Recycled Aggregate Concrete: Durability related properties – Interest for precast concrete product

P. Rougeau, L. Schmitt, J. Mai-Nhu
CERIB

Impacts énergétiques, environnementaux et sanitaires

RECYBETON

AUGC Association Universitaire de Génie Civil

ECOLE FRANCAISE DU BETON

IREX Institut pour la recherche appliquée et l'expérimentation en génie civil

ANR

Context

Aggregate resources in France

Recycled aggregate characteristics

Durability related properties

Reuse of recycled aggregate in precast products

Conclusion

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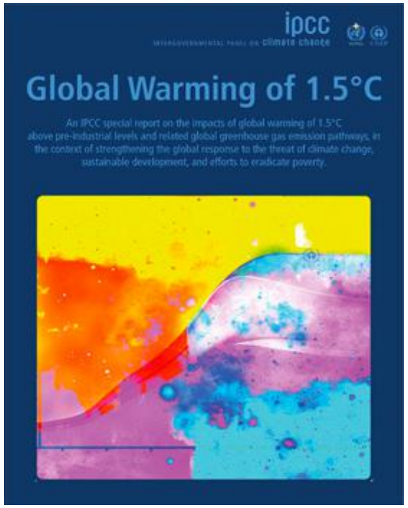
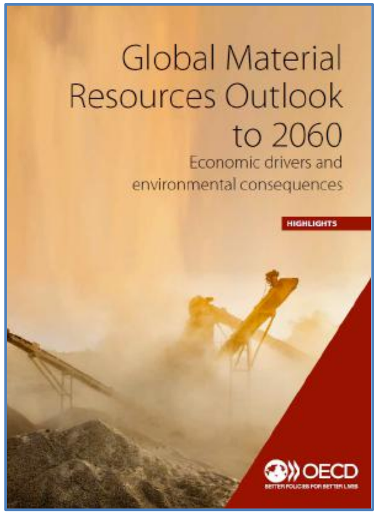
Re-use of aggregate: an old story….

Pompéï

PARIS2015 COP21

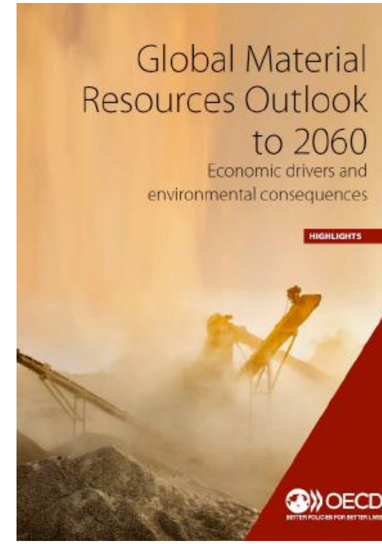
COP24·KATOWICE 2018
UNITED NATIONS CLIMATE CHANGE CONFERENCE



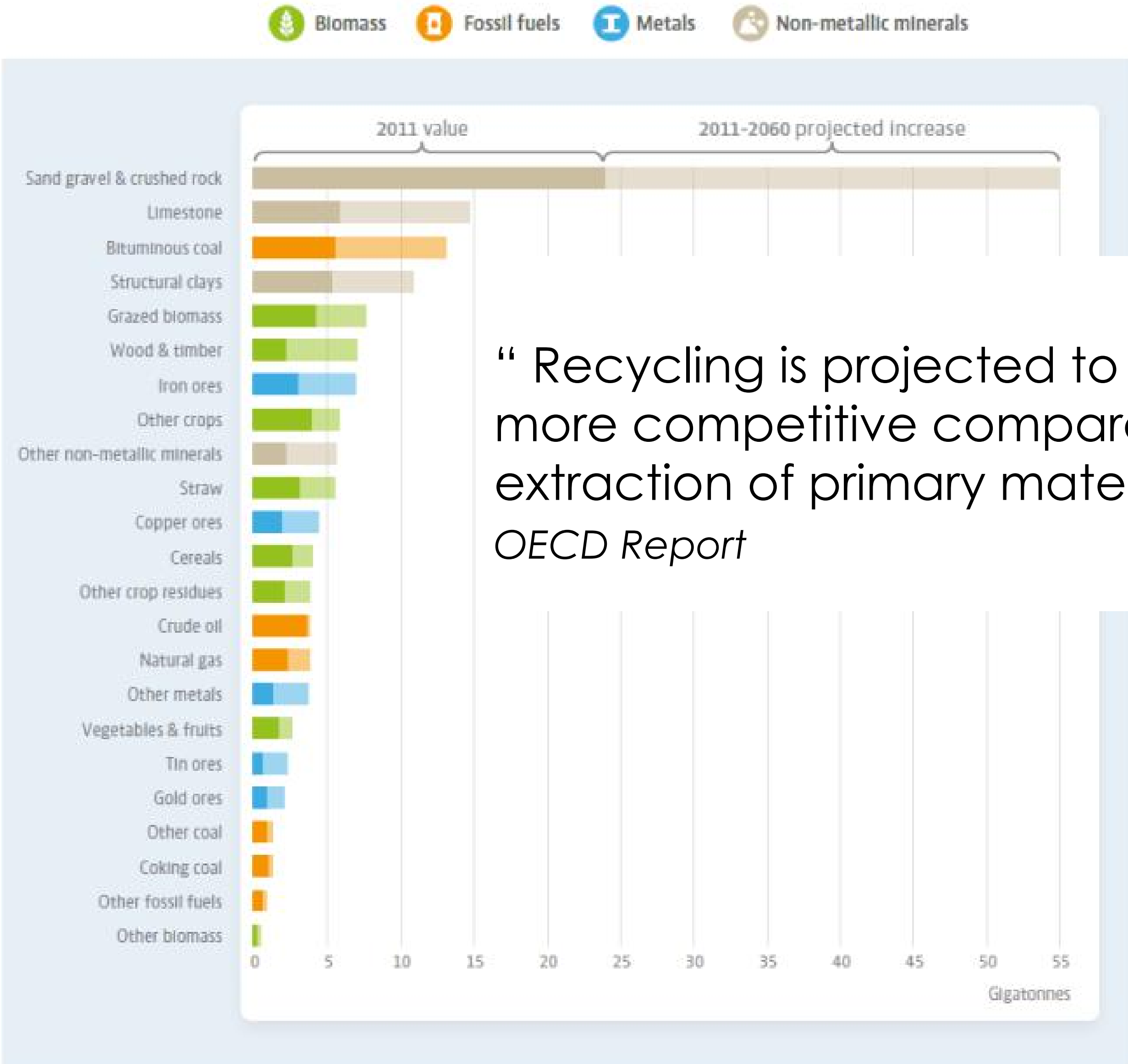


“Our objective has to be achieving a circular economy where we maintain the value of products and materials for as long as possible and we minimise waste generation. The challenge is to create more value from fewer natural resources,”

OECD Deputy Secretary-General Rintaro Tamaki.

