



The role of chemical research in the commercial adoption of alkali activated concrete

Jannie van Deventer^{1,2}, John Provis¹ & **Peter Duxson**^{1,2}

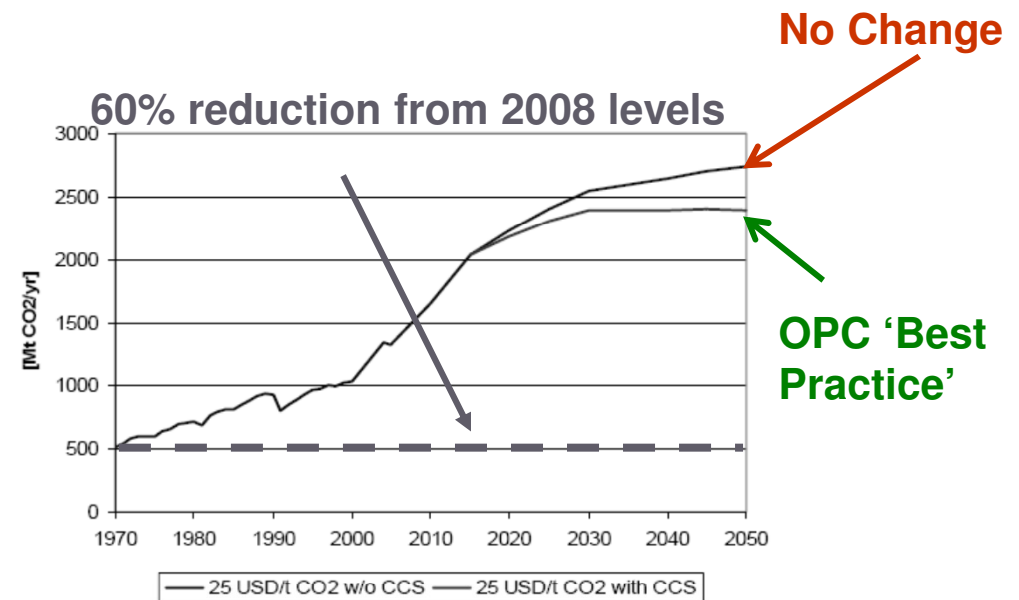
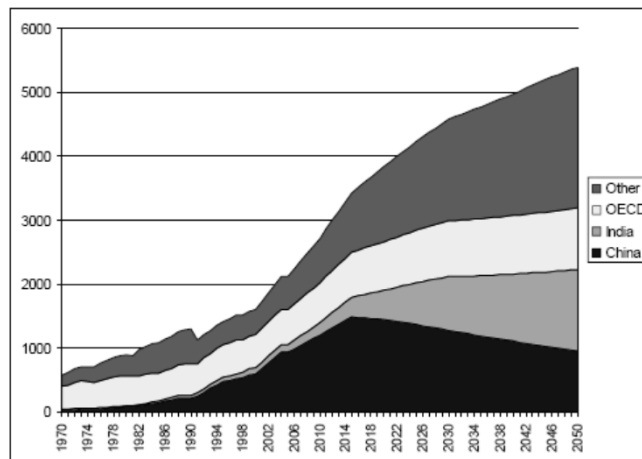
¹The University of Melbourne, ²Zeobond



Some facts about Cement

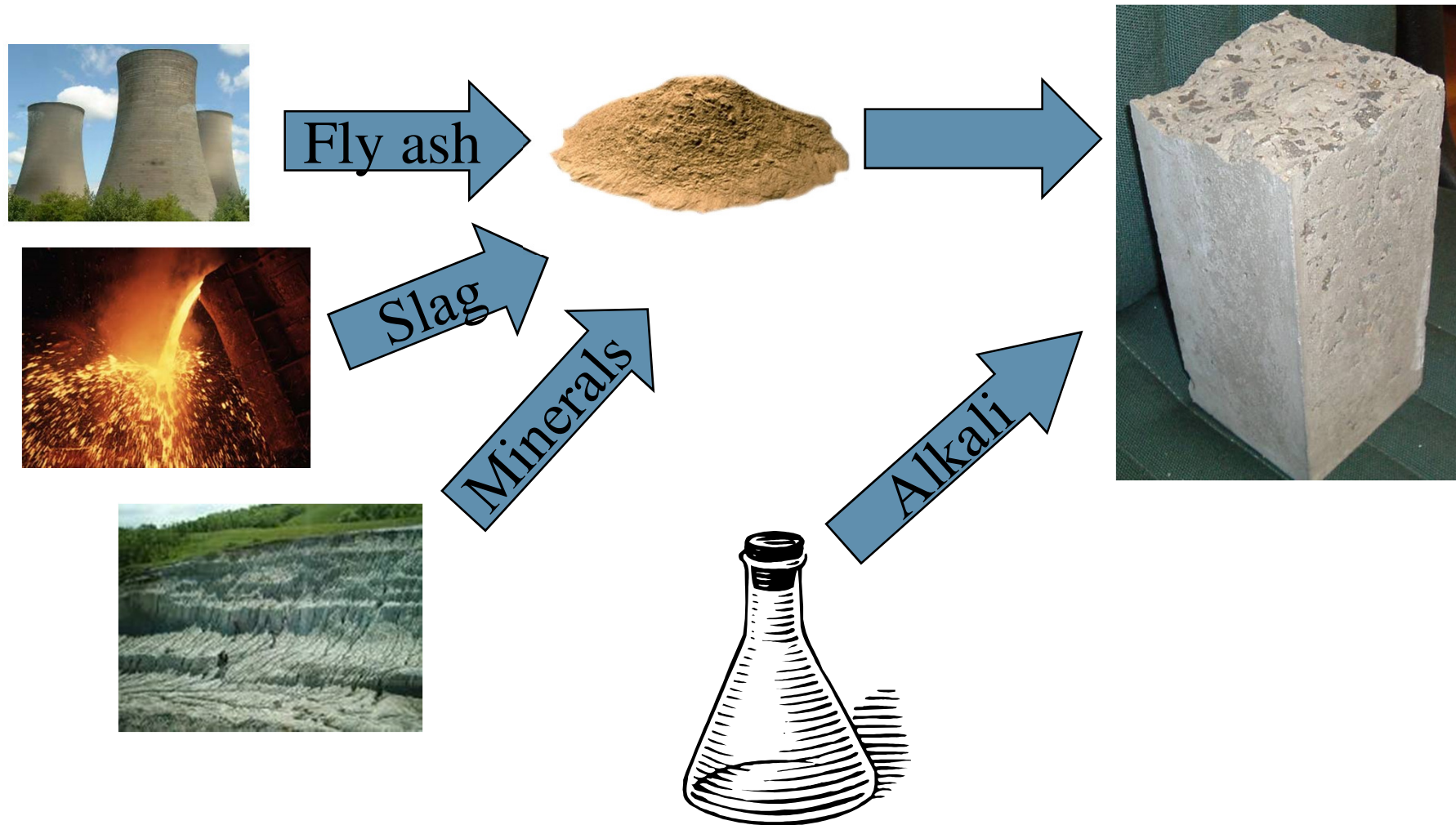
- Cement manufacture makes up 5-8% of all CO₂ (3rd highest)
- Second most used material next to WATER
- 1 ton of CO₂ per 1 ton of cement
- Market to double to 2050

Global Cement Production 1970-2050



- Alternatives to OPC are required to meet market demand for low CO₂ building materials.

Geopolymers: A big part of the solution



What does this mean in practice?



Manufacture cement through capital intensive cement plant.



