Resistance to Alkali-Silica Reaction of Carbon-Dioxide-Cured Calcium Silicate Cement (CSC) Mortar and Concrete Compared to That Made with Ordinary Portland Cement (OPC)

Solidia Technologies

U.S. Department of Transportation
Federal Highway Administration

Sada Sahu, Ph.D., Principal Scientist
Solidia Technologies

Richard Meininger, Research Civil Engineer
Federal Highway Administration, Turner-Fairbank Highway Research Center

Anna Maria Workshop 2017

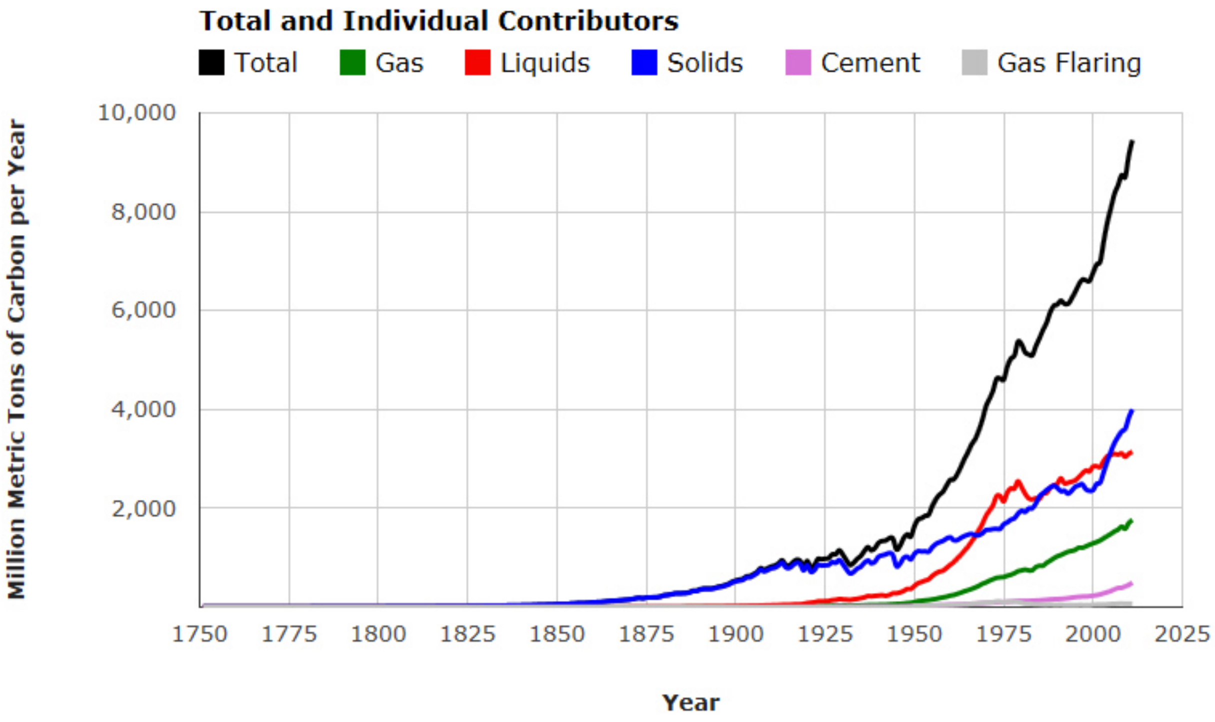
Acknowledgement

Where noted in the slides, work was performed under a cooperative agreement between Solidia Technologies and Federal Highway Administration (FHWA): DTFH6115H00020

Note: *The FHWA neither promotes nor endorses a particular technology; the cooperative research work was carried out so that FHWA and the highway community can gain knowledge about new technology and whether it might be applied to highway construction or maintenance.*

CO_2 Emissions by Sector

Cement industry contributes ~5% of CO_2



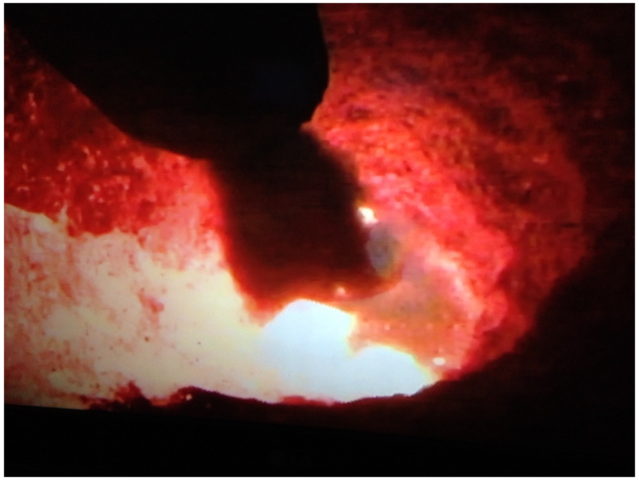
Source: Boden, T.A., G. Marland, and R. J. Andres. 2015. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/00001_V2015.