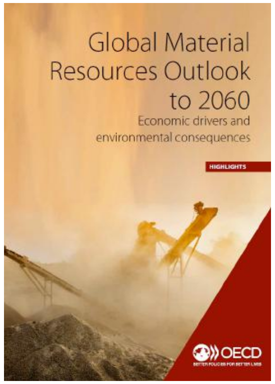


OCDE Report - October 2018



" Recycling is projected to become more competitive compared to the extraction of primary materials »

OECD Report



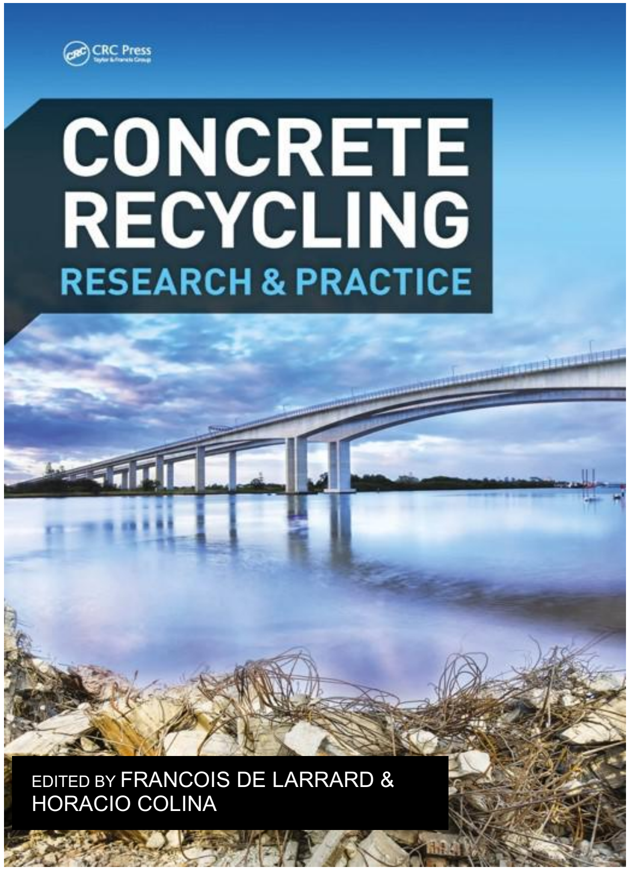
OCDE Report - October 2018

RECYBETON

- Context
- **Recybéton Project**
- Recycled aggregate characteristics
- Durability related properties
- Reuse of recycled aggregate in precast products
- Conclusion

Next presentation…

RECYBETON. A French National R&D project on Complete Recycling of Concretes - Horacio Colina



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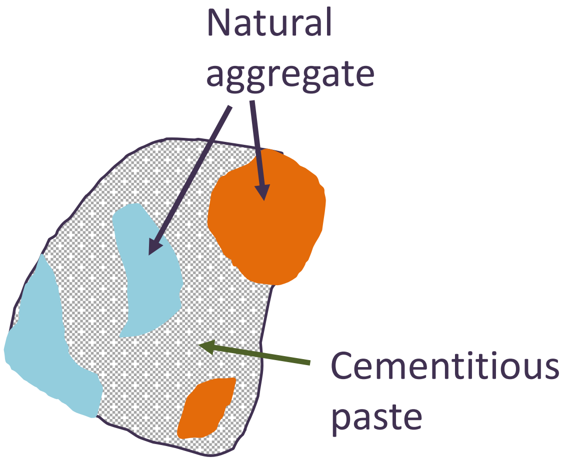

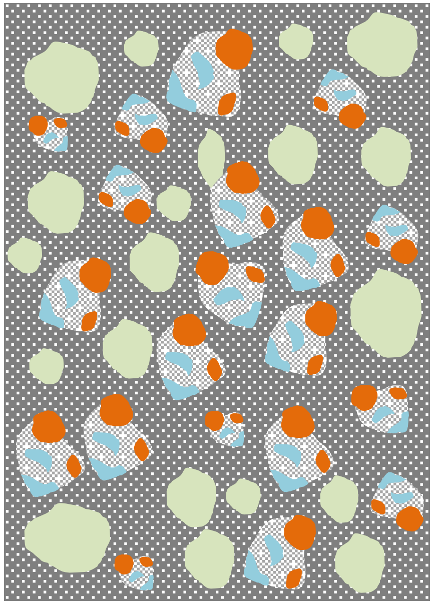

Comparatively to (good) natural rock:

- Less natural rock and cementitious paste
- Possible other material coming from deconstruction
- Lower mechanical strength
- More variability
- Higher porosity and water asborption
- More water exchange at fresh and hardening state