Flyash replaces cement in the concrete process



Charge truck with aggregates & cement. Adjust workability with water and admixtures



Transport to worksite and discharge



Finish with established skills



Charge truck with Aggregates, Flyash & activator(s)

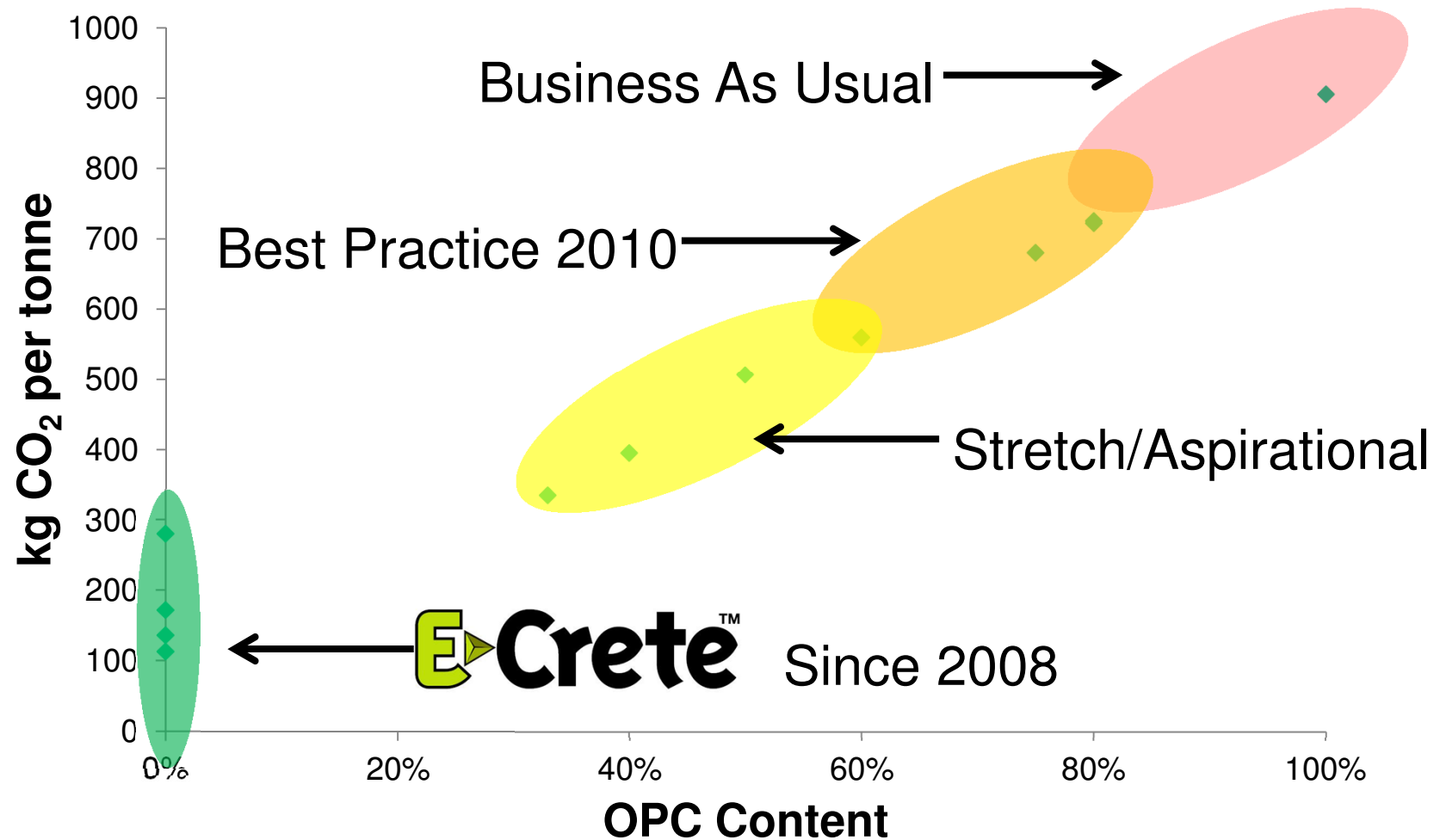


Transport to worksite and discharge.



Finish with established skills

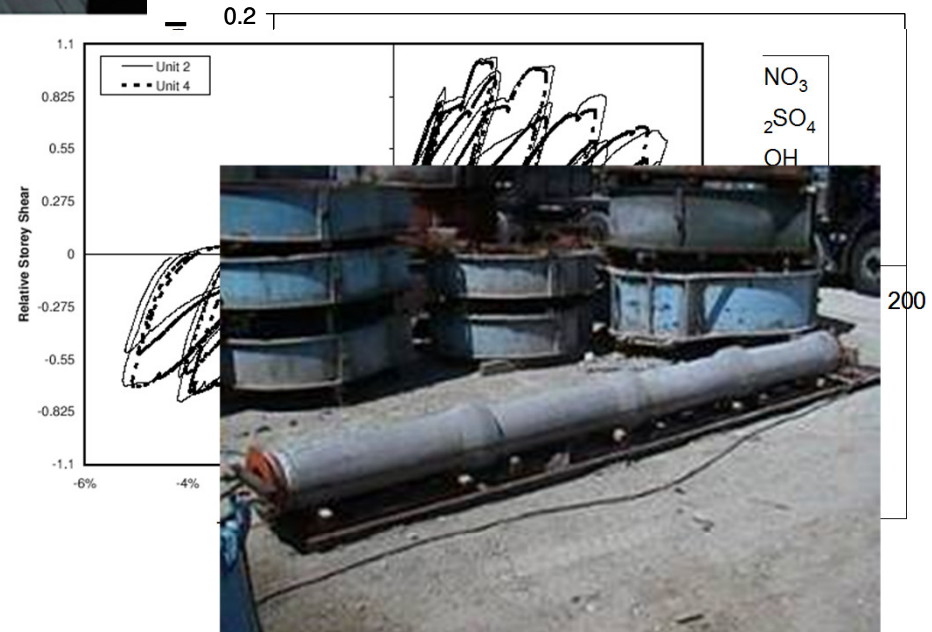
Who's who in the CO₂ Zoo?



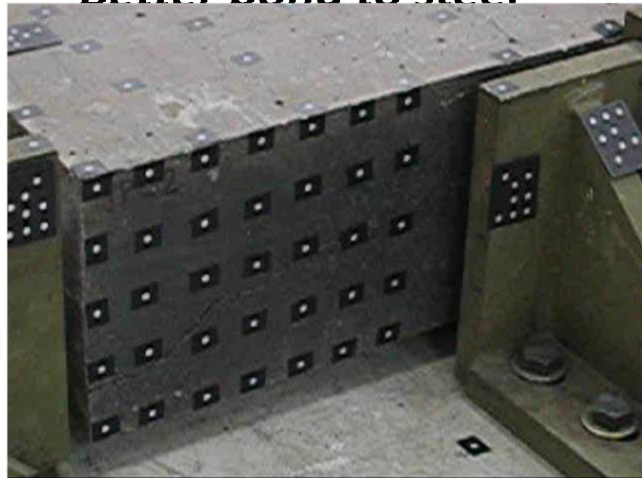
Better than Sliced Bread?



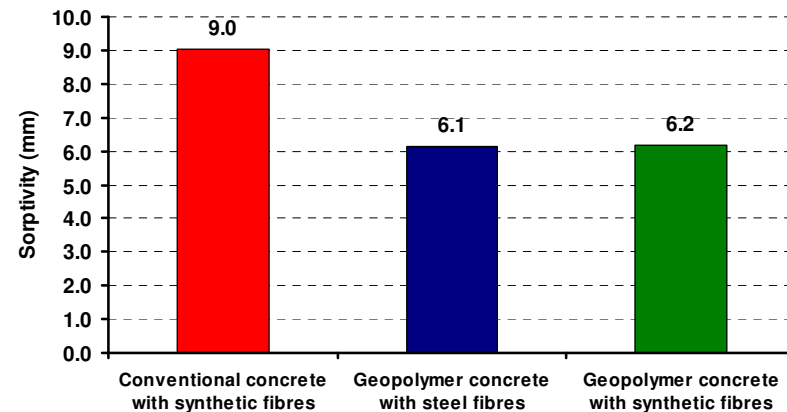
abilit
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Better bond to steel



