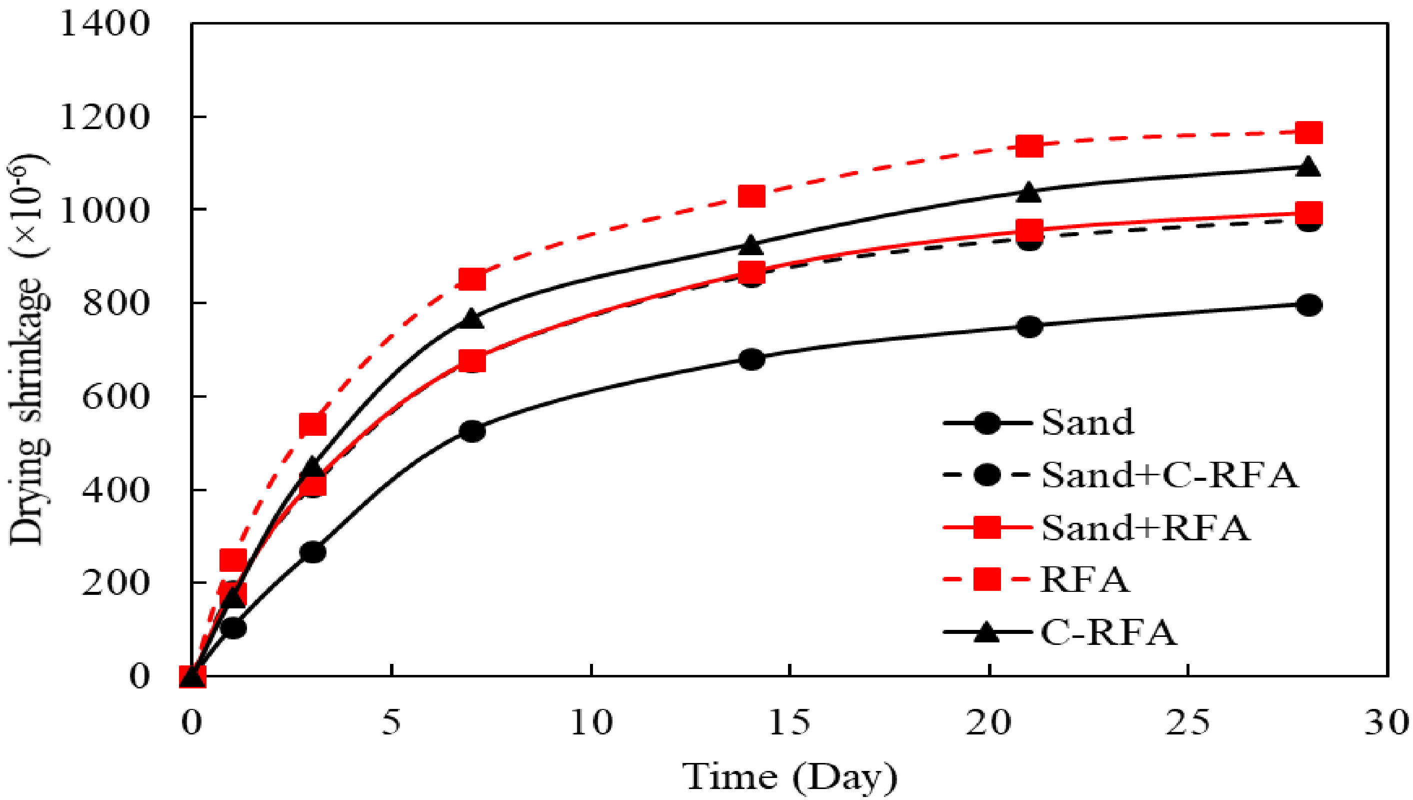
Compressive strength



Fast wet carbonation for FRCA particles from 0.15-5 mm

Effect on mortar specimens

Drying shrinkage



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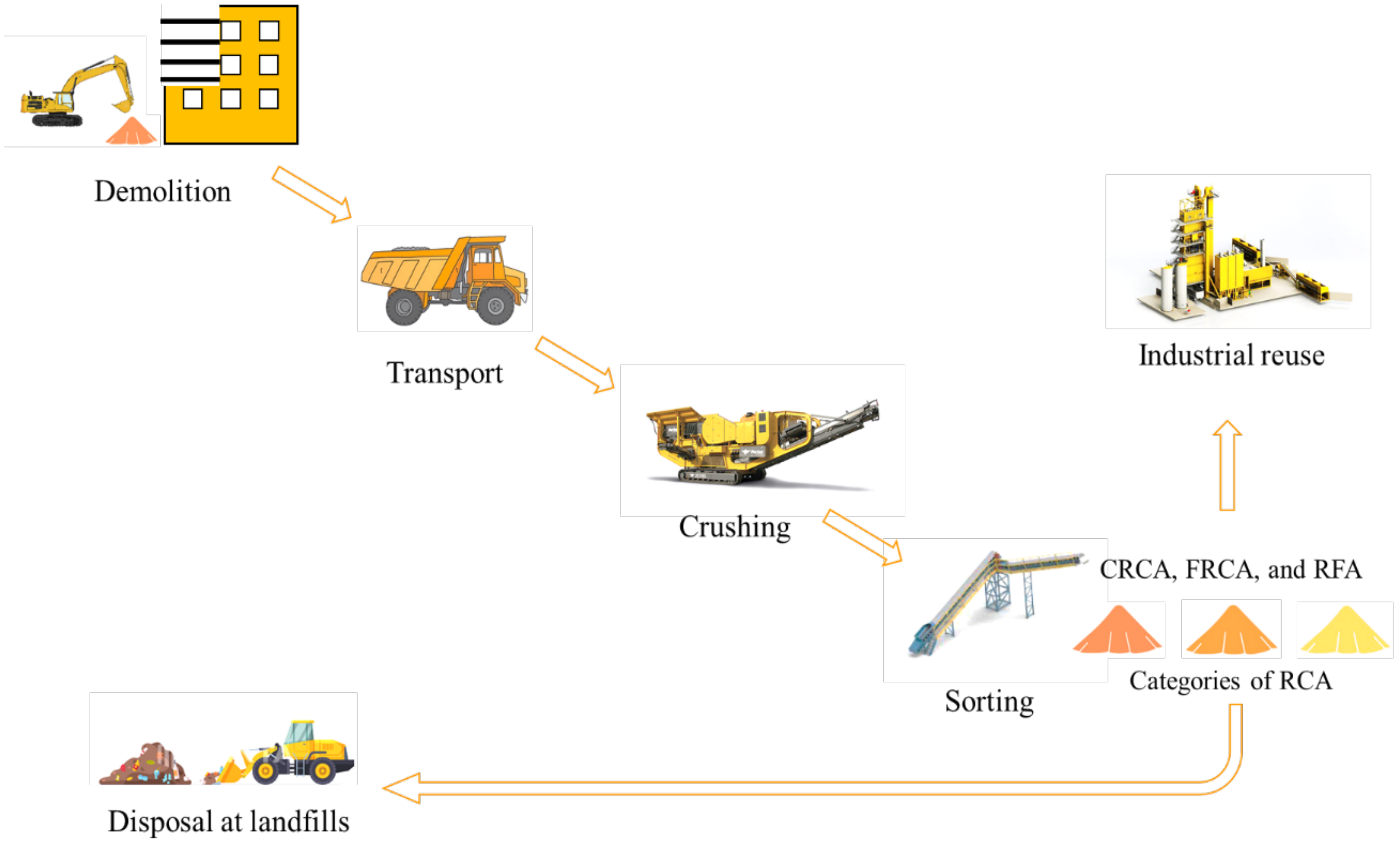