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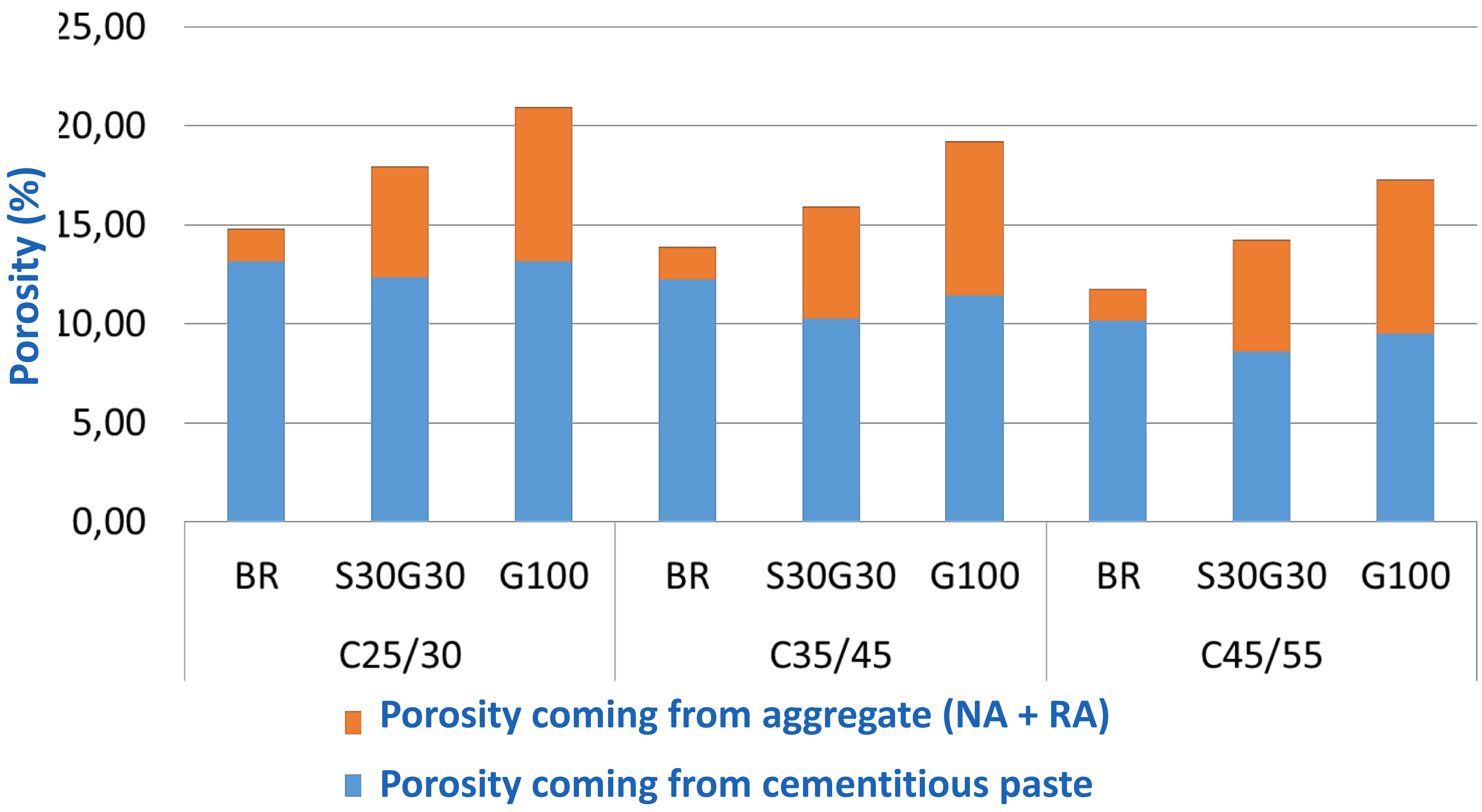
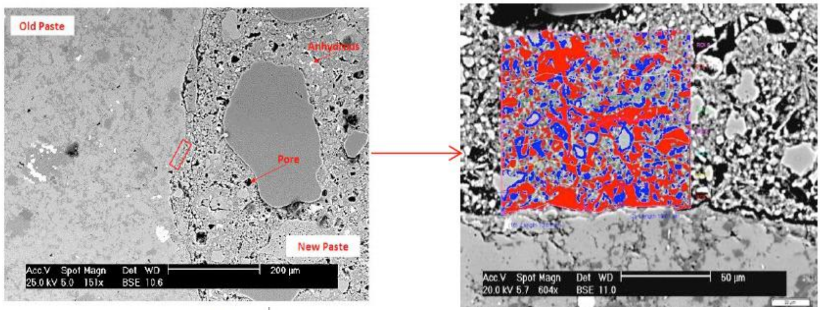
- **Microstructure**:
  - E Garcia-Diaz, G Le Saout (C2MA – Mines d'Alès)
  - A Djerbi Tegguer (IFSTTAR)
- **Durability-transport properties:**
  - A Djerbi Tegguer, M. Saillio (IFSTTAR)
  - L. Schmitt, J. Mai-Nhu, P. Rougeau (CERIB)
- **Risks due to ettringite and thaumasite formation:**
  - N Leklou, O Amiri (GeM, Université de Nantes)
  - JM Mechling, R. Trauchessec, A. Lecomte (Institut Jean Lamour, Université de Lorraine)
  - I Moulin, T. Lenormand, (LERM)
- **Resistance to freeze/thaw cycles:**
  - S. Omary, E. Ghorbel, G. Wardeh (L2MGC, Université de Cergy-Pontoise)
  - L. Schmitt, J. Mai-Nhu, P. Rougeau (CERIB)
- **Alkali-silica reactions :**
  - JM Mechling, A. Lecomte (Institut Jean Lamour, Université de Lorraine)
  - D Bulteel (IMT Lille Douai)
  - M Cyr (LMDC, Université de Toulouse)

MIX PROPORTION OF CONCRETES

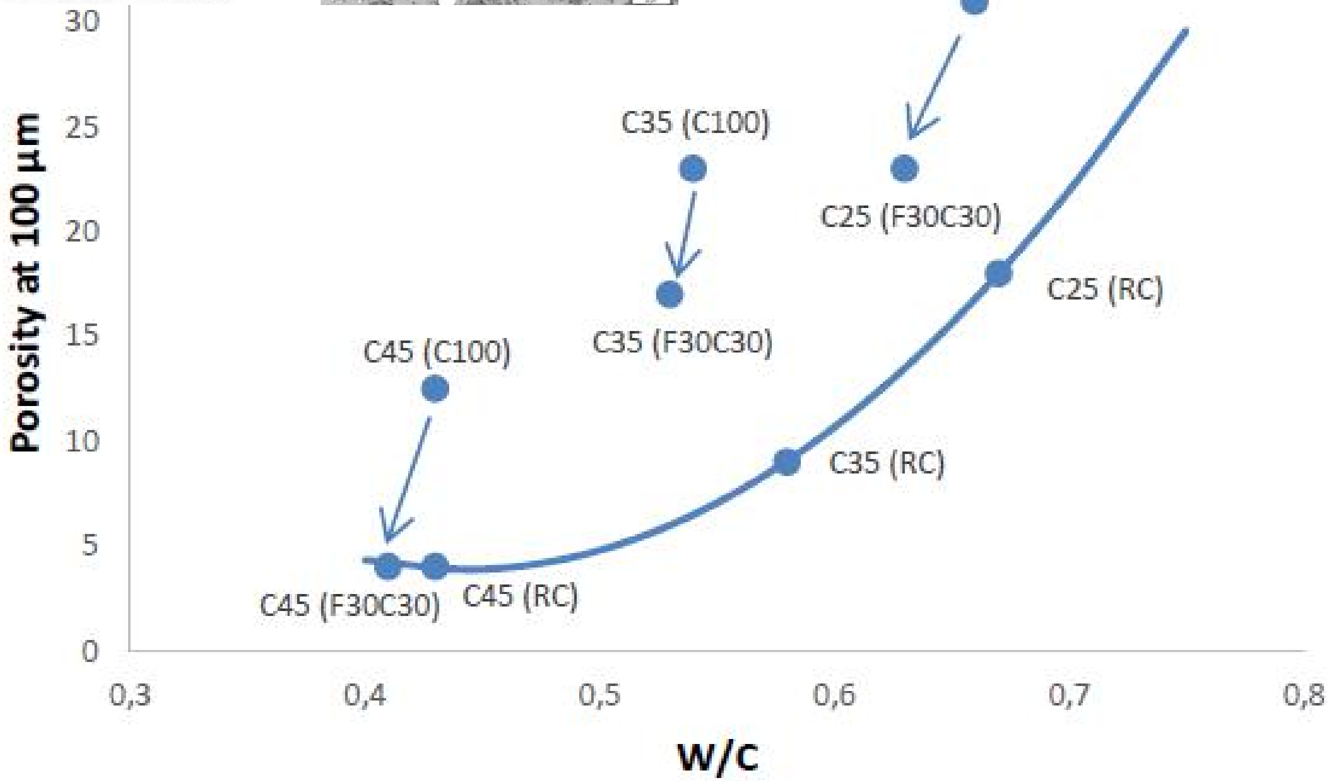
	C25/30			C35/45			C45/55		
	NAC	F30C30	C100	NAC	F30C30	C100	NAC	F30C30	C100
Water (l/m^3)	184	177	176	178	158	172	168	148	150
CEM II/A-L 42,5 N (kg/m^3)	267	282	279	299	324	336	390	371	369
Filler (kg/m^3)	45	49	70	58	44	53	100	65	73
FNA (0/4) (kg/m^3)	772	492	794	769	495	782	732	483	775
FRA (0/4) (kg/m^3)	0	233	0	0	216	0	0	229	0
NCA (4/10) (kg/m^3)	264	167	0	264	169	0	250	164	0
RCA (4/10) (kg/m^3)	0	151	161	0	143	158	0	148	157
NCA (6,3/20) (kg/m^3)	811	539	0	808	546	0	769	529	0
RCA (10/20) (kg/m^3)	0	167	691	0	164	682	0	162	676
Superplasticizer (kg/m^3)	0.14	0.13	0.08	0.29	0.66	0.25	1.23	1.28	0.92
w/eq binder	0.57	0.54	0.53	0.49	0.46	0.47	0.34	0.35	0.36
$F_{cm,28}$ (MPa)	31.8	32.4	29.4	40.7	46.6	39.8	61.4	58.8	51.2