surfac
 100%
 n



Tunable surface properties

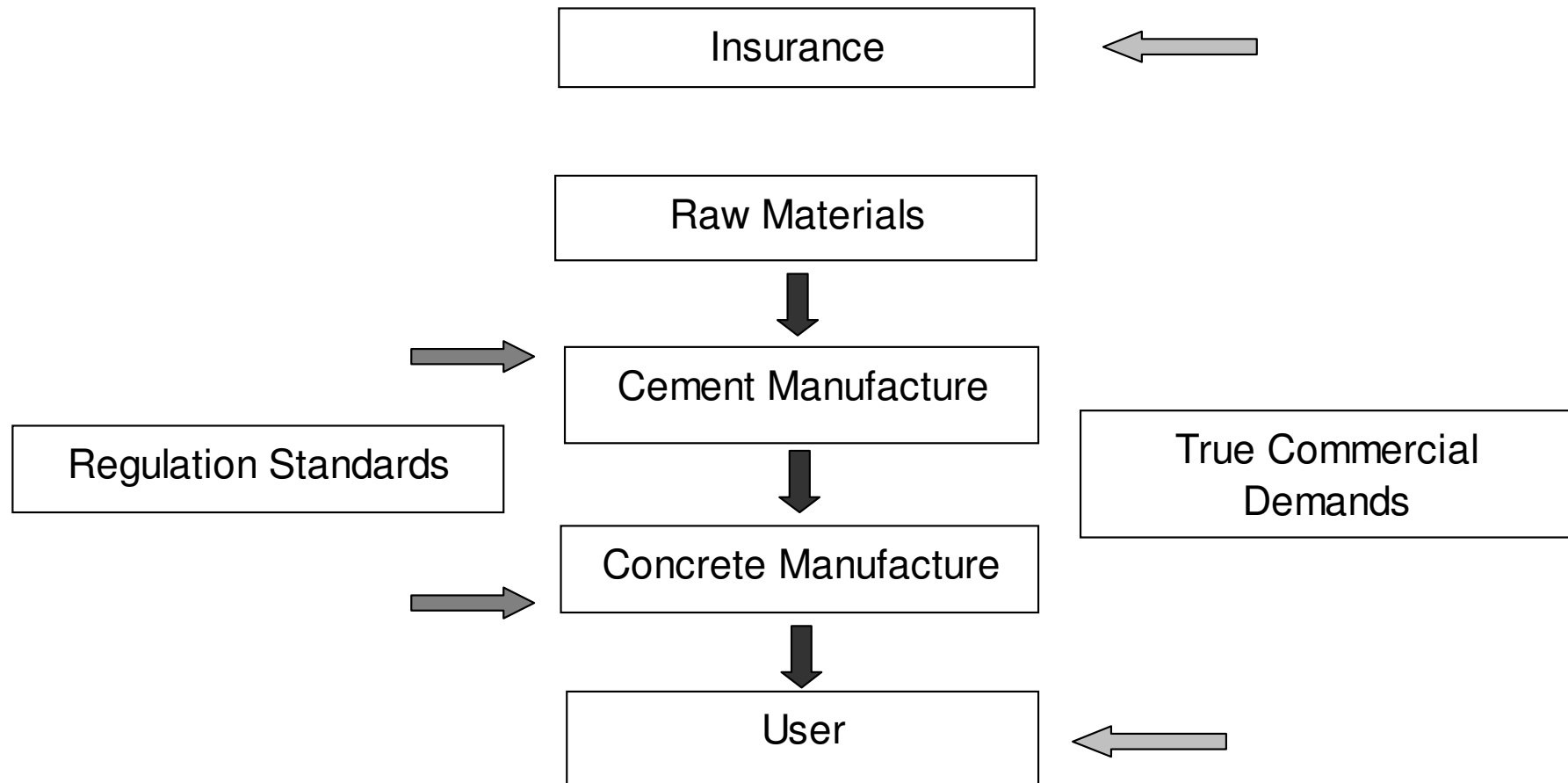


So where is the “BUT”...

Nobody wants to be first

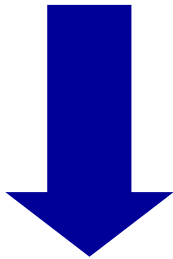


Value Chain & the Risk Tree



Key Barriers to Adoption

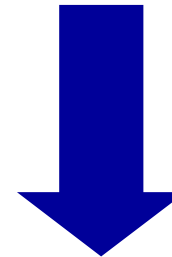
Track Record
(you are “not first”)



Old structures
Lots of applications



Standards
(you are so “not first” they have even got a standard for it)



Experts who agree
Science that is compelling

Zeobond's Track Record



4 years and counting.... versus 150 years for OPC

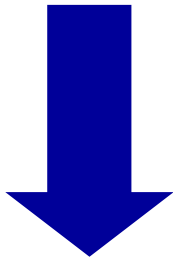
Maybe WE already have the answer?

Soviet/Ukraine work (1960-)
Prof. Davidovits (1978-)
Prof. Palomo (1995-)
Siloxo (1999-2005)
Many, many others....



Key Barriers to Adoption

Track Record
(you are “not first”)

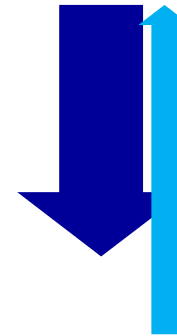


Old structures
Lots of application



Standards
(you are so “not first” they have even got a standard for it)

EN/BS/ASTM



Experts who agree
RILEM TC 224

Science that is compelling
Academic Publication

RILEM TC 224 (2007-2011)

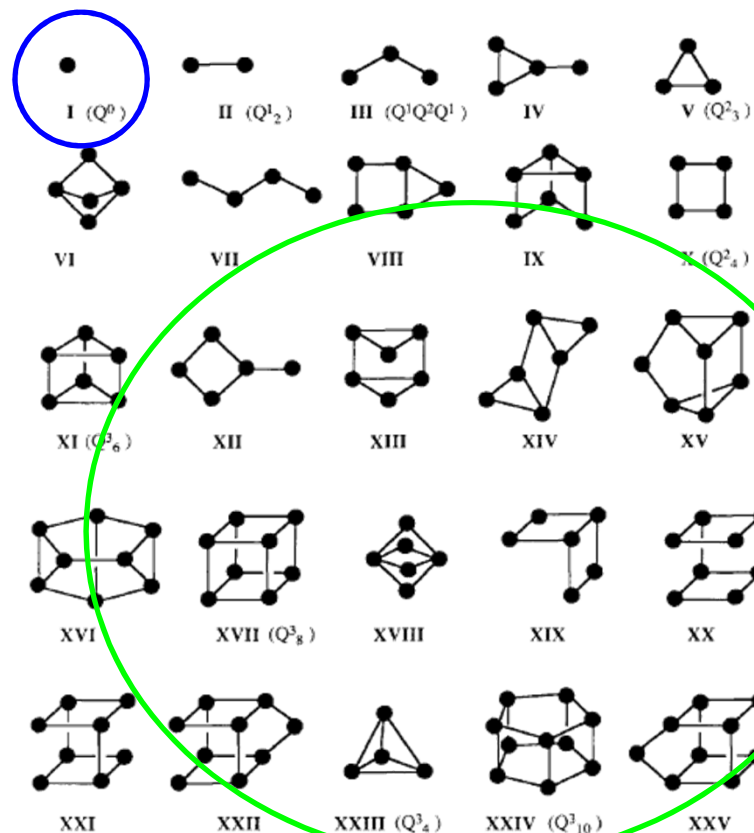
- Performance tests and measures for 'cement' and 'concrete' are broadly acceptable for alkali-activated materials.
- Durability tests (especially accelerated) for all concrete are poor and rely too heavily on correlation
- Durability tests for OPC cement/concrete do not work with alkali-activated materials
- New tests (accelerated) are needed that take into account different chemistry and structure.

Durability – start with a little science

- Pore structure is key
 - If things can't get in to the material, they can't damage it
 - Hydrate phases in OPC fill the internal space
 - Geopolymer gel isn't a hydrate, so the water in the material is free, and in pores
- Need to understand and control porosity

Solution chemistry is key – why?

Reactive



■ Varying extents of deprotonation

■ Speciation dependent on:

- Composition
- Concentration
- Alkali cation(s)
- Temperature

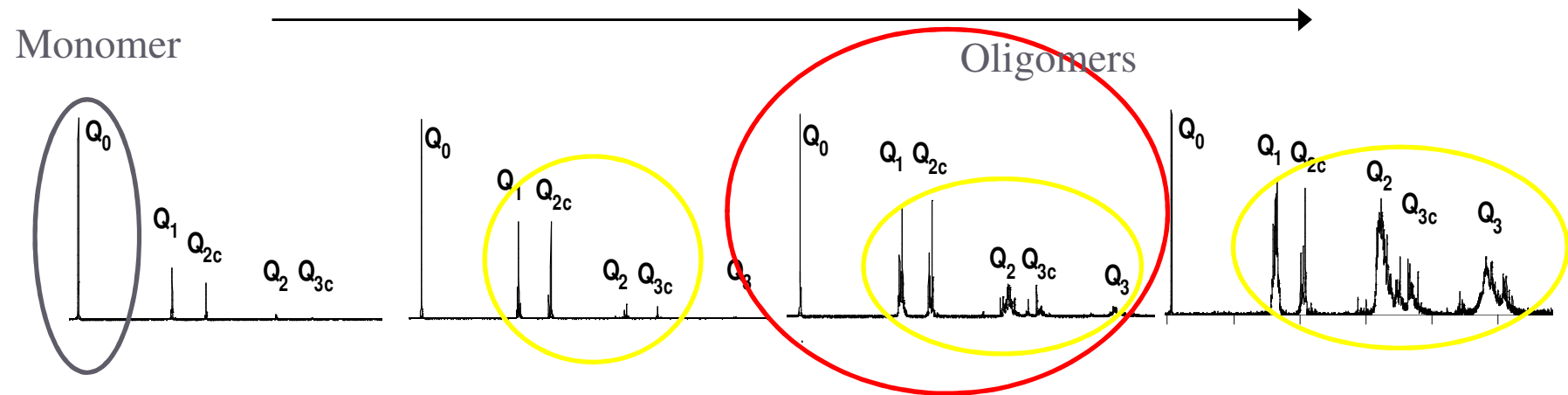
Not reactive

T.W. Swaddle, J. Salerno, P.A. Tregloan, *Chem. Soc. Rev.* **1994**, 23, 319.