Sources of CO_2 Emissions in OPC Manufacturing

Portland cement manufacturing emits over 800 kg of CO_2 per ton of clinker produced

- Decomposition of limestone
  - $CaCO_3 \rightarrow CaO + CO_2$
  - Emits 540 kg of CO_2 per ton of clinker

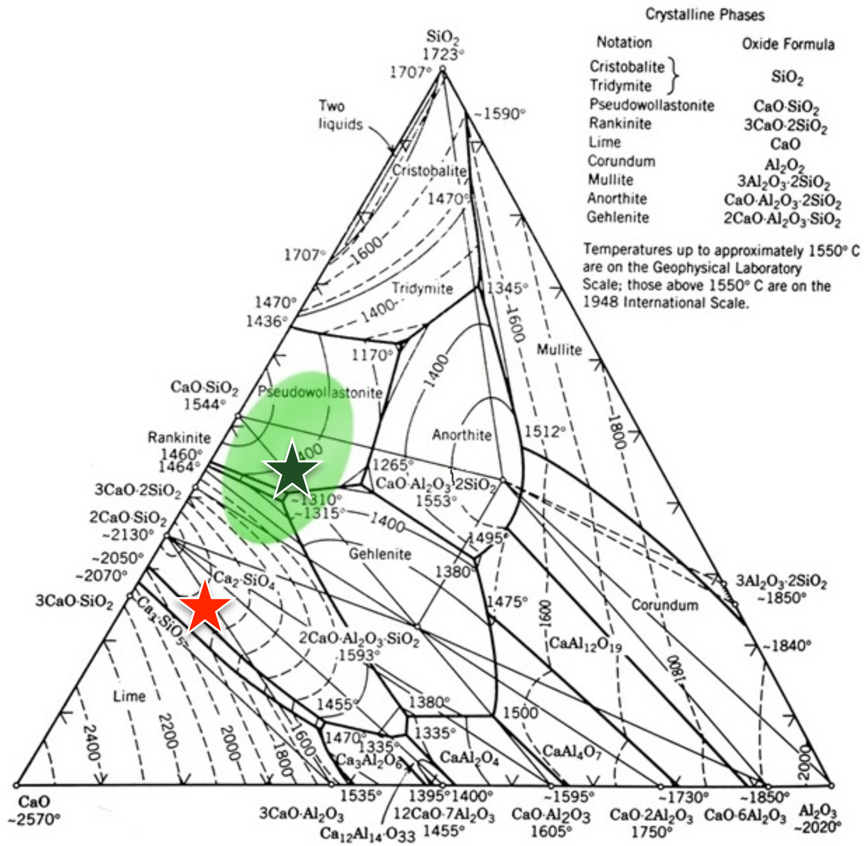
- Burning of fossil fuels to heat the kiln
  - Clinkerization temperature = 1450^{O}C
  - Emits 270 kg of CO_2 per ton of clinker



Solidia Technologies

Solidia Cement™ Raw Mix Design

Component	OPC Raw Mix	SC Raw Mix
CaO	40-45%	28-32%
SiO_2	13-15%	30-35%
Al_2O_3	1-5%	<5%
Fe_2O_3	1-5%	<5%
MgO	<1%	<1%
LOI	35-40%	25-30%



Solidia Cement Phase Composition

Portland Cement (wt.%)	Solidia Cement (wt.%)
C_3S = 50-70	C_2S = 1-9
C_2S = 15-30	C_3S_2 = 10-20
C_3A = 5-10	CS = 20-50
C_4AF = 5-15	C_2AS syn. = 5-30
CSH_2 = 3-5	Amorphous = 20-30

Solidia Concrete™ Curing by CO_2 Sequestration

- Carbonation of low calcium phases in Solidia Cement:

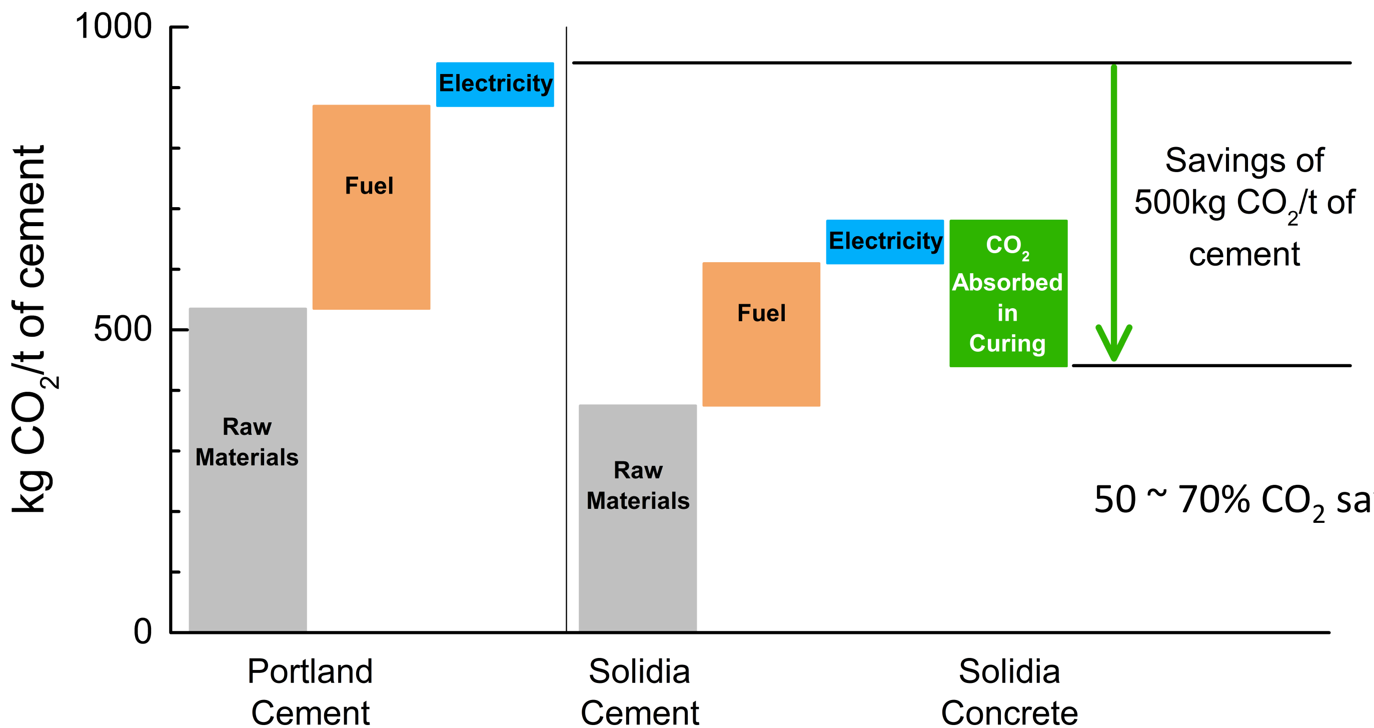
$$CaO\cdot SiO_2 + CO_2 \xrightarrow{H_2O\ (l)} CaCO_3 + SiO_2$$

