Sustainable Self-Consolidating Concrete: Utilization of Limestone Powders

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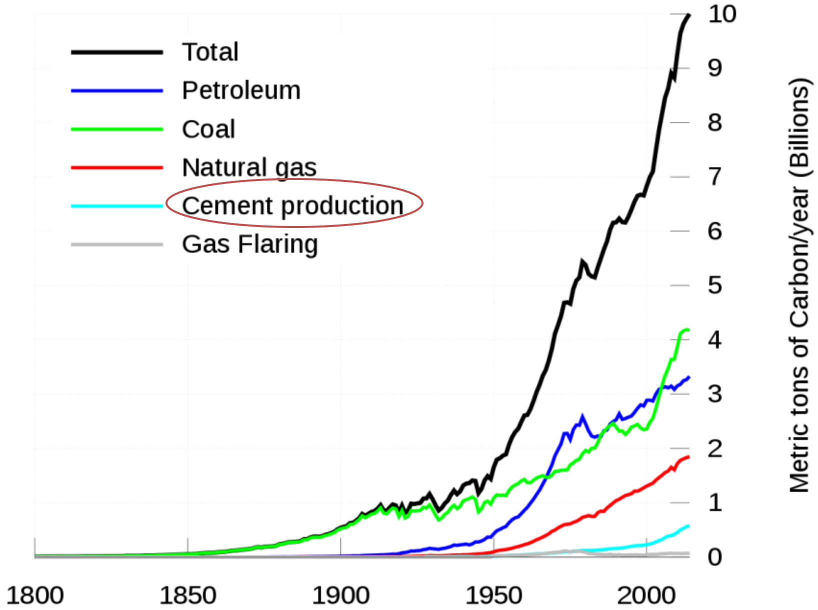
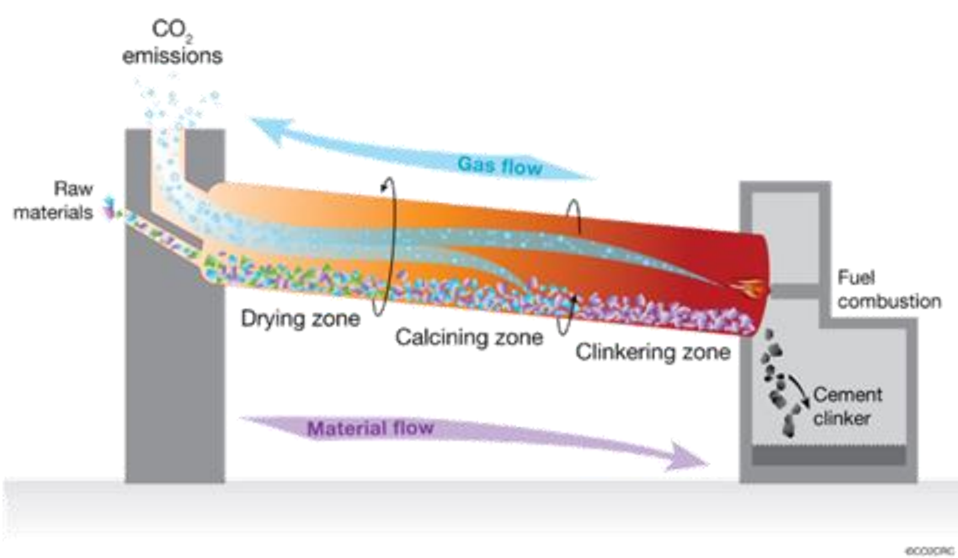
Background/Motivation

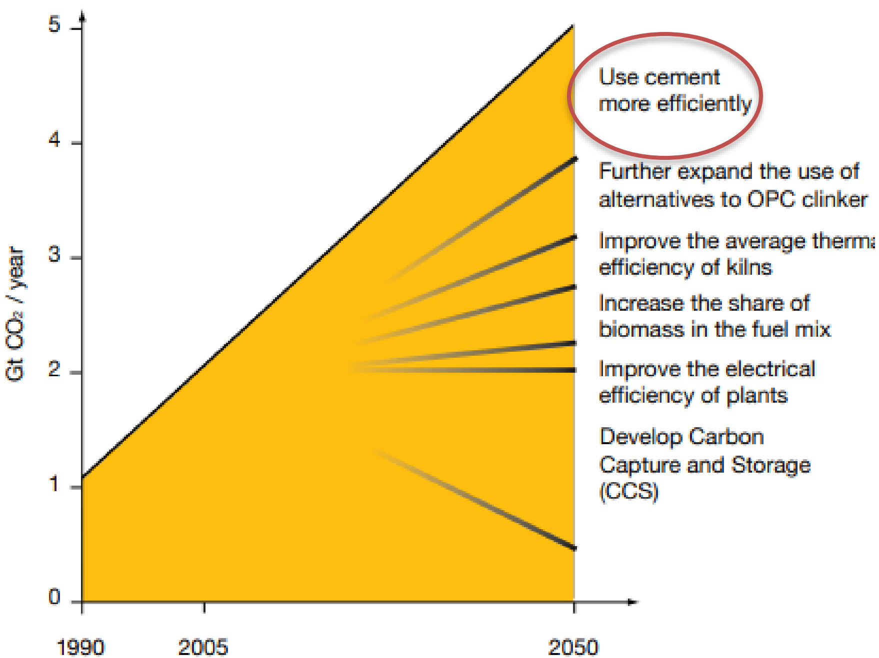
- Twenty *giga*tons of concrete are placed *each* year, a tripling over the past 20 years.
- Rate of concrete use outpaces population growth.
- Cement production is the 4th largest industrial contributor of anthropogenic CO_2