Silicate speciation

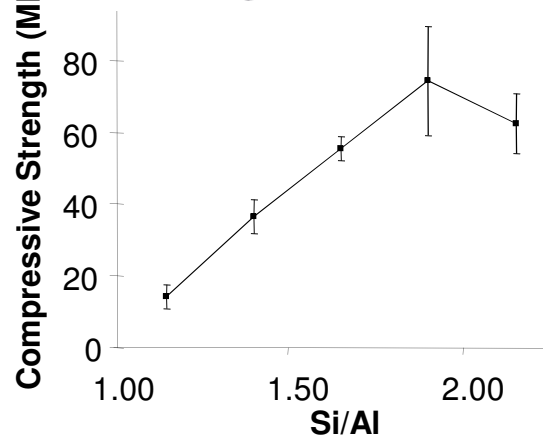
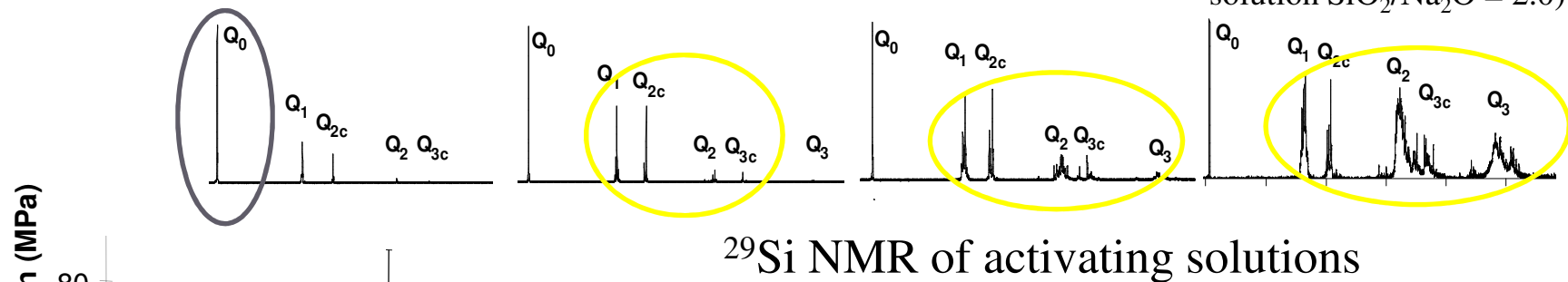
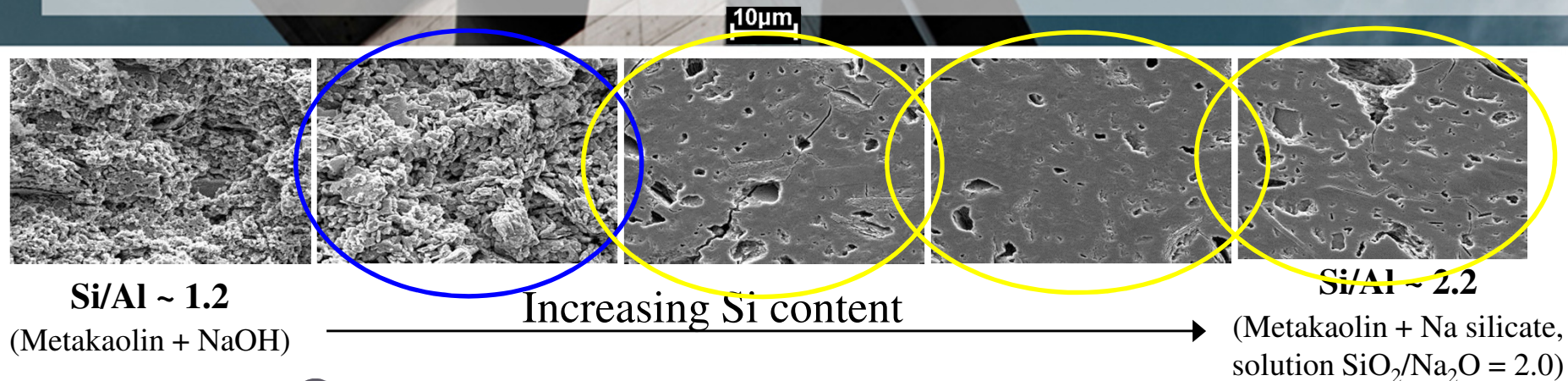
^{29}Si NMR

Solution $\text{SiO}_2/\text{Na}_2\text{O}$



REACTION KINETIC CONTROL

Geopolymer microstructure

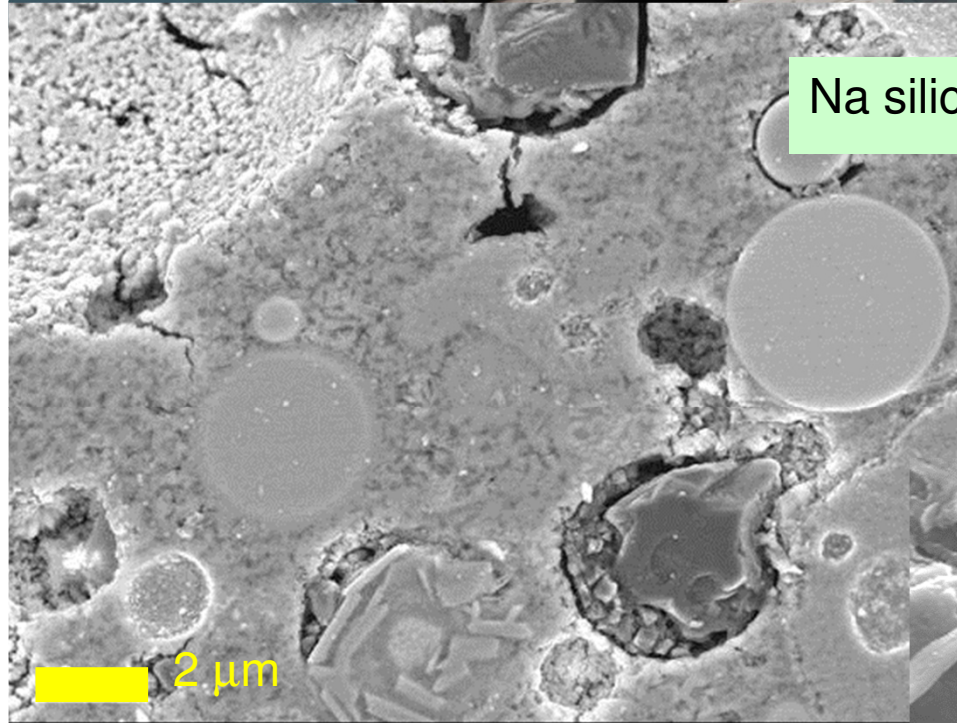


**Structure-property correlation
=> Property prediction**

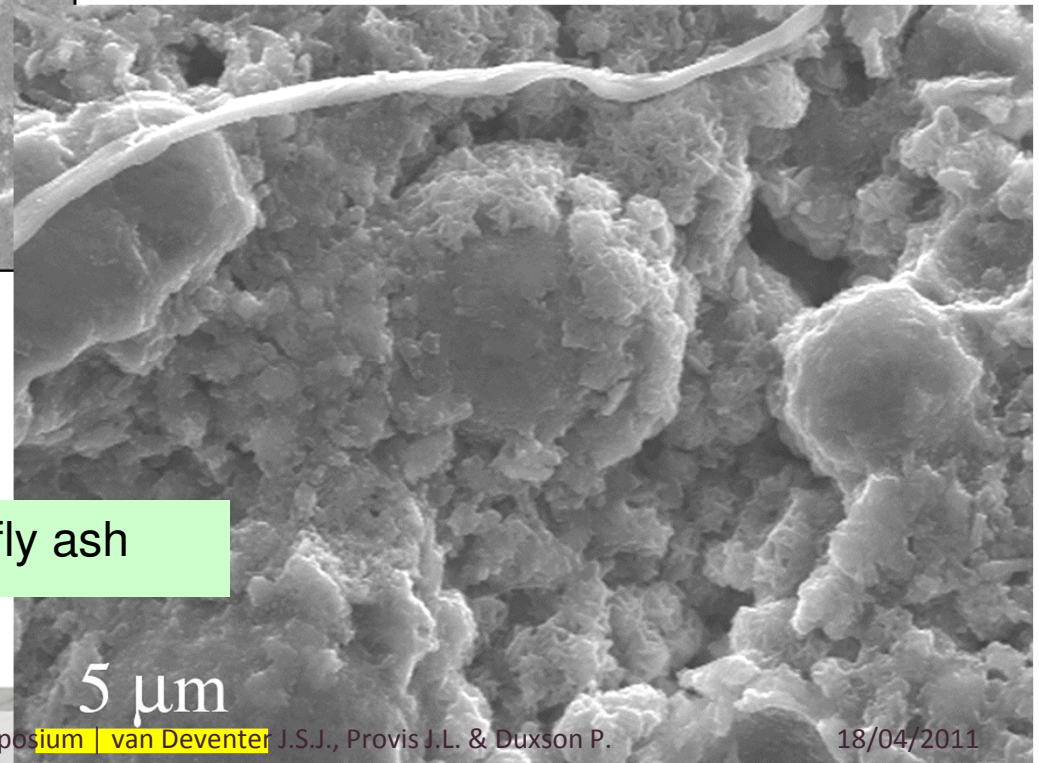
P. Duxson, J.L. Provis, S.W. Mallicoat, G.C. Lukey, W.M. Kriven, J.S.J. van Deventer, *Coll. Surf. A* **2005**, 269, 47