$$3CaO\cdot 2SiO_2 + 3CO_2 \xrightarrow{H_2O\ (l)} 3CaCO_3 + 2SiO_2$$

$$2CaO\cdot SiO_2 + 2CO_2 \xrightarrow{H_2O\ (l)} 2CaCO_3 + SiO_2$$

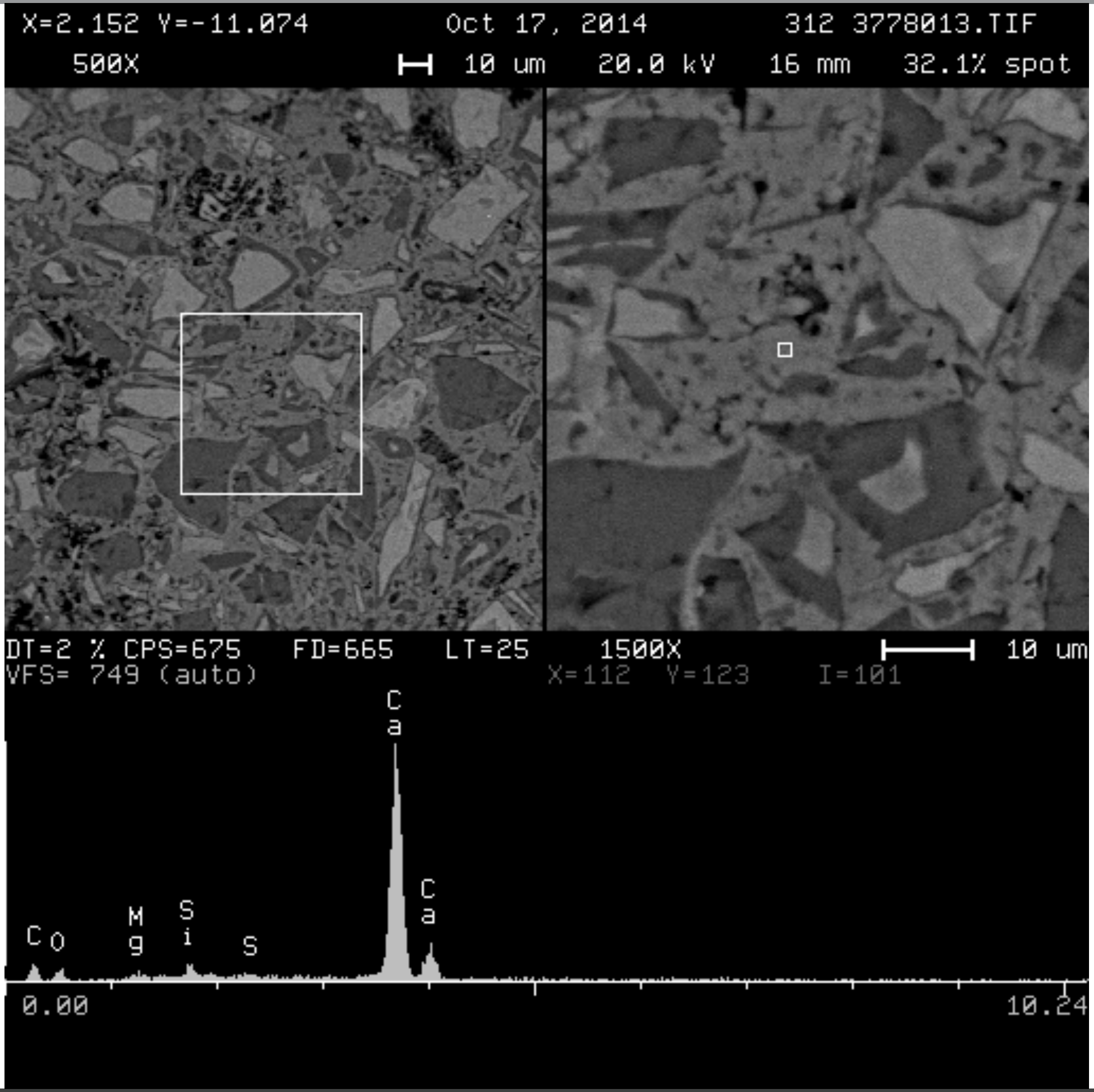
- Solidia Concrete curing begins only when Solidia Cement, CO_2 and H_2O (l) are simultaneously present in the system.
- Solidia Concrete curing sequesters up to 300 kg of CO_2 per ton of Solidia Cement.

Reduction in CO_2 Emissions



50 ~ 70% CO_2 savings

Pore Filling by Calcite



Performance of Solidia Concrete

Mix Design

Materials	Weight (lbs)
Solidia Cement	590
Sand	1384
Coarse aggregate 1 (3/8")	698
Coarse aggregate 1 (3/4")	1242
Water	229
w/c	0.39
Admixtures	
Glenium*	2.27
MBAE90*	1.36
Admix 13*	2.27

* ml per lbs of cementitious
Admix 13 = Solidia in-house made set retarder

Compressive Strength
(Solidia Concrete vs. OPC)

Curing Time	D514	D531
OPC 7 days (psi)	7335	
OPC 28 days (psi)	8414	
CS 3 days (psi)		9250

Mechanical Properties

Property	ASTM Test	D483-1
Compressive strength	C39	9,145 psi
Split tensile strength	C496	931 psi
Flexural strength	C78	783 psi
Modulus of elasticity	C469	7,192,400 psi
Poisson's ratio	C469	0.17