Water porosity



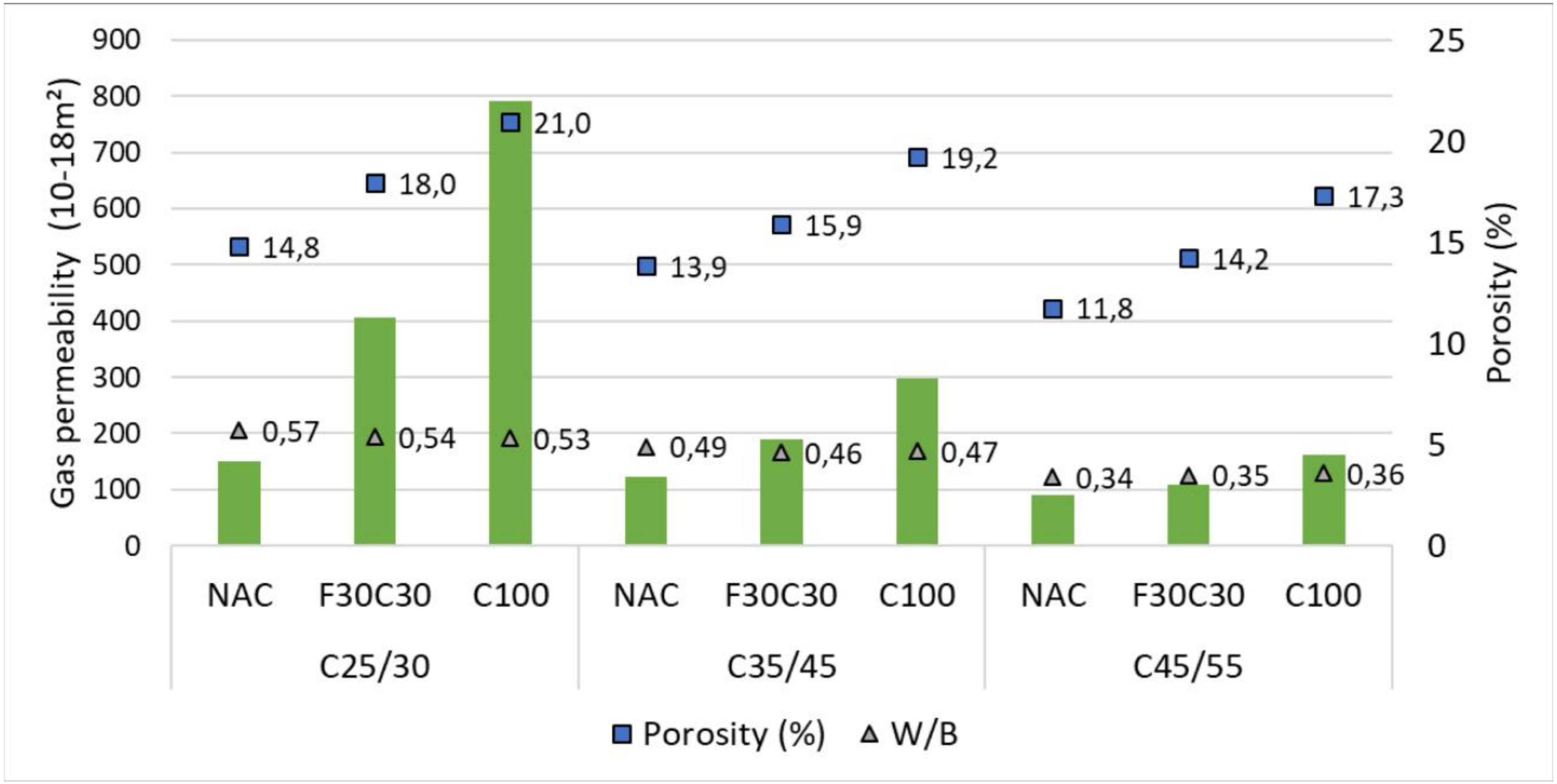


Interface Transition Zone (ITZ) of RAC



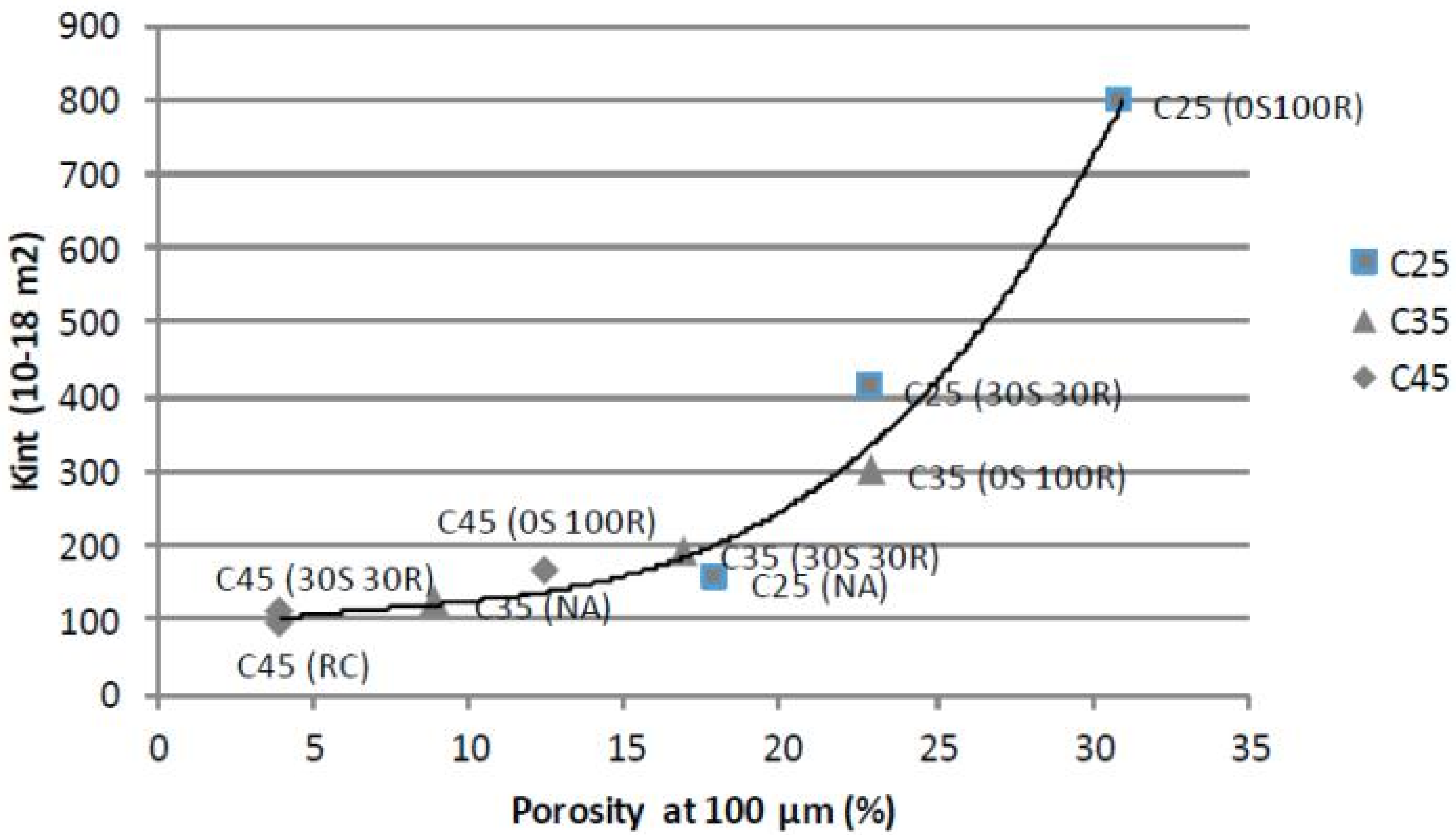
Porosity of the cementitious paste at 100 µm from the aggregate *(E. Garcia Diaz et al., 2018)*