Material Flow of Demolition of Concrete Structures

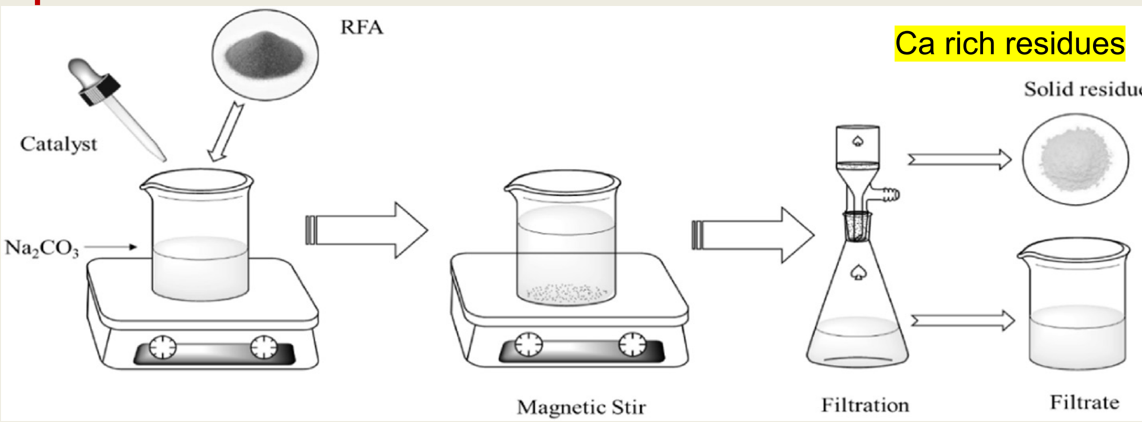


CRCA-coarse recycled aggregate
FRCA- fine recycled aggregate
RFA- recycled fine powder

Preparation of calcium-rich and a silica-rich materials by two-step carbonation (1)

The two-step carbonation process:

Step 1: Extraction of Ca^{2+} and carbonation to form Ca-rich residue

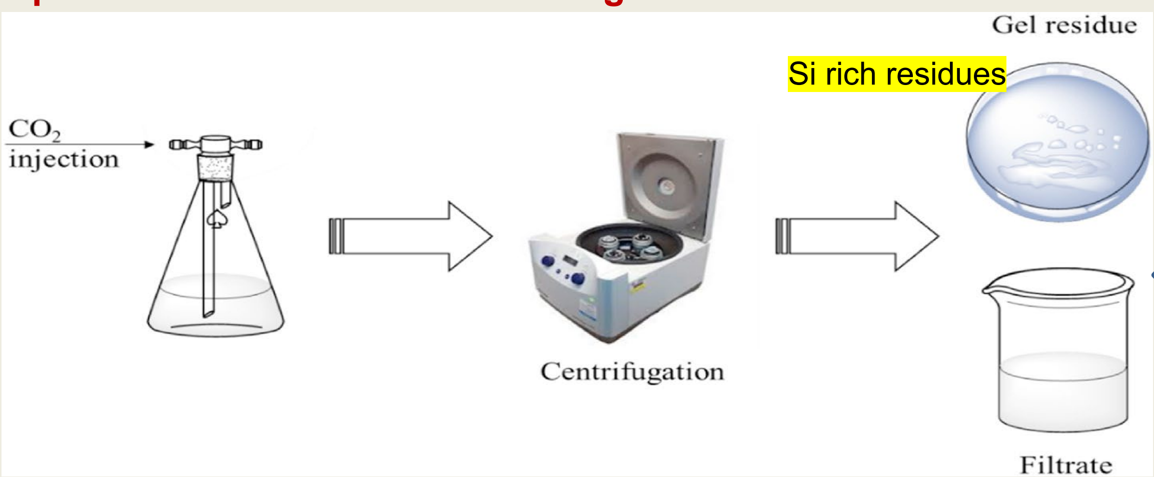


$$Ca(OH)_2 + Na_2CO_3 \xrightarrow{TEA} CaCO_3\downarrow + 2NaOH$$

$$C_xS_yH_z + xNa_2CO_3 \xrightarrow{TEA} xCaCO_3\downarrow + yNa_2SiO_3 + (2x-2y)NaOH + \left(\frac{z-2x+2y}{2}\right)H_2O$$

$$AFm/AFt + \left(\frac{y+3z+a}{2}\right)Na_2CO_3 \xrightarrow{TEA} xCaCO_3\downarrow + yNaAlO_2 + zNa_3[Fe(OH)_6] + aNaOH + bCaSO_4nH_2O + cH_2O$$

Step 2: Carbonation to form Si-rich gel

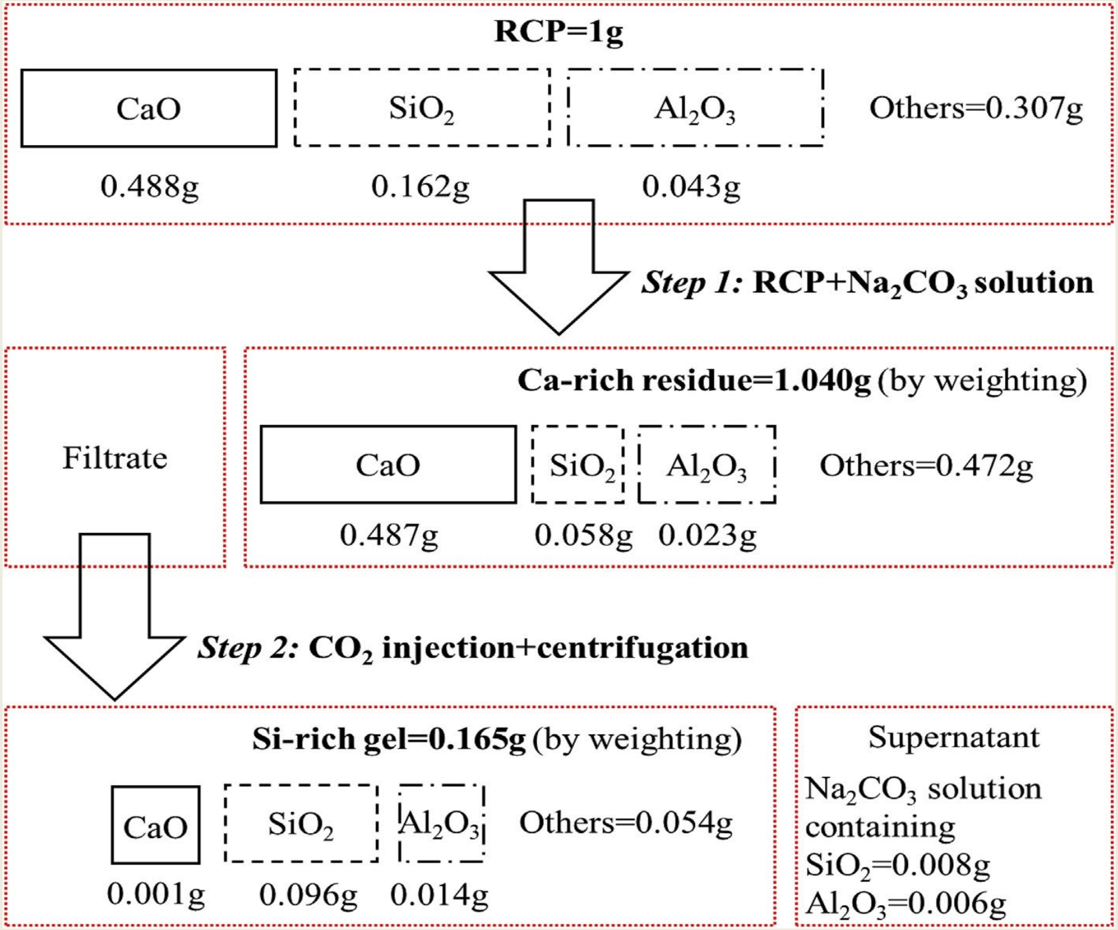


$$Na_2SiO_3 + 2NaAlO_2 + 2CO_2 + (m+n)H_2O \rightarrow SiO_2nH_2O + Al_2O_3mH_2O + 2Na_2CO_3$$

Xiaoliang Fang, Dongxing Xuan, Baojian zhan, **Poon C. S.** (2021) Journal of Cleaner Production, 290: 125192

Preparation of calcium-rich and a silica-rich materials by two-step carbonation (2)