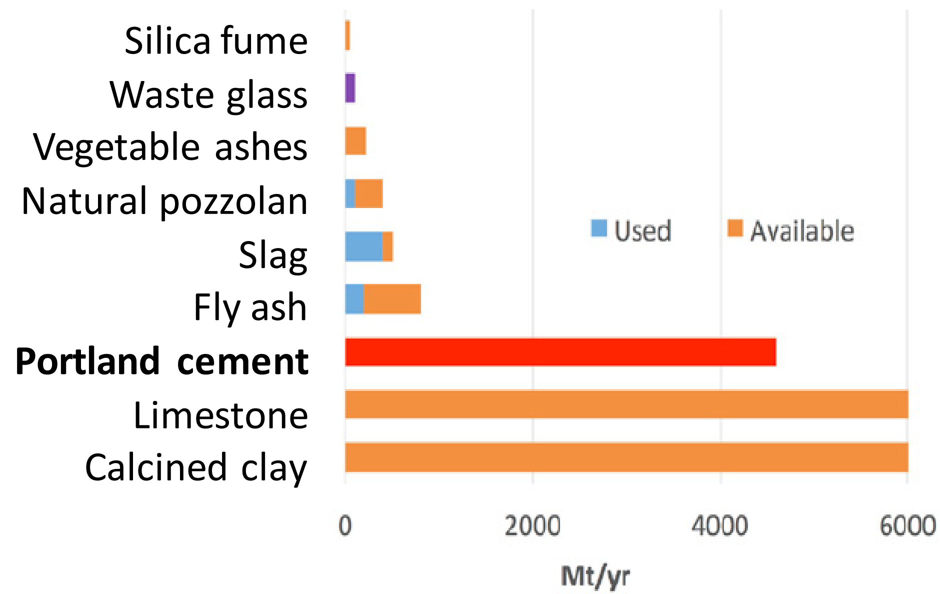




Background/Motivation

- One method proposed to reduce the carbon footprint is to use cement more efficiently
- Efficient cement use includes partial substitution of cement with: (1) Supplementary cementitious materials (SCMs) and/or (2) Mineral fillers
- Must be scalable

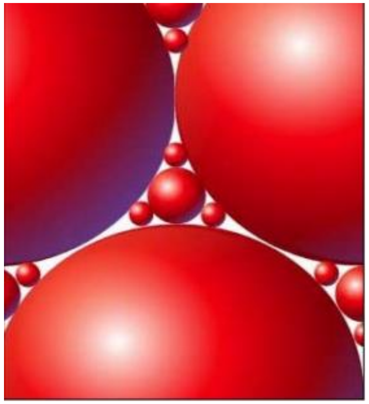




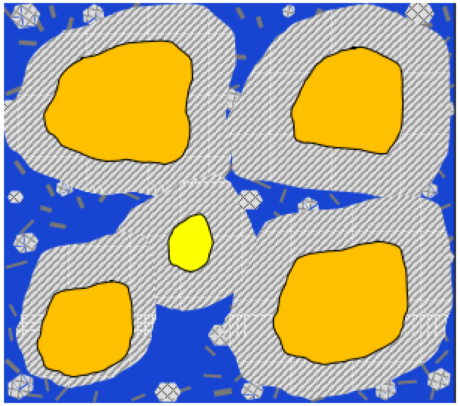
Hydration with Limestone

Limestone affects hydration in four main ways:

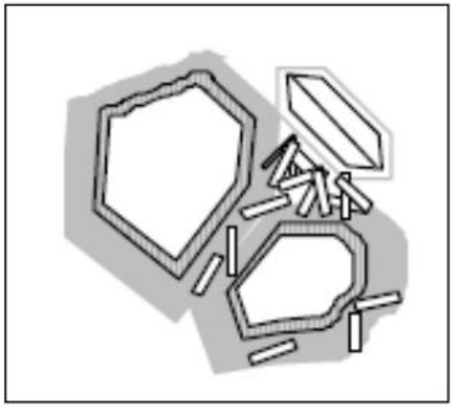
- Dilution – cement is being replaced by less reactive limestone
- Particle packing – by varying the size of the particles, you may get a more efficient packing structure
- Nucleation – fine limestone powders provide sites for CSH precipitation
- Chemical – unhydrated C_3A reacts with limestone to form monocarbonate and hemicarbonate