Jannie van Deventer – CEO Zeobond Group

Silicate vs. hydroxide activation



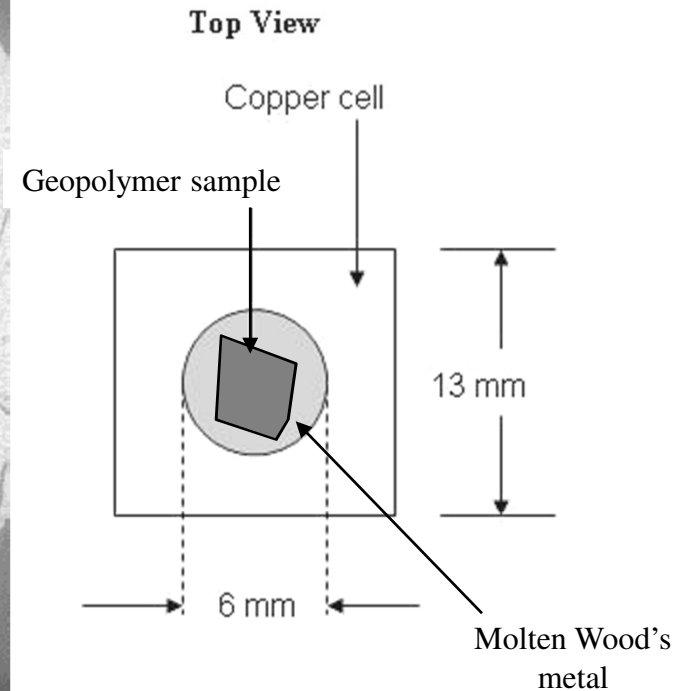
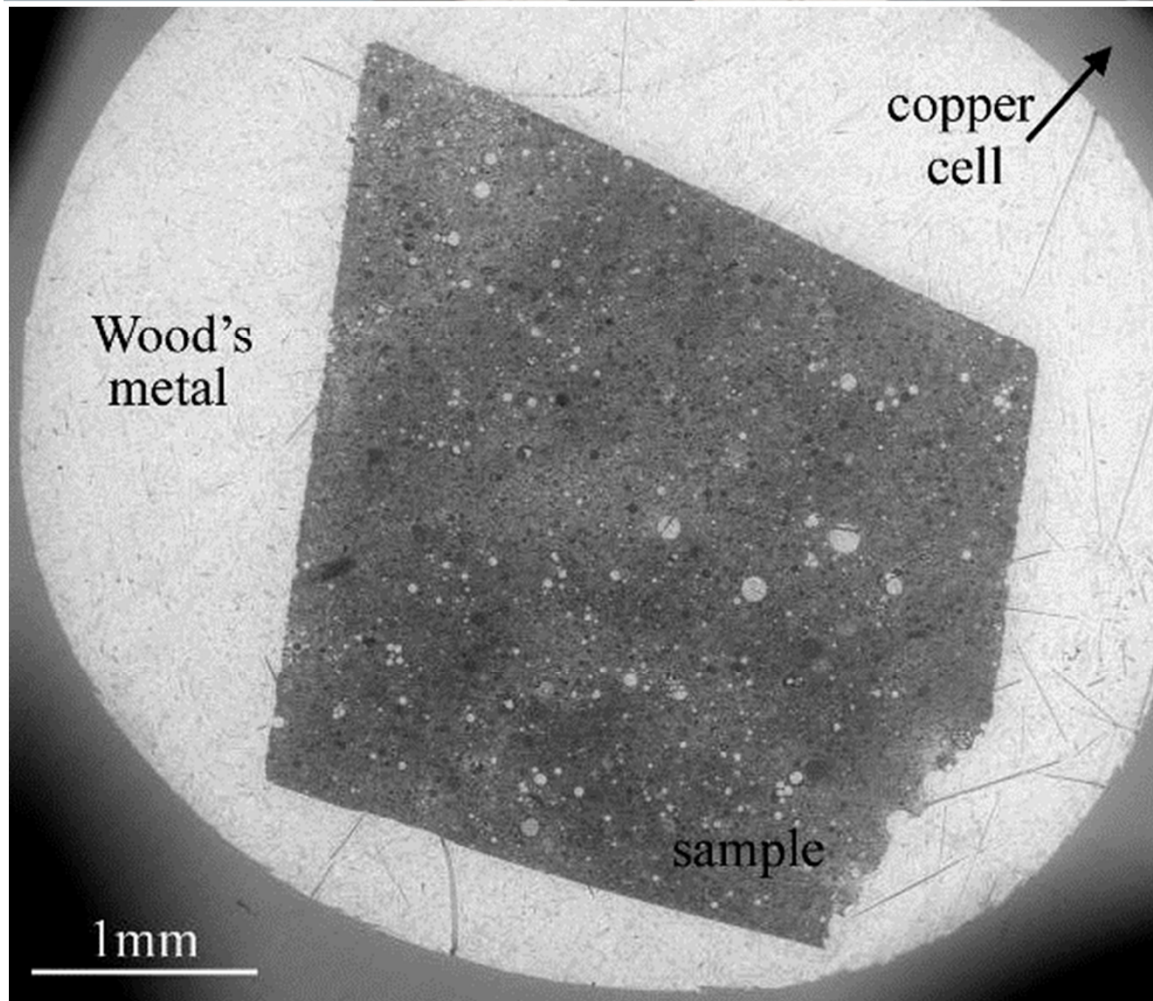
Na silicate + fly ash



NaOH + fly ash

R.R. Lloyd, J.L. Provis, J.S.J. van Deventer,
Journal of Materials Science **2009**, 44: 620-631.

Porosimetry – Wood's Metal intrusion

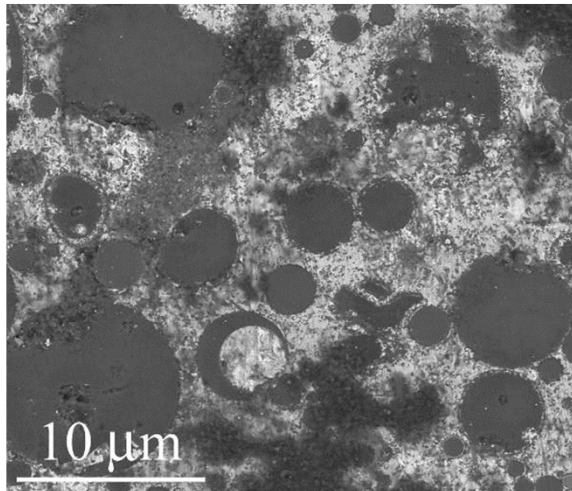


R.R. Lloyd, J.L. Provis, K.J. Smeaton, J.S.J. van Deventer, *Microporous and Mesoporous Materials*, **2009**, 126, 32-39.

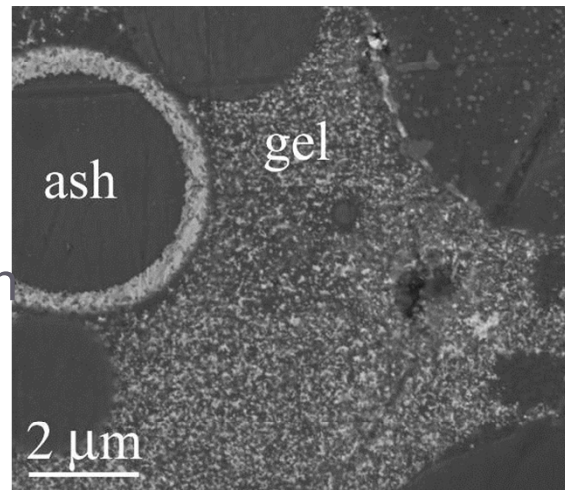
Porosimetry – Wood's Metal intrusion

(class F fly ash + Na silicate, $M_s = 1$)