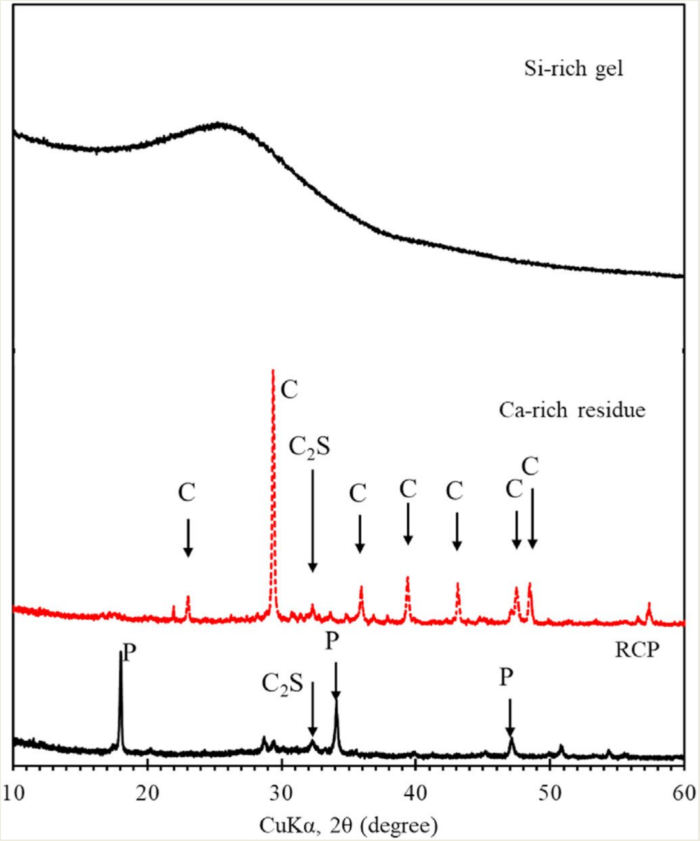
➢ CO_2 sequestration and production of value added products



Xiaoliang Fang, Dongxing Xuan, Baojian zhan, **Poon C. S.** (2021) Journal of Cleaner Production, 290: 125192

Preparation of calcium-rich and a silica-rich materials by two-step carbonation (5)

➢Compositions of Si-rich and Ca-rich materials

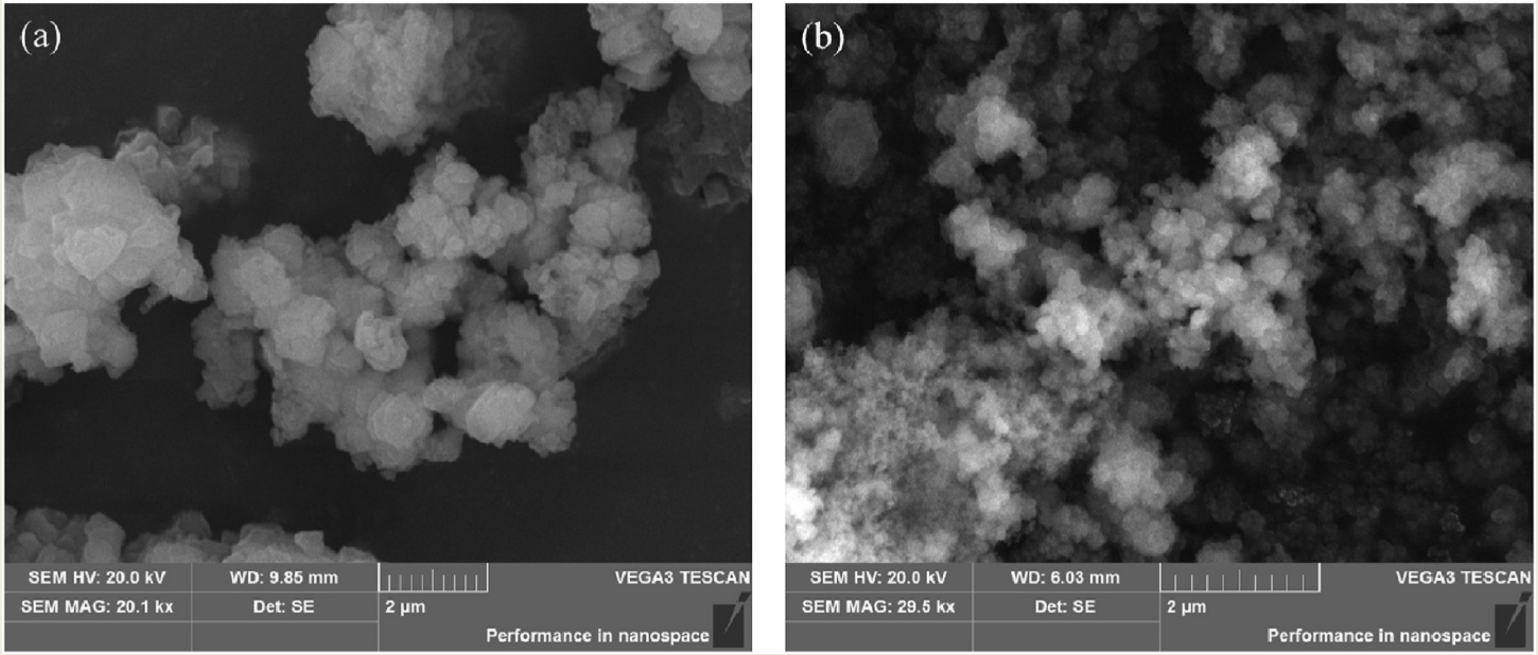


The Ca-rich residue mainly consisted of calcite；

Xiaoliang Fang, Dongxing Xuan, Baojian Zhan, **Poon C. S.** (2021) Journal of Cleaner Production, 290: 125192

Preparation of calcium-rich and a silica-rich materials by two-step carbonation (6)

➢Morphologies of Si-rich and Ca-rich materials



SEM image of (a) Ca-rich residue, and (b) Si-rich gel.