Gas permeability

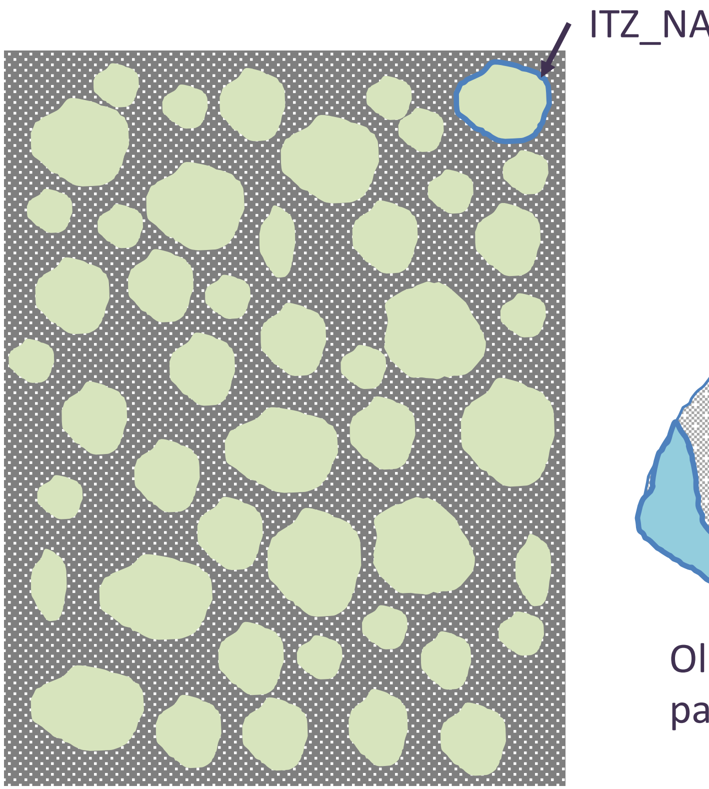


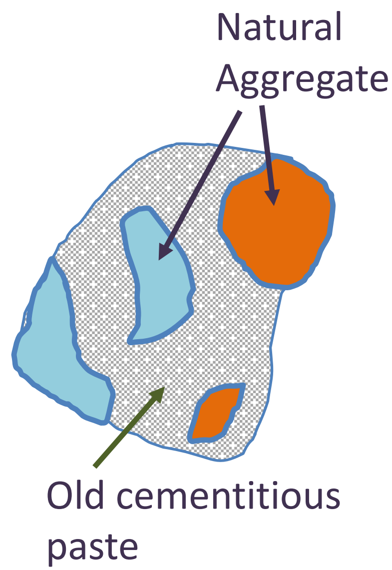
Gas permeability vs porosity at 100 µm (ITZ)

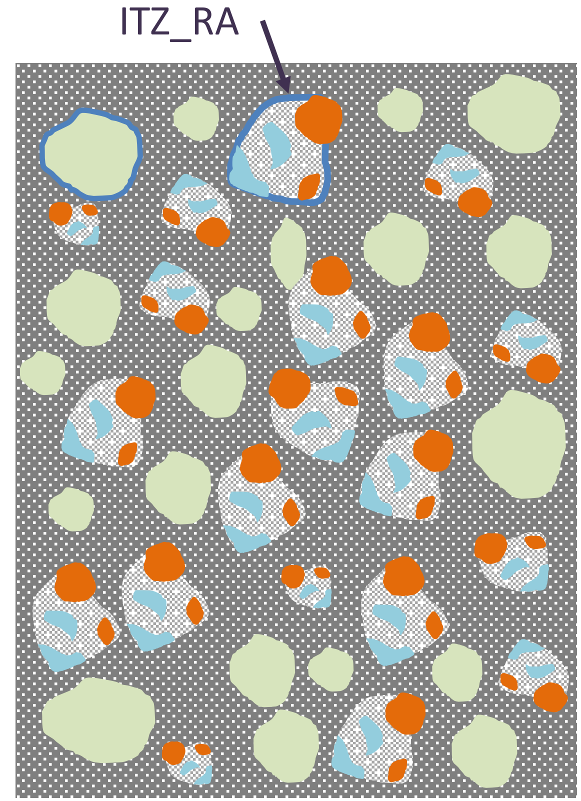
(E. Garcia Diaz et al., 2018)



CHLORIDE MIGRATION







Concrete with Natural Aggregate (NA)

Recycled Aggregate (RA)

Concrete with NA and RA

$$D_e = v_{paste}D_{paste} + v_{NA}D_{NA} + v_{ITZ\_NA}D_{ITZ\_NA}$$

$$\neq v_{paste}D_{paste} + v_{ITZ\_NA}D_{ITZ\_NA}$$

$$D_e = v_{paste}D_{paste} + v_{NA}D_{NA} + v_{RA}D_{RA} + v_{ITZ\_NA}D_{ITZ\_NA} + v_{ITZ\_RA}D_{ITZ\_RA}$$