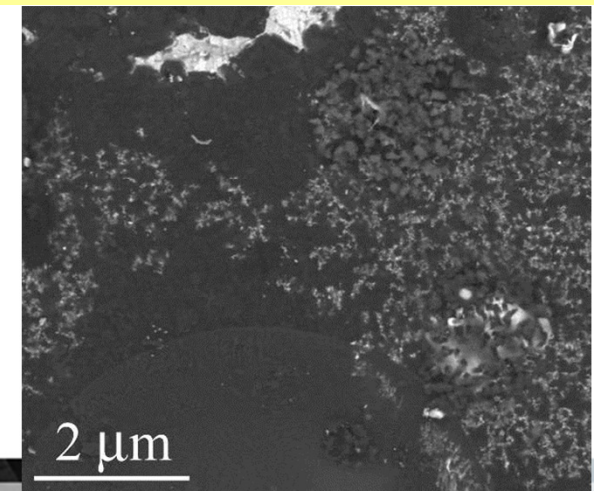
Increasing gel formation



Low activator concentration

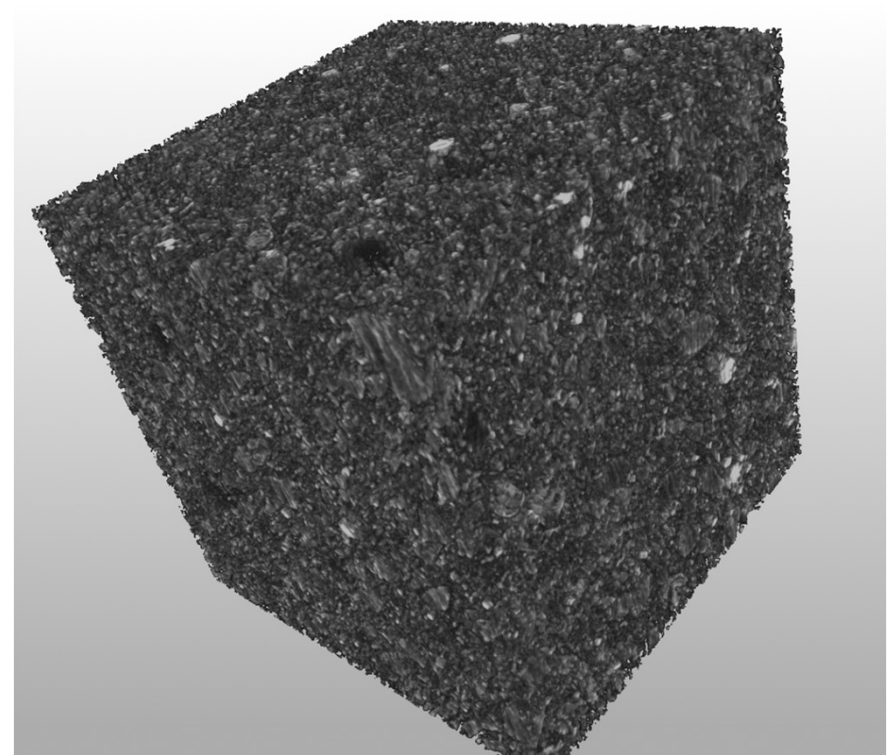
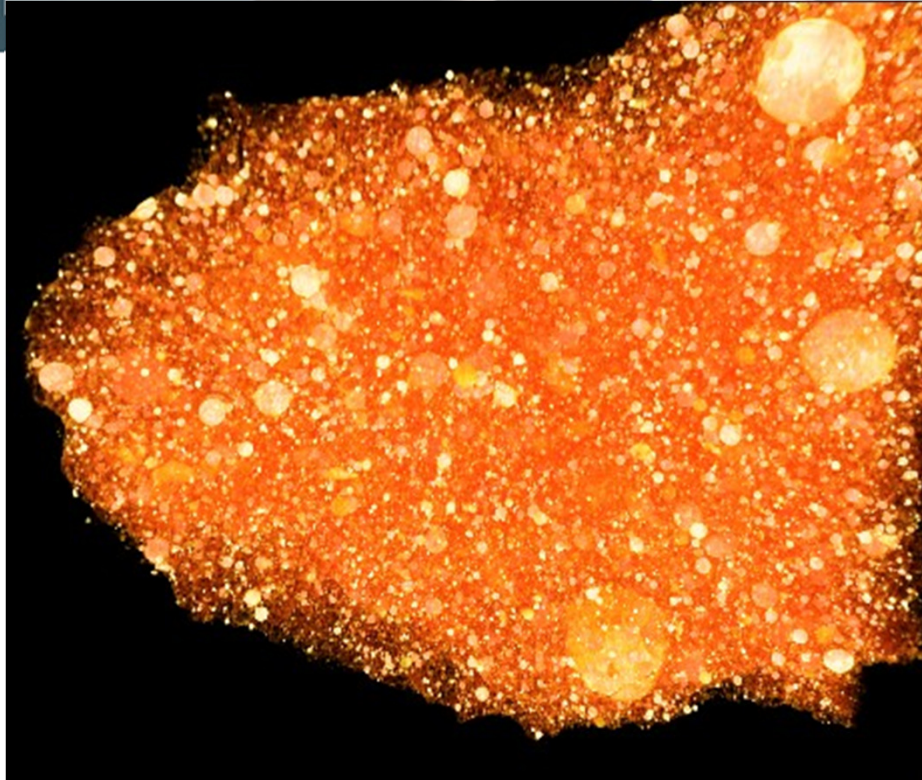


High activator concentration



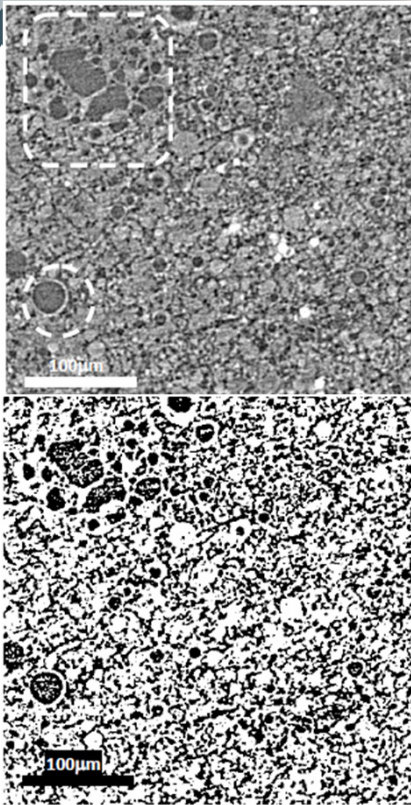
R.R. Lloyd, J.L. Provis, K.J. Smeaton, J.S.J. van Deventer,
Microporous and Mesoporous Materials, **2009**, 126: 32-39.

Synchrotron X-ray tomography



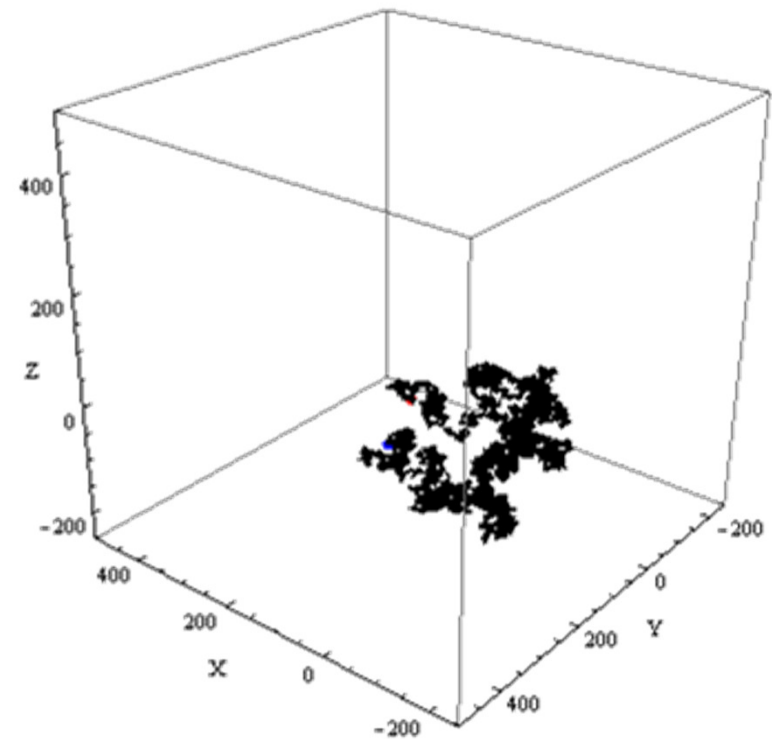
Beamline 2-BM, Advanced Photon Source, Argonne National Lab

Making use of the pretty pictures...