- The Ca-rich residue mainly consisted of crystalline calcite；
- The Si-rich gel was in the form of agglomerated spherical particles

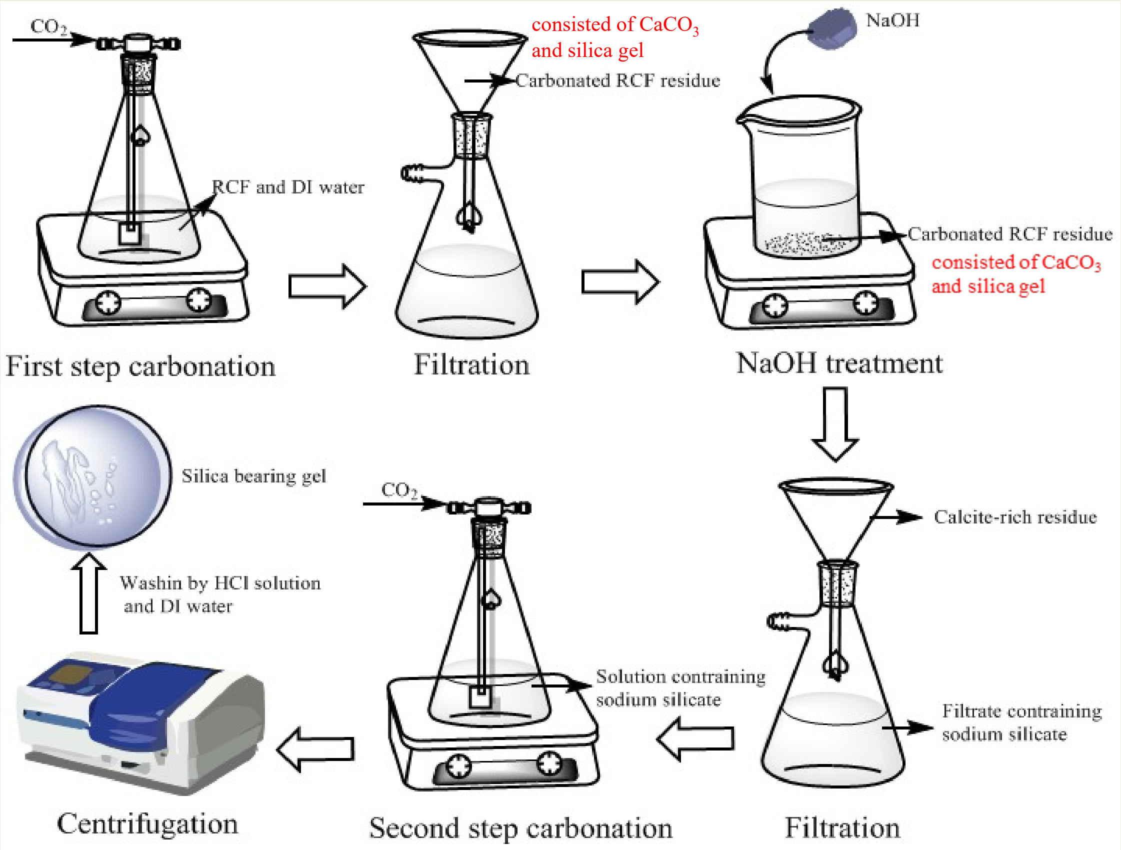
Xiaoliang Fang, Dongxing Xuan, Baojian zhan, **Poon C. S.** (2021)Journal of Cleaner Production, 290: 125192

Preparation of nano-silica by another two-step wet carbonation (1)

The two-step carbonation process

Step 1: The wet carbonation of Fine RCA in water

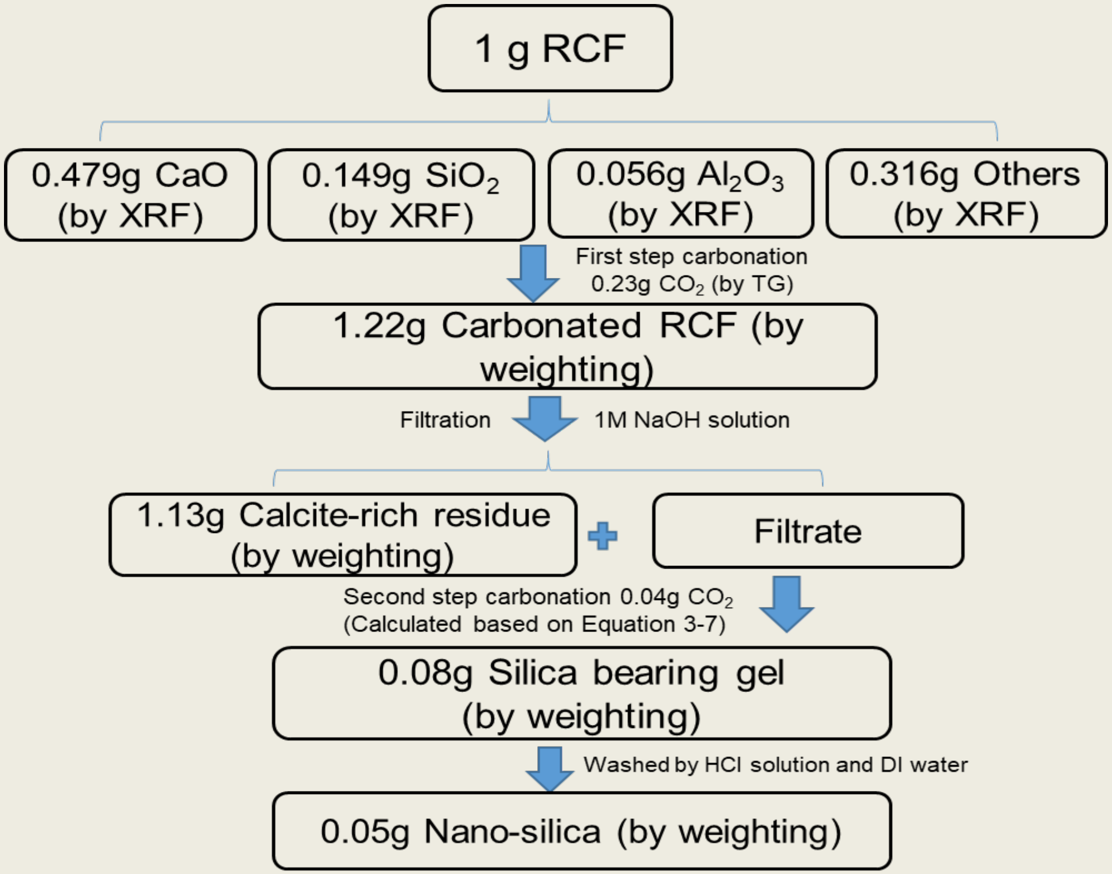
Step 2: Extraction of silica phase by wet carbonation