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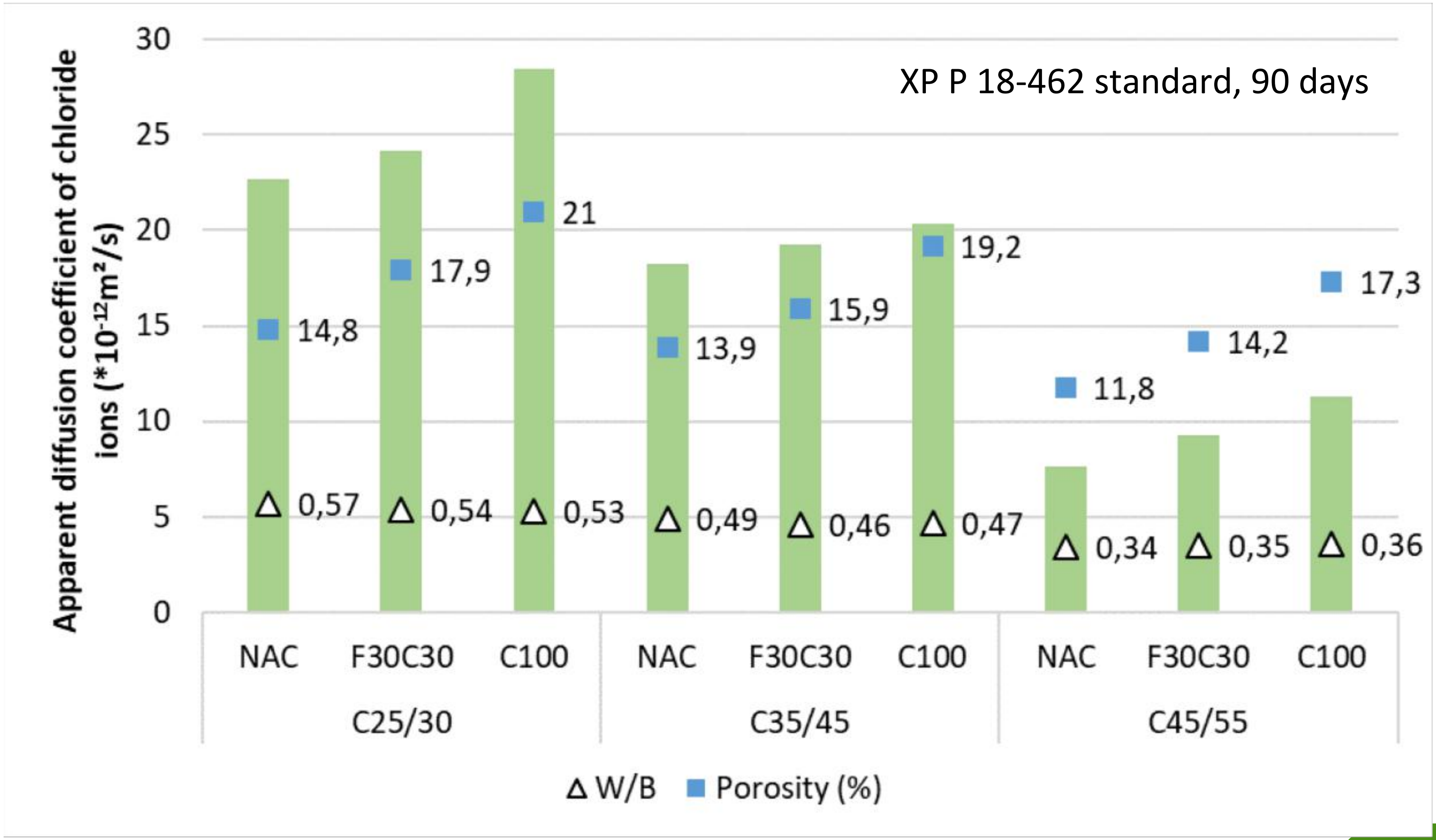
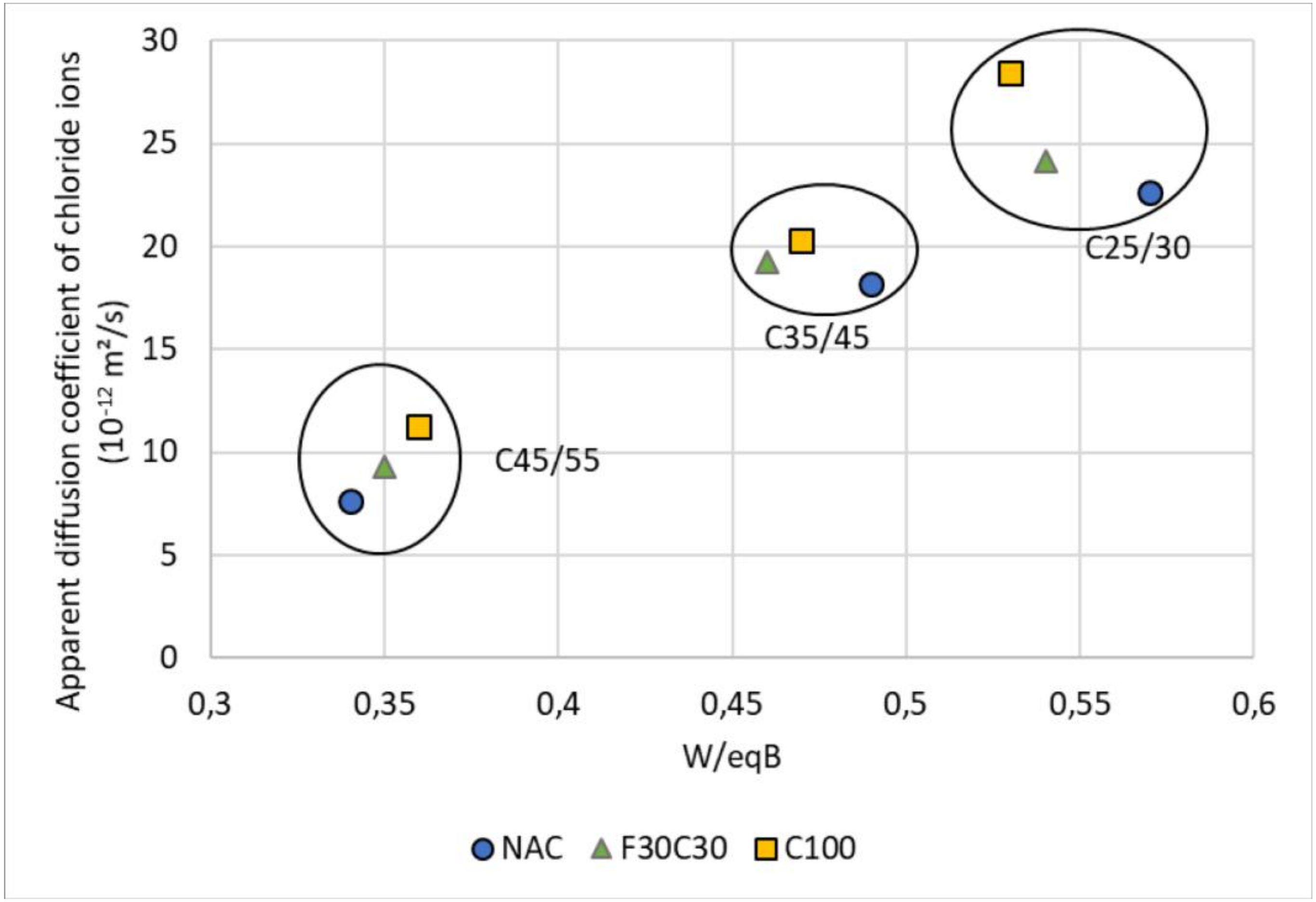
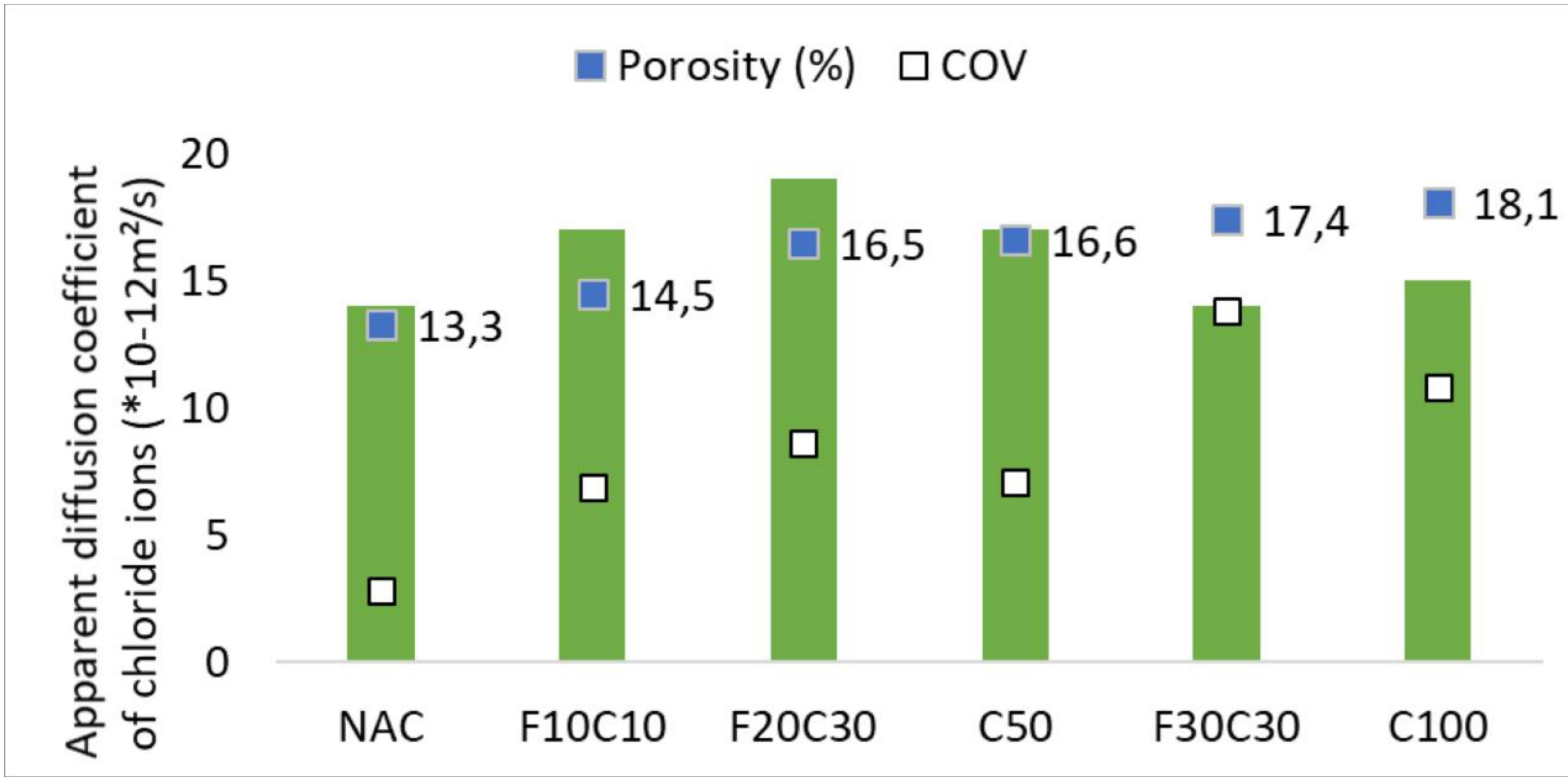
Chloride migration