ASR Testing

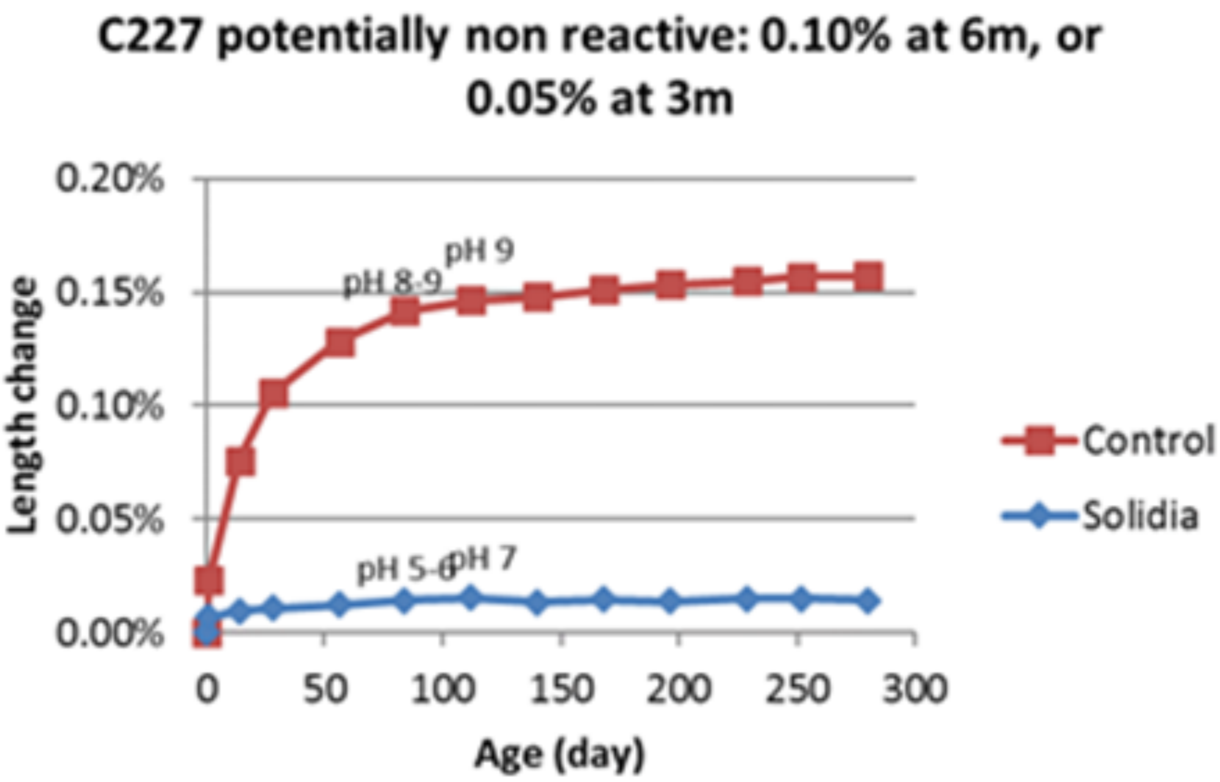
Materials:

- 1x1x12-inch Mortar Bar – Fused Silica Sand
- 3x3x12-inch Concrete Prism – New Mexico Placitas coarse aggregate + non reactive sand
- OPC Type I/II Na_2Oe = 0.96%
- Solidia Cement (SC-Pecs) Na_2Oe = 0.86%

Methods:

- ASTM C 227 – Mortar Bar
- ASTM C1293 – Concrete Prism
- ASTM C 1260 – Not selected