Shen Peiliang, Jian-xin Lu, **Poon C. S.** (2021). Synthesis of amorphous nano-silica from recycled concrete fines by two-step wet carbonation Cement and Concrete Research, accepted

Preparation of nano-silica by two-step wet carbonation (2)

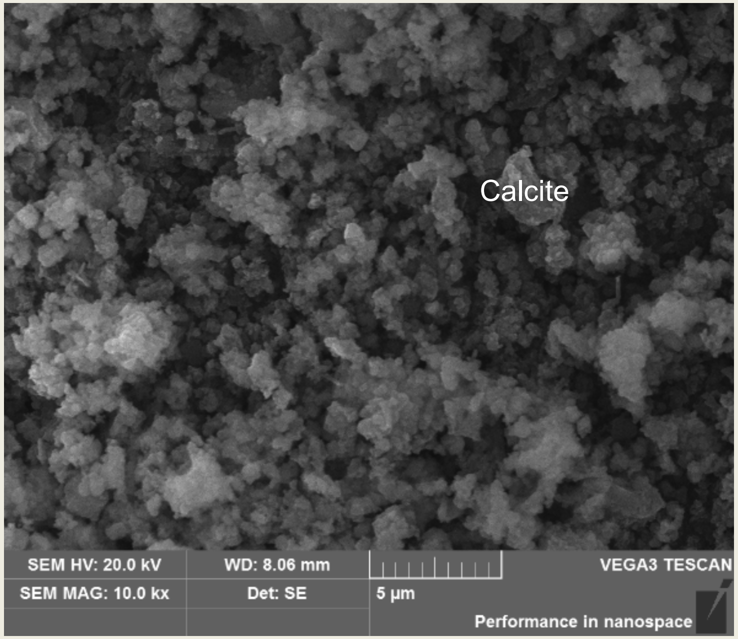
- CO_2 sequestration and production:0.27 g CO_2 per 1 g RCF

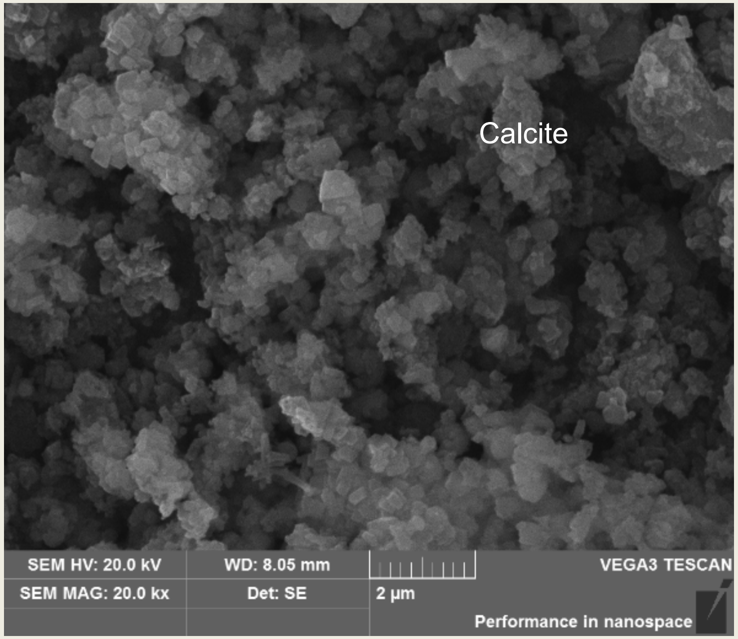


Shen Peiliang, Jian-xin Lu, **Poon C. S.** (2021). Cement and Concrete Research, accepted

Preparation of nano-silica by two-step wet carbonation

➢Microstructure of carbonation products after first step wet carbonation





SEM images of RCF after 60 min carbonation

- Many crystalline calcite grains with a size of less than 5 μm could be observed;
- Some amorphous phases can be observed the surface of the calcite;