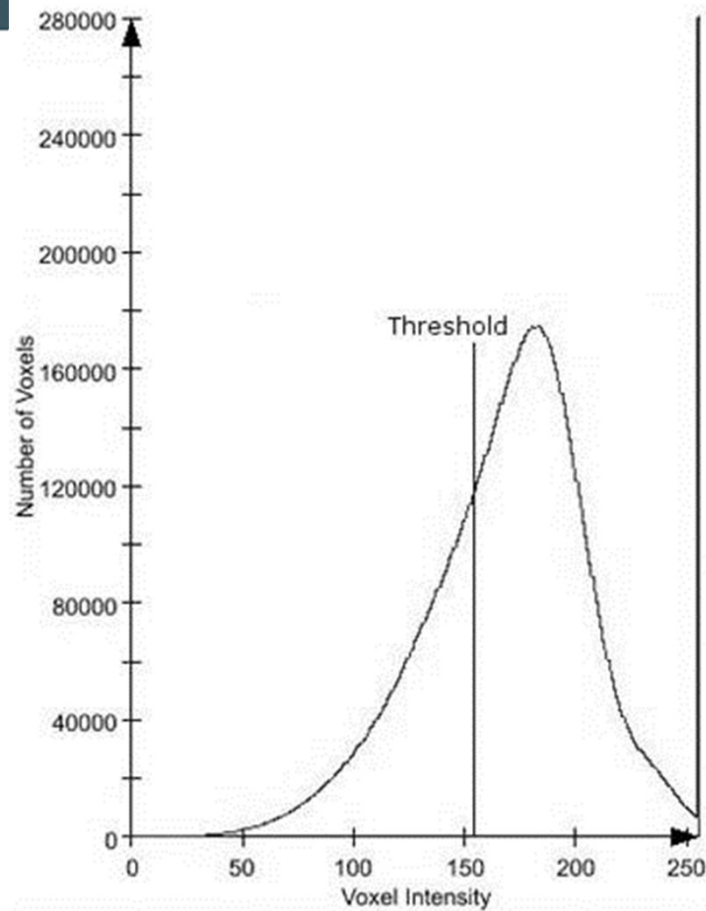
Threshold into pore and non-pore regions
(difference defined somehow..?!)
to calculate pore network connectivity

Then send random walkers
through the pore structure
to calculate percolation and
tortuosity

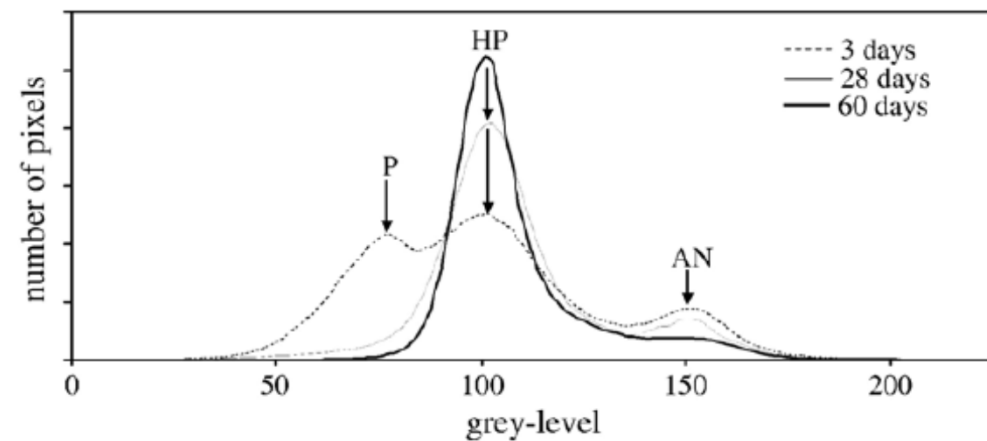


J.L. Provis, R.J. Myers, C.E. White, V. Rose, J.S.J. van Deventer, *Cement & Concrete Research*, submitted

Choosing a threshold?