Length Change Mortar Samples

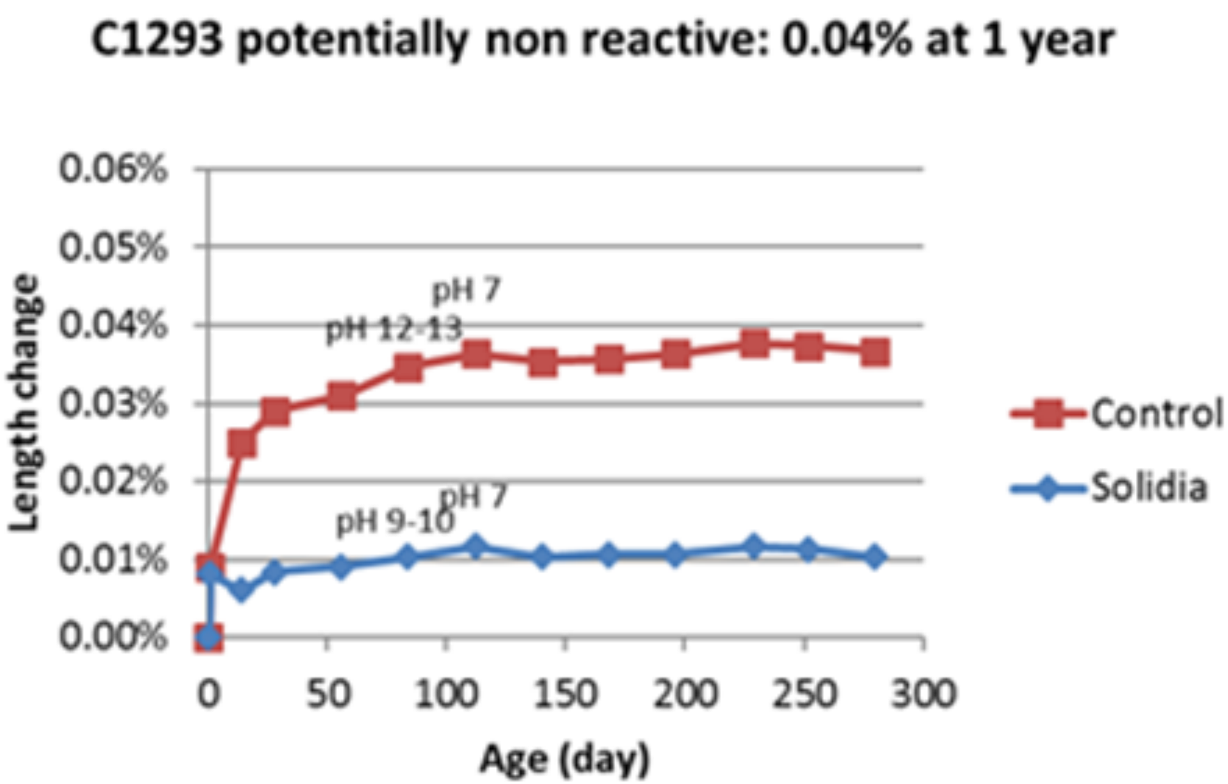


OPC Na_2Oe = 0.96%   SC-Pecs Na_2Oe = 0.86%

U.S. Department of Transportation
Federal Highway Administration

Solidia Technologies

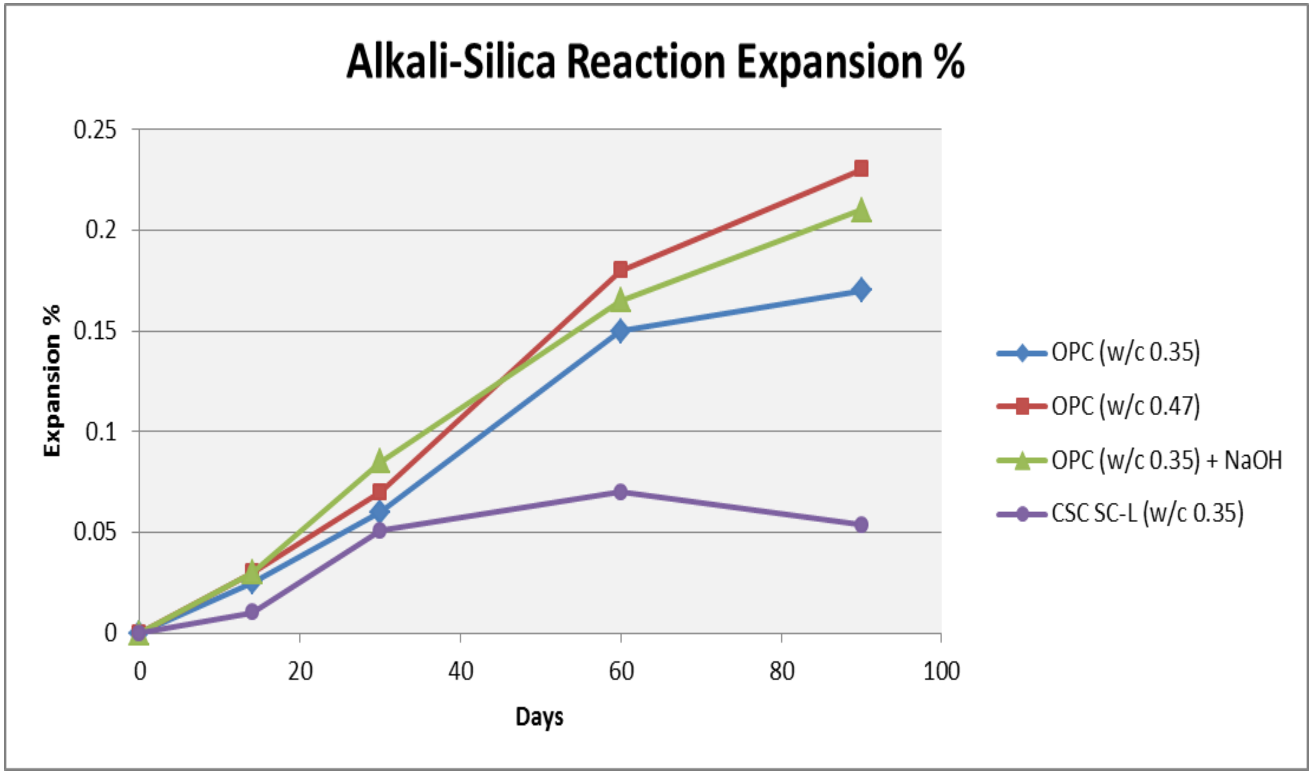
Length Change Concrete Samples



OPC $Na_2Oe = 0.96\%$ SC-Pecs $Na_2Oe = 0.86\%$

U.S. Department of Transportation
Federal Highway Administration
Solidia Technologies