Chloride migration




Porosity (%)
COV
Apparent diffusion coefficient of chloride ions (*10-12m²/s)
20
15
10
5
0
13,3
14,5
16,5
16,6
17,4
18,1
NAC
F10C10
F20C30
C50
F30C30
C100

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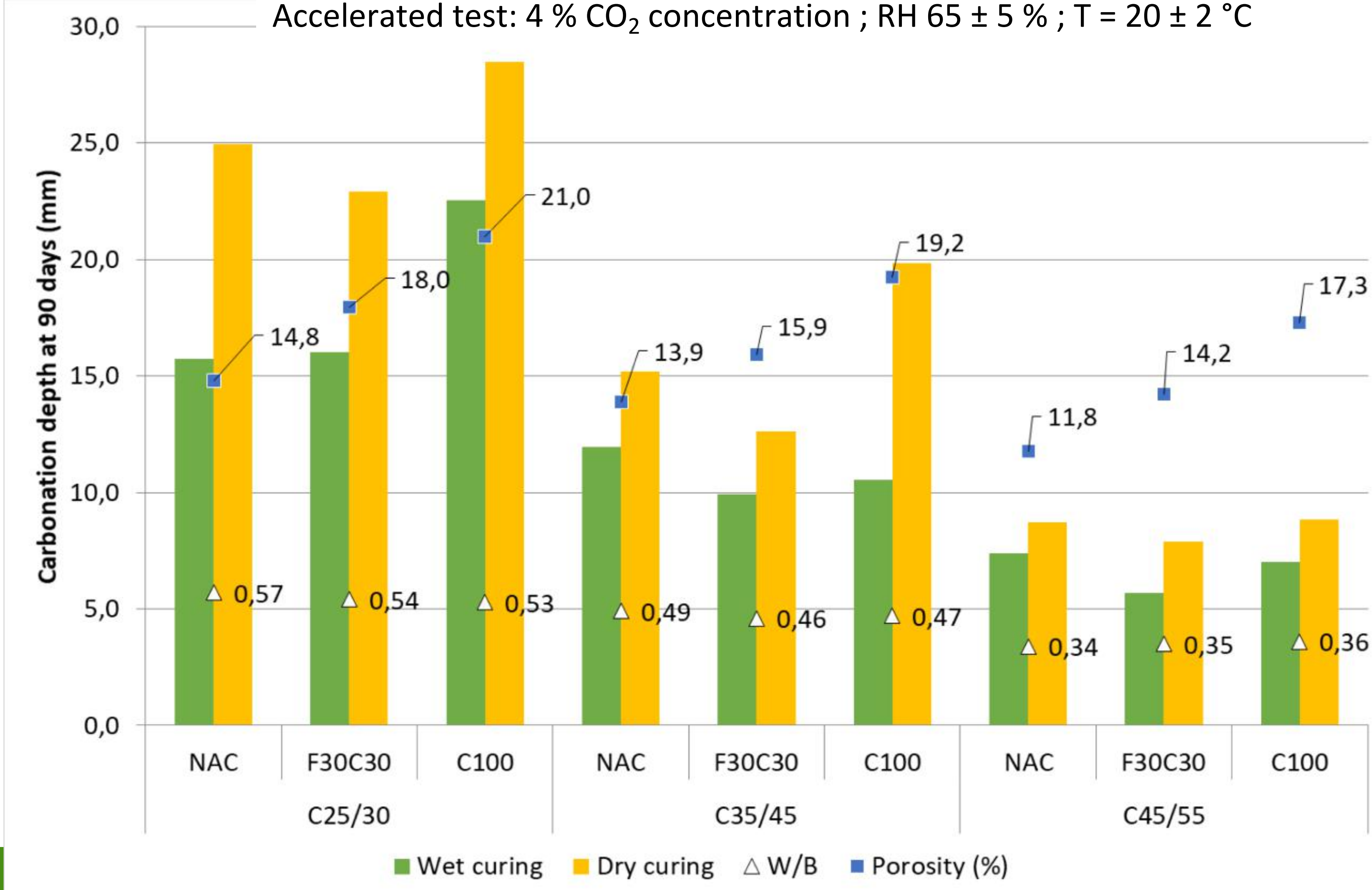
Accelerated carbonation test