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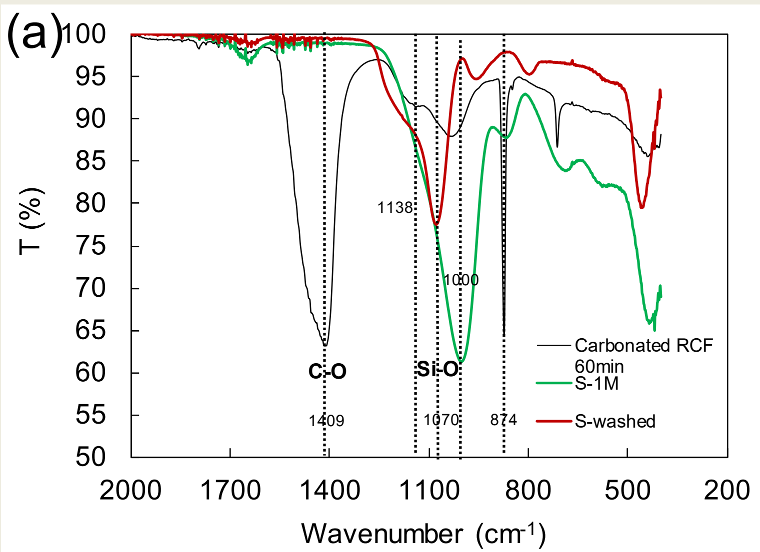
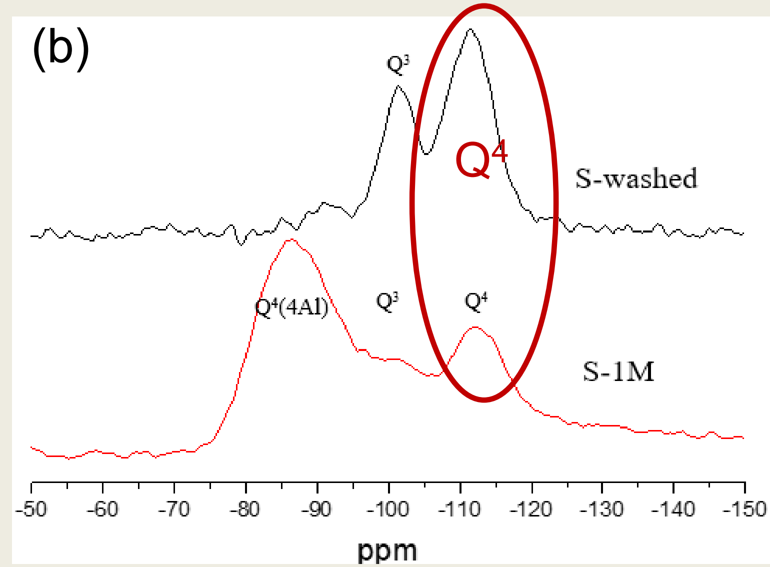
Preparation of nano-silica by two-step wet carbonation

➢Compositions of products after second step wet carbonation process





The detailed composition of silica bearing gel: (a) FTIR results, (b) NMR results

- The wavenumber of Si-O was increased to 1070 cm^{-1} indicated the presence of silica;
- The Q^4 units were the dominated in S-washed, which indicated that it was a kind of highly polymerized amorphous silica.

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Table The chemical composition of silica bearing gel and residue

NO.	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3	P_2O_5
S-1M	12.8	0.202	24.9	60.6	1.01	0.264	0.121	0.055
S-2M	15.5	/	22.4	56.9	0.854	3.98	0.108	/
S-5M	11.03	0.499	25.6	59.7	0.384	1.40	0.125	0.17
S-washed	/	/	0.56	98.8	0.16	0.29	0.072	/
Residue	5.5	1.05	3.32	14.2	0.173	70.3	3.43	0.165

- An amorphous silica with a high purity of 98.8% could be prepared.

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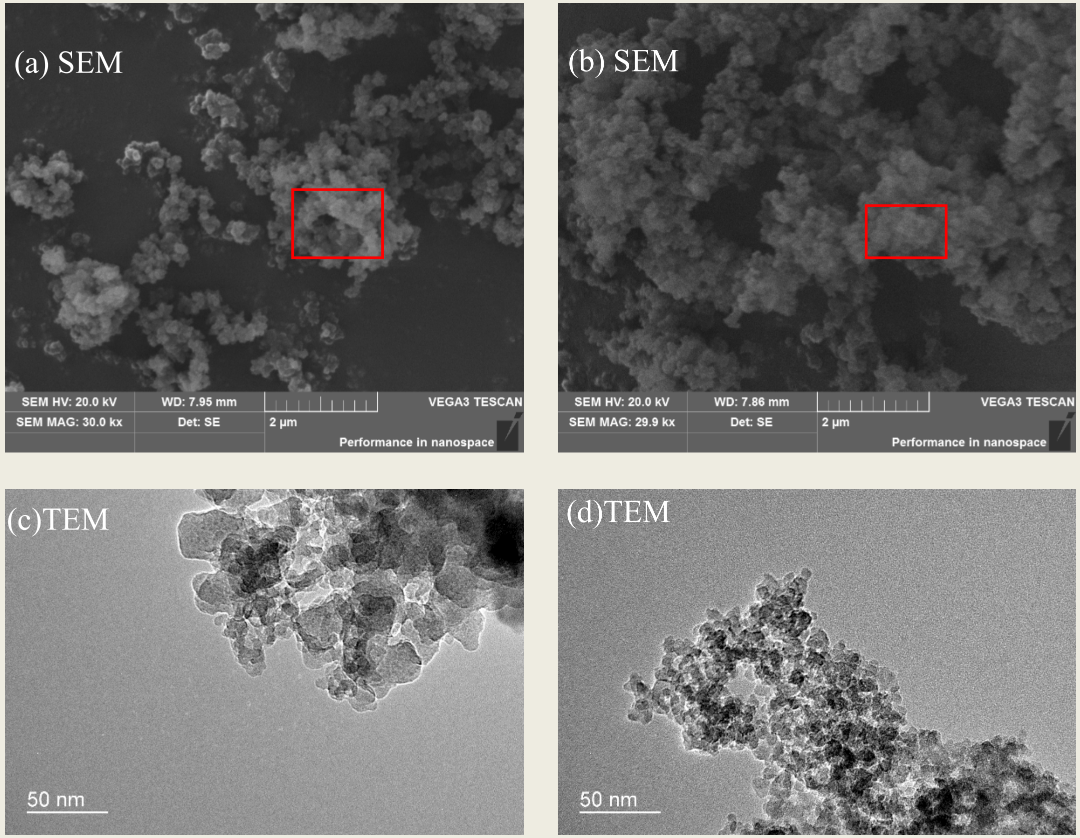
SEM/TEM images of nano silica