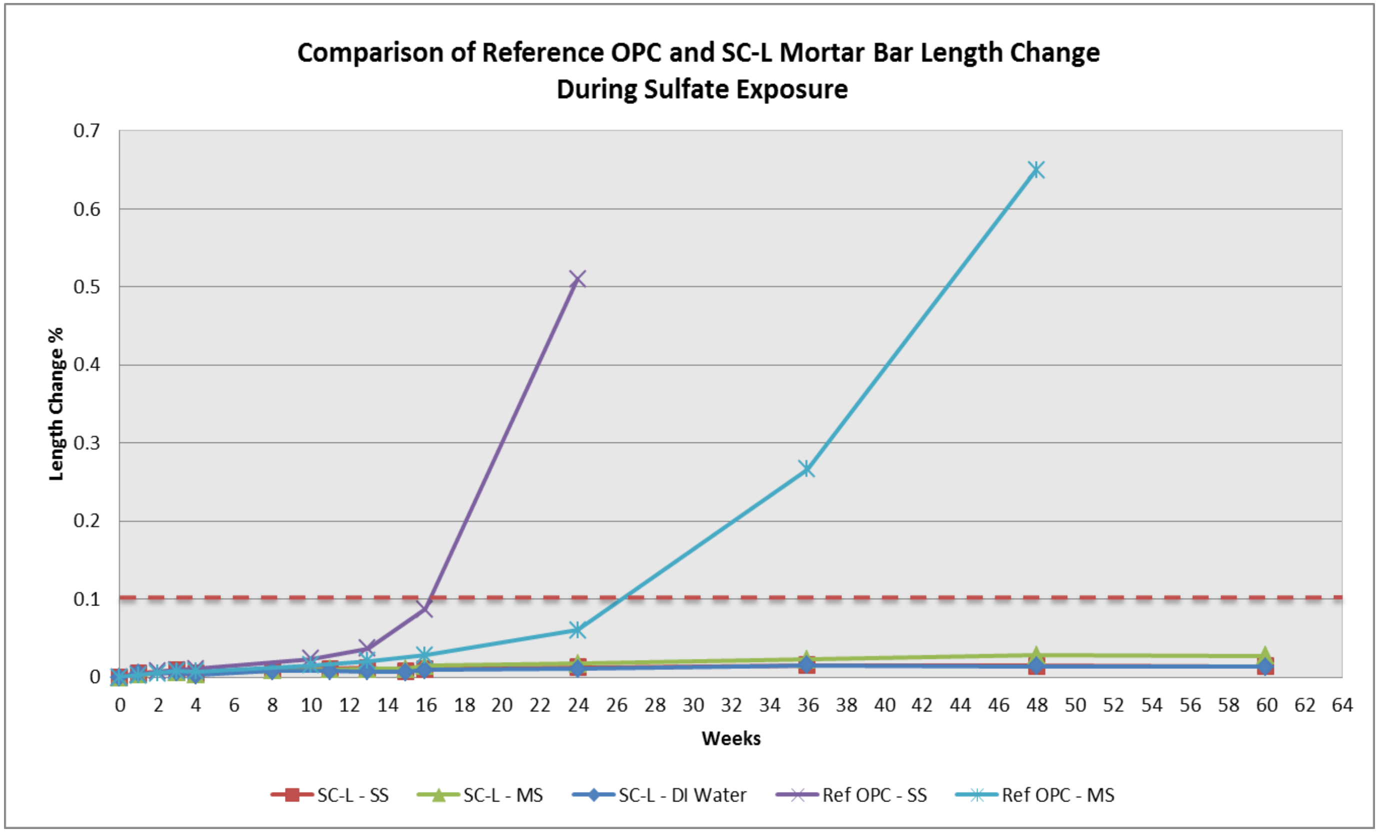
Length Change Mortar Samples



Test done at Purdue University by Jan Olek et al.
Jobe sand from Texas, SC-L Na_2Oe = 1.6

