Concrete sustainability

Application to road pavements

Patrick A. Bonnaud[1], Krystyn J. Van Vliet[2], Akira Miyamoto[1]

[1]New Industry Creation Hatchery Center - Tohoku University – Sendai, Japan
[2]Department of Materials Science & Engineering - MIT, Cambridge, MA, USA

October 8th, 2014

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Sustainable transportation system

Key challenge: enhance the vehicles' fuel economy

http://www.zercustoms.com

Car makers:
1. Fuel efficiency of engines
2. Tires
3. Suspension systems
+ reduction of car weight


http://wifflegif.com

Another strategy:

Reduce emissions due to pavement-vehicle interactions (PVIs) by optimizing **pavement design** and **materials properties**

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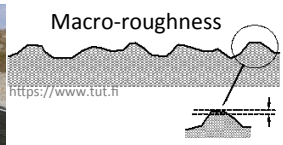
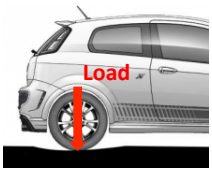
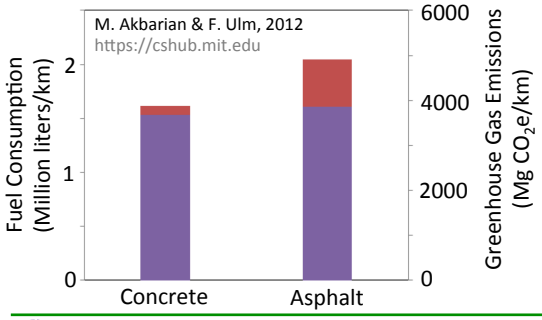
PVI main factors on fuel consumption



Road-roughness



Road deflection



Road-roughness
Concrete ~ Asphalt

Road deflection
Concrete > Asphalt

+ beyond 15 years concrete roads are more environmental friendly!
(lower global warming potential)

PVI: Pavement-Vehicle Interaction

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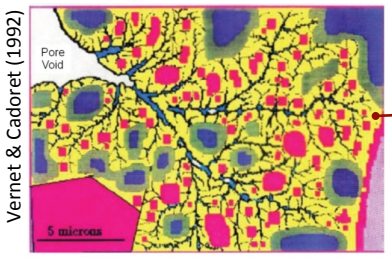
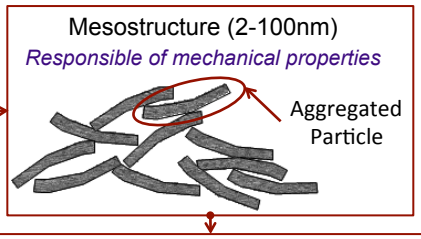
Cement: the glue in concrete

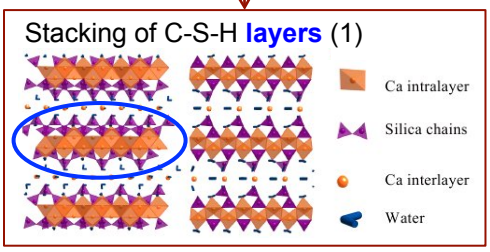
An heterogeneous material



Blue: Liquid water **Pink:** Portlandite
Yellow: C-S-H **Purple:** Cement powder

Calcium Silicate Hydrates (C-S-H)
Most abundant | binding phase | multi-scale porosity | stoichiometry characterized by Ca/Si





(1) Manzano et al., *Physica Status Solidi (a)* 204 (2007) 17751780

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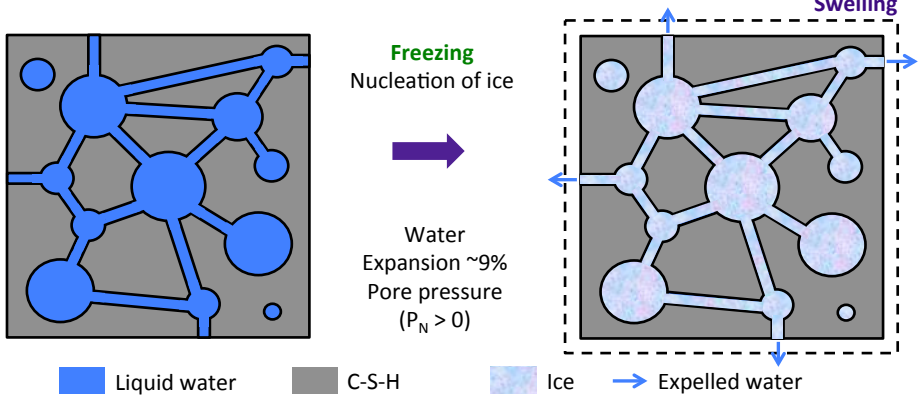
#1 problem in cold regions: water freezing