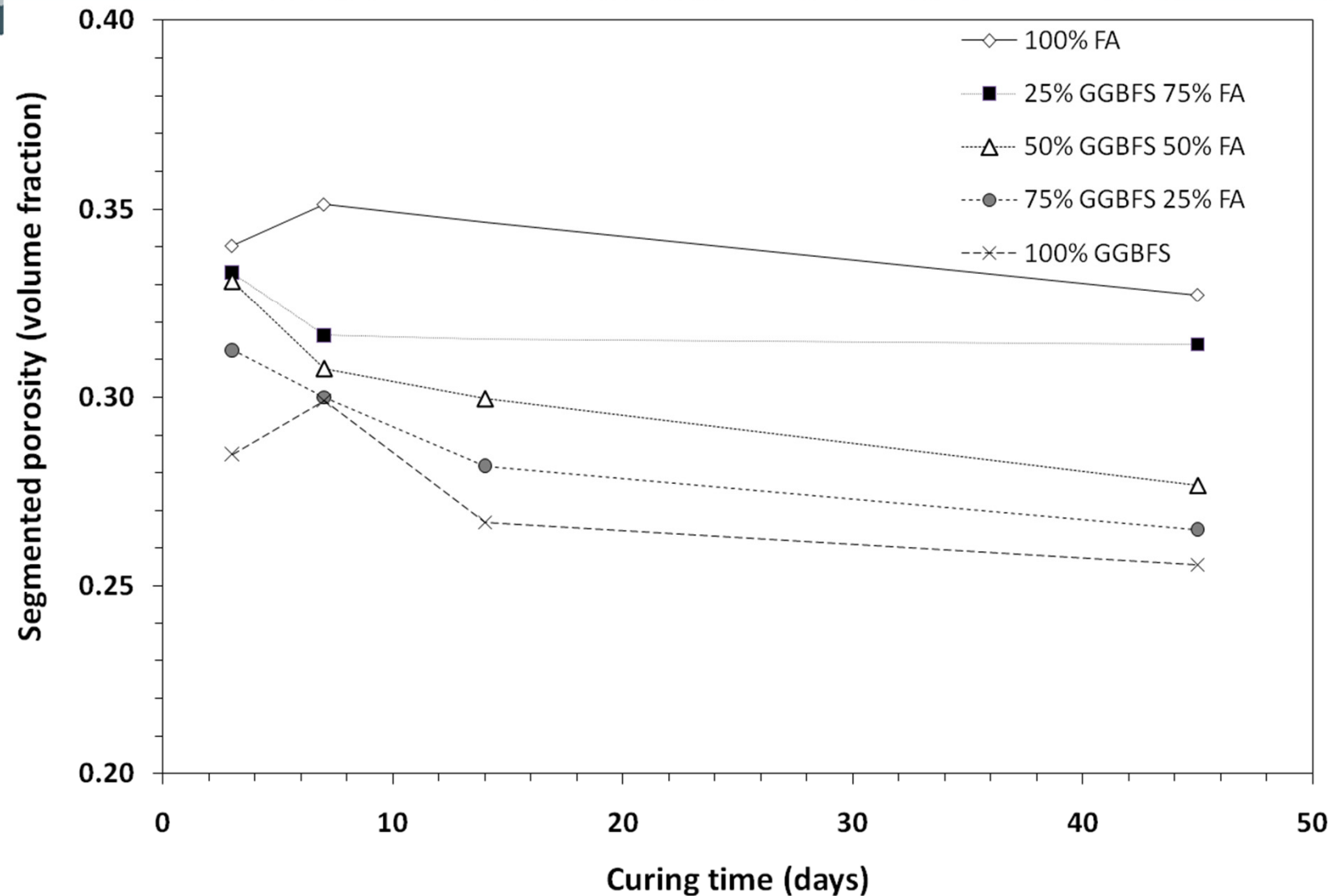
Geopolymer



OPC

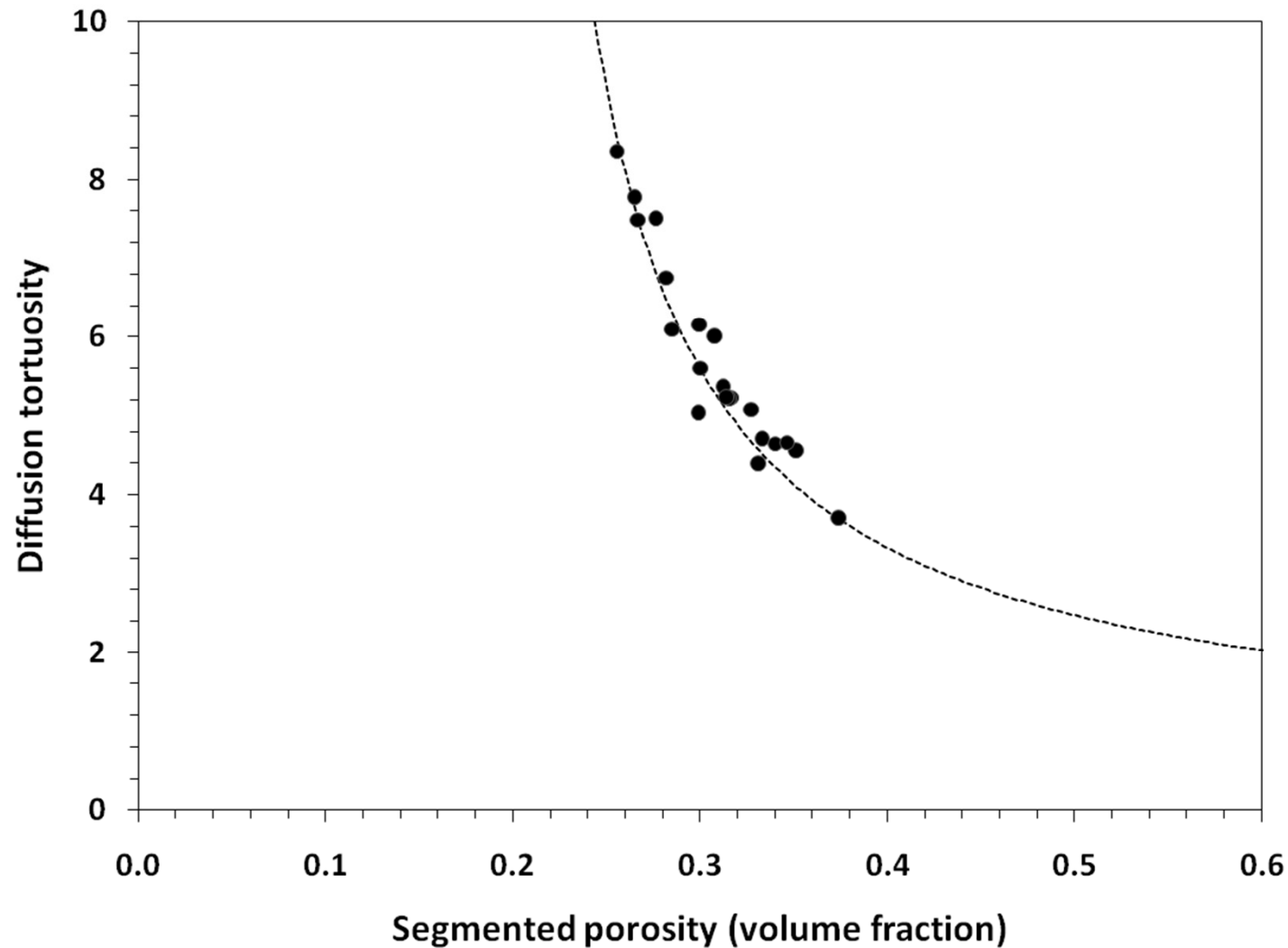
OPC histogram: E. Gallucci *et al. Cement & Concrete Research* **2007**, 37: 360-368.

Porosity vs time & composition



J.L. Provis, R.J. Myers, C.E. White, V. Rose, J.S.J. van Deventer, *Cement & Concrete Research*, submitted

Porosity vs. Tortuosity

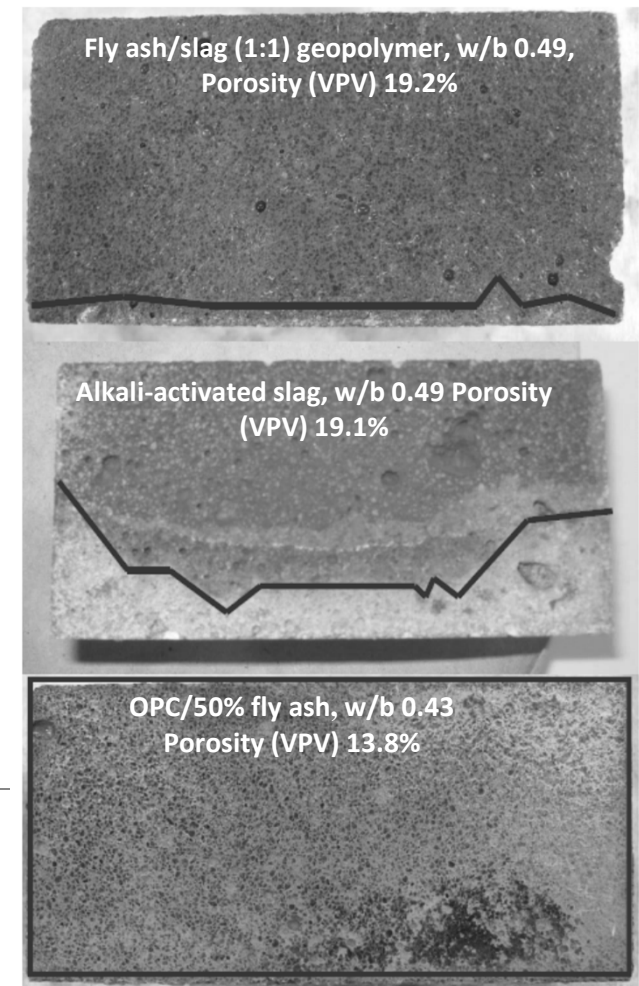
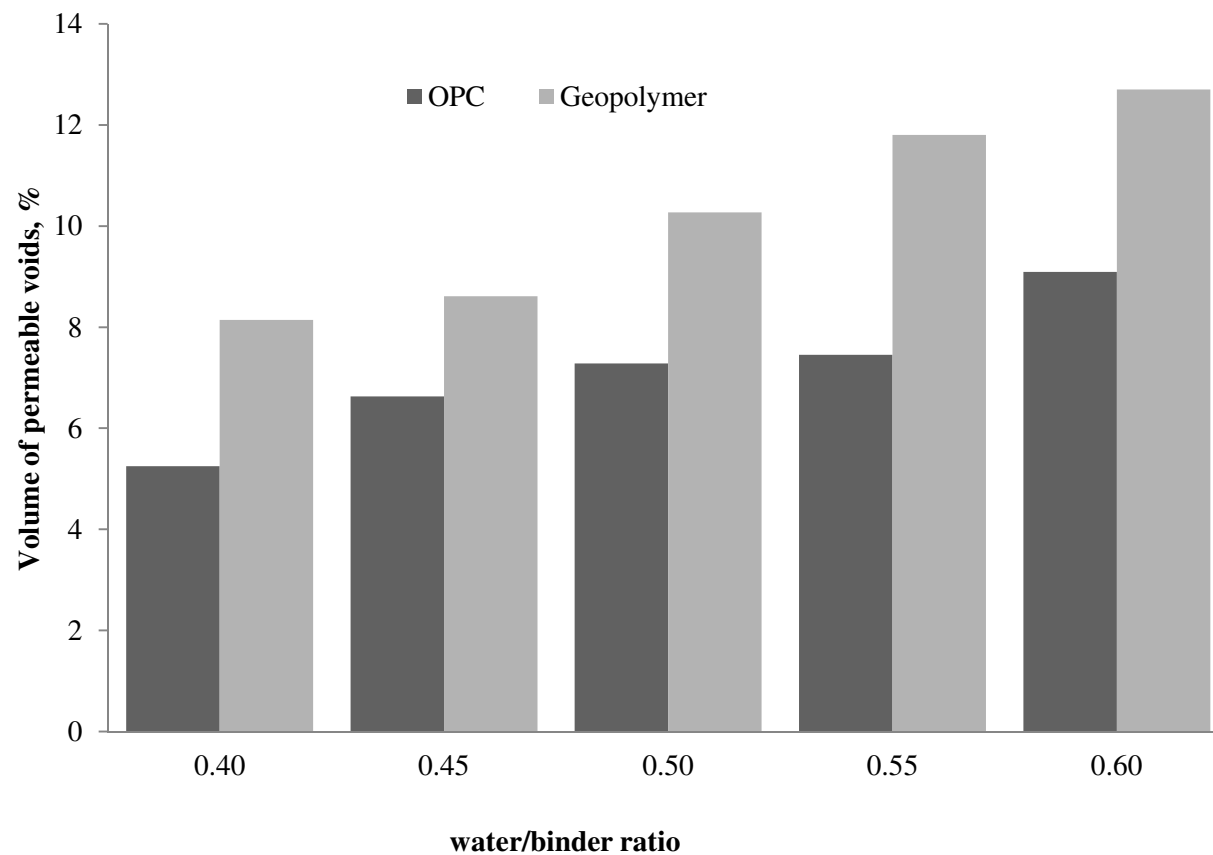


J.L. Provis, R.J. Myers, C.E. White, V. Rose, J.S.J. van Deventer, *Cement & Concrete Research*, submitted

The Crux – A good result isn't enough

VPV – An OPC measure of pores

NTB 492 – A real measure of Chloride



Roles of Research/Commercialisation

- So much has been achieved in commercialisation and basic research, BUT it is not enough yet.
- Draw fundamental links between Chemistry and real-world experience
 - RILEM TC
 - Academia
 - Targeted Industrial-Academic partnerships
 - Publish new/exciting information
- Accelerated durability tests critical to standard formation and scale adoption
 - Excellent Research is the only path
 - Needs to be informed by industrial producers