Improved particle packing



Nucleation Sites



Chemical Reaction

Precast Concrete

Requirements:

- Highly flowable → self-consolidating (SCC)
- Rapid set
- Rapid strength development
- Low shrinkage and creep
- Smooth surface finish

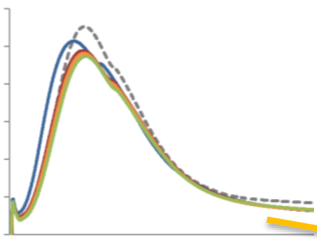
Limestone benefits (compared with fly ash)

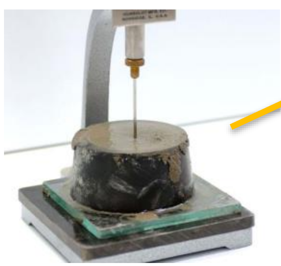
- Less wear and tear on equipment
- Improved workability and surface finish
- Cost savings ($46/ton vs $60/ton)
- Less seasonal variability

Research Objectives

To evaluate how SCC used for precast application is affected by:

- The median particle size of the limestone powder
- Cement replacement by mass (15% and 25%)



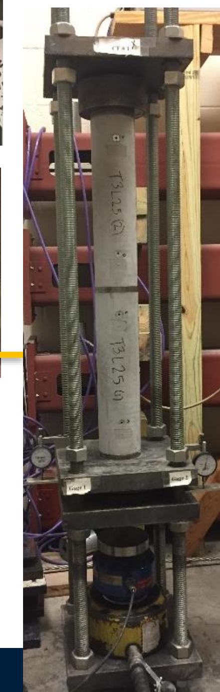


Cement Paste

- Hydration kinetics
- Time of set

Concrete

- Workability
- Compressive strength
- Creep
- Drying shrinkage
- Surface finish



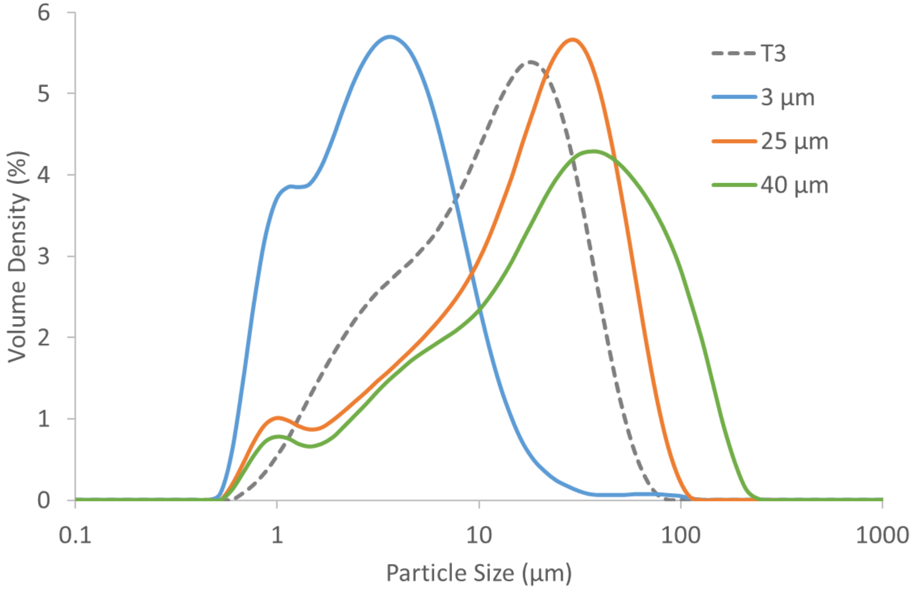
Limestone blended SCC

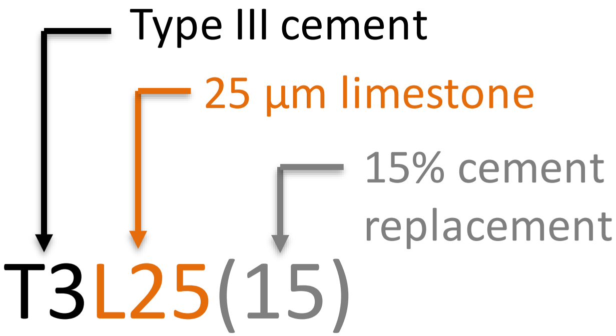
Cement:

- ASTM C150 Type III (T3)

Limestone Powders:

- 3 µm
- 25 µm
- 40 µm



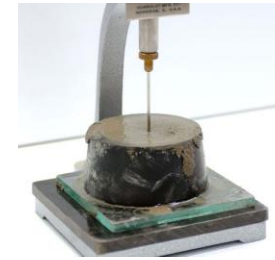