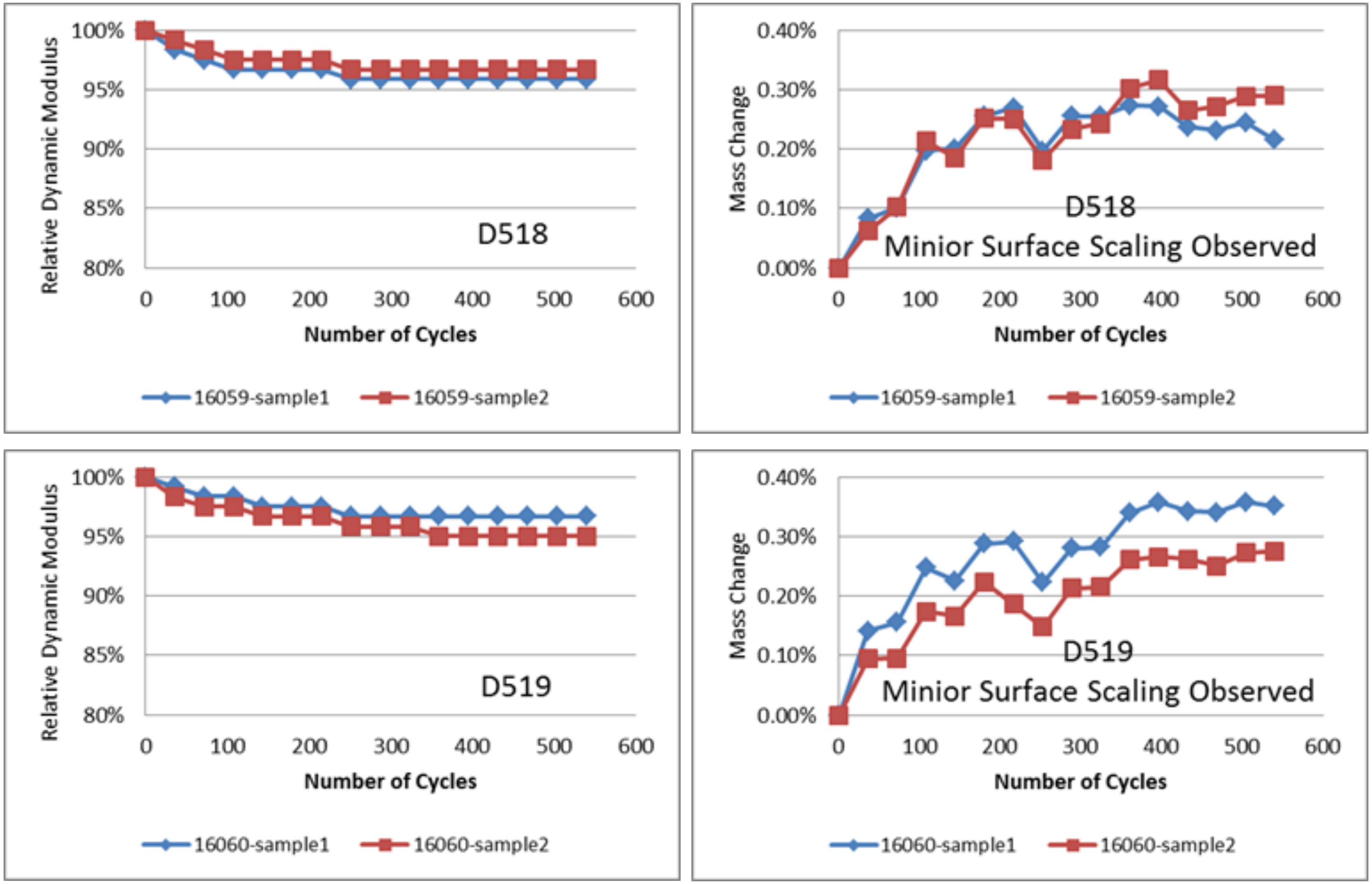
U.S. Department of Transportation
Federal Highway Administration
Solidia Technologies

Sulfate Resistance



Test done at Purdue University by Jan Olek et al.

Freezing/Thawing Testing



ASTMC-666 Procedure A

Summary

- Solidia Cement is a sustainable cement
  - ~30% reduction in CO_2 emissions during cement production
  - 30-40% CO_2 utilization during curing of concrete
- The mechanical properties of Solidia Concrete are equivalent or better than OPC-based concrete with a shorter curing period
- Solidia Cement has better resistance to ASR
- Solidia Cement has better resistance to sulfate attack
- Good performance in cold weather exposure
  - Passes freeze-thaw resistance in water as per ASTM C666 - procedure A (Relative dynamic modulus of elasticity >90% after 540 freeze-thaw cycles)

Acknowledgement

Where noted in the slides, work was performed under a cooperative agreement between Solidia Technologies and Federal Highway Administration (FHWA): DTFH6115H00020

Note: *The FHWA neither promotes nor endorses a particular technology; the cooperative research work was carried out so that FHWA and the highway community can gain knowledge about new technology and whether it might be applied to highway construction or maintenance.*