S-1M S-washed

Figure 12 The SEM and TEM images of silica bearing gel

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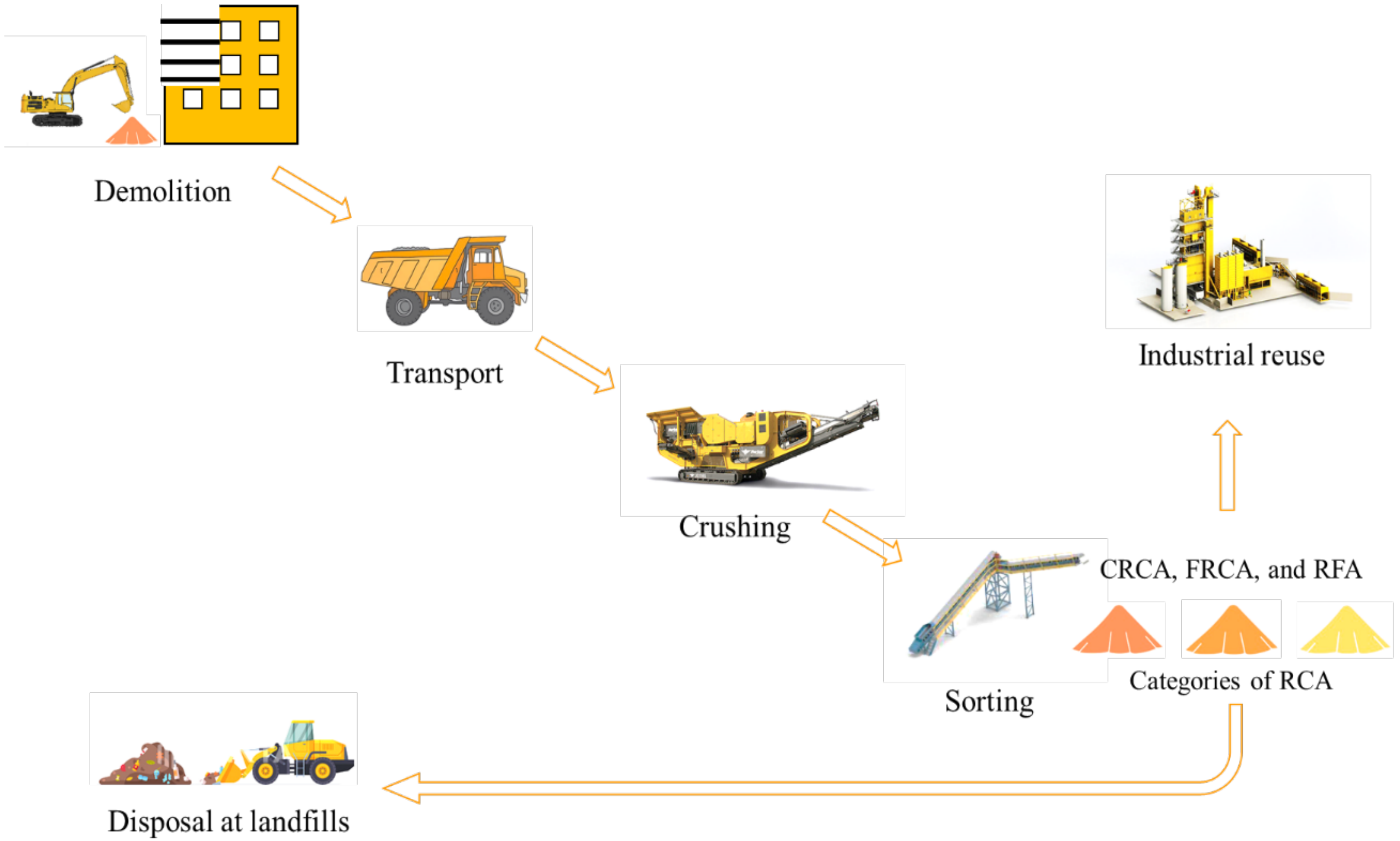
Material Flow of Demolition of Concrete Structures



CRCA-coarse recycled aggregate
FRCA- fine recycled aggregate
RFA- recycled fine powder

Conclusion

- Accelerated carbonation can be utilized for valorization of concrete waste
- After carbonation, coarse fractions can be upcycled for use in concrete
- Waste cement fine powder can be upcycled to calcite and silica
- Waste CO_2 can also be sequestrated

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Thank You!

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