Non-air-entrained pastes (water saturated porosity)



Swelling → Hydraulic Pressure + Crystallization Pressure

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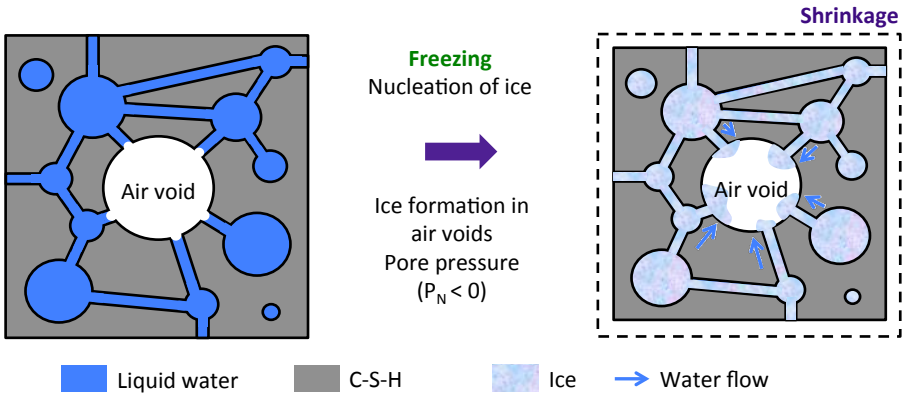
#1 problem in cold regions: water freezing

Air-entrained pastes (inclusion of air voids)



Shrinkage → Suction of water in neighboring pore by ice in air voids

Improve concrete resistance, but don't stop its deterioration!

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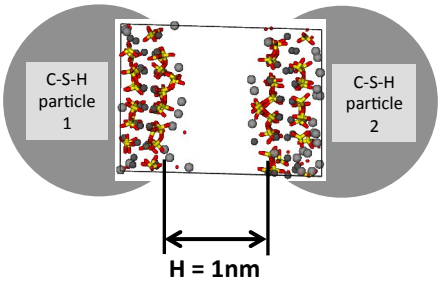
Problem statement

What's the origin of the disruptive pore pressure in the smallest nanopores upon freezing?

How to quantify it?

Molecular simulations between two C-S-H particles



Hydraulic pressure
Effect of water densification

Crystallization pressure
Effect of crystallization forces (increase of the fluid order)

R. J.-M. Pellenq et al., *PNAS* 106 (2009) 16102.

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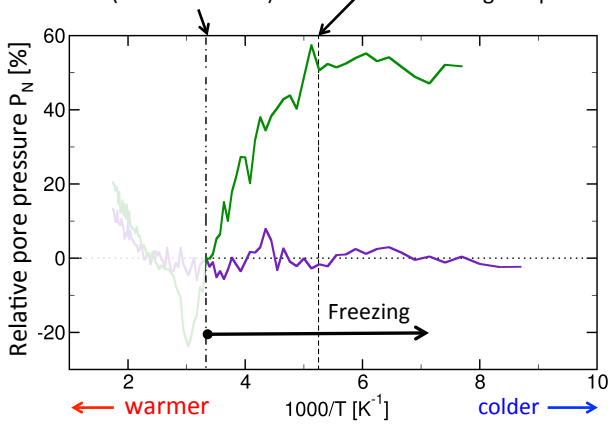
Pressure in a C-S-H nanopore

Bulk liquid-gas transition (reference state)

Bulk melting temperature



Water densification increases significantly the pore pressure (up to ~50%)
Crystallization forces barely affect the pore pressure (±5%)

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Summary

- Road pavement design and materials properties play a role on fuel consumption of the overall transportation system
- Concrete roads: a good alternative to improve sustainability, but problem of frost damages
- Molecular scale simulations are valuable tools to improve concrete properties in such extreme conditions

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#1 pavement problem in cold regions

Freeze-thaw cycles affect the road-roughness

Internal cracks (Ice-water phase transition in pores)

Loss of mechanical properties

Scaling (deicer salts)

Degradation of concrete surface layer

D-cracking (Saturation of concrete by accumulation of water under the pavement)

Frost heave (Soil saturation by water)

http://www.cement.org

What are the fundamental physical processes behind these damage mechanisms?

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