Wet curing: in water (20°C) until 90 day

Dry curing: 3 days in water (20°C) and 87 days (20°C ±2, RH 50% ± 5)

Accelerated test: 4 % CO_2 concentration ; RH 65 ± 5 % ; T = 20 ± 2 °C



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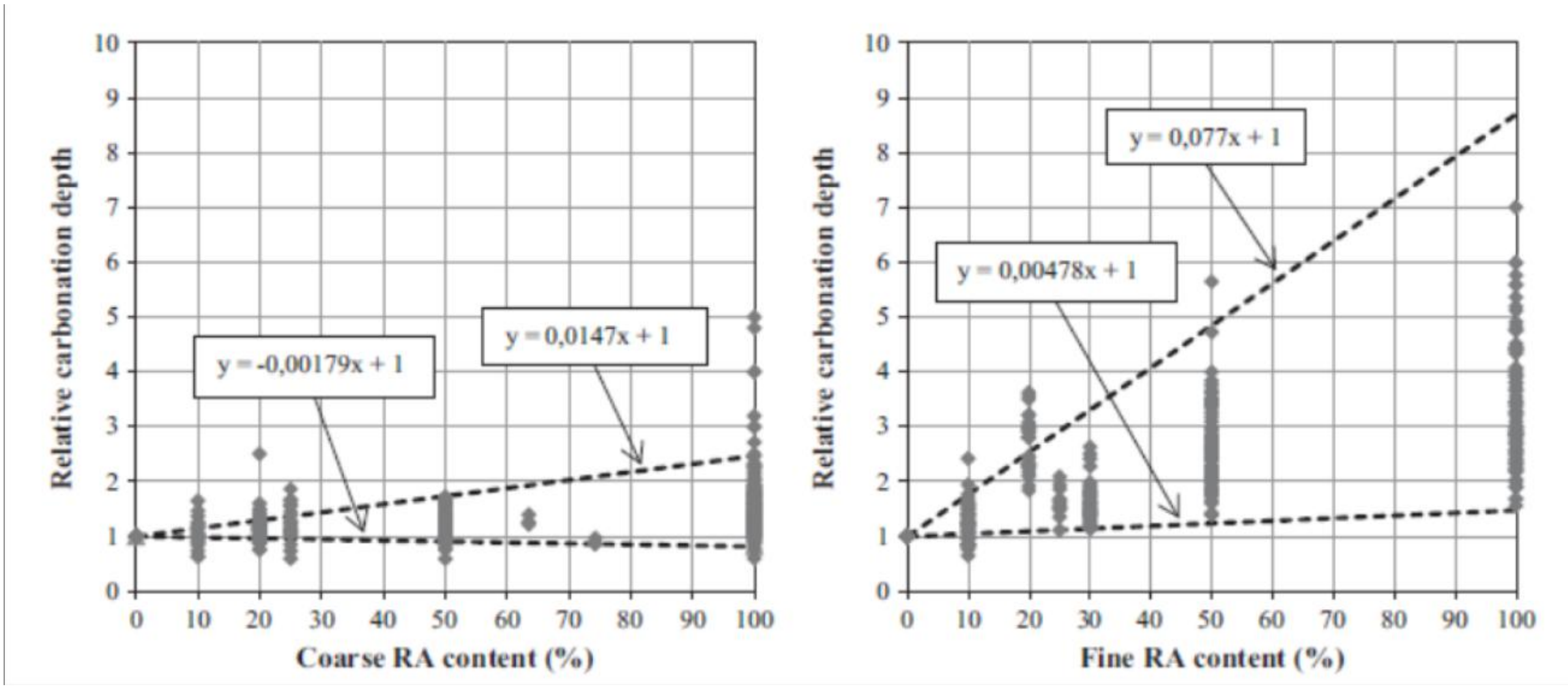

Relative carbonation depth vs replacement level for Coarse RA and Fine RA (Silva et al. 2015)

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Recycling Concrete from the industrial processes of precast concrete plants

In France: ≈ 500,000 tons per year

The origin and shape of these materials vary widely as they are generated during each stage of production:

- Residues from the cleaning of mixers, transport buckets, machinery hoppers, molds, machines and workshops
- Rejected or unused mixes
- Defective fresh products removed from the machine, broken products during handling, storage or loading
- Products destroyed during the control tests;
- Residues of unusable aggregates;
- Powdered residues resulting from surface treatments such as sandblasting;
- Solid residues from the clearing of settling ponds.

Reuse of concrete coming from eclectric poles for new wall elements

CMEG

- 400 T/year of recycled aggregate (6 000 T/year of aggregate)
- No decrease of compressive strength
- Compatibility with the industrial process
- Financial balance achieved, positive image for the company
- Wall elements with recycled aggregate

Valorization of manufacturing waste of concrete products

MARLUX

- Concrete slabs: garden slabs, sealing slabs for roof terraces ...
- Manufacturing rejects stored out of the weather
  Crushing campaign carried out once or twice a year
- About 1,000 tons of new aggregates / campaign
- Aggregates from size 0/6 mm
- The new aggregates are used to make the concrete mass of paving products

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Conclusion (1/3)

- Contribution of microstructure observations to the understanding of RA mechanisms

- Determining role of the Interfacial Transition Zone (ITZ) on water exchange and transfer properties

- Heterogeneity of results in the literature:
  - ✓ the diversity of recycled aggregates used
  - ✓ the differences in methodologies used for the composition parameters of concretes
  - ✓ the diversity of the operating modes

- "Diffusion barrier" effect when the cement matrix of the new concrete is compact

Conclusion (2/3)

- Positive effect on hydration due to the presence of water in recycled aggregates: a second-order effect

From an operational point of view:

- Recycled aggregates reduce transfer properties, but predictably and proportionally to the substitution rate
- Excellent durability by optimizing the compositions (decrease of W/B ratio)
- The higher variability of recycled aggregate means more follow-up

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Conclusion (3/3)

Recommendations of PN Recybeton for substitution rate of RA type 1 (NF EN 206/CN):

	X0	XC1, XC2		XC3, XC4, XF1		XD1, XS1		XF2, XD2, XD3		XS2, XS3		XF3, XF4*		XA
CRA type 1	60	40	60	30	50	30	50	20	40	10	30	10	30	5***
FRA**	30	10	20	10	20	10	20	10	15	10	15	5***	15	5***
Additional rules to NF EN 206/CN		/	****	/	****	/	****	/	****	/	****	/	****	

* Frost resistant RA
** FRA with a water absorption lesser than 10 %
*** Only for RA coming from return concrete
**** Threshold value max W/B decreased by 0,05

Rules to use RA for prestressed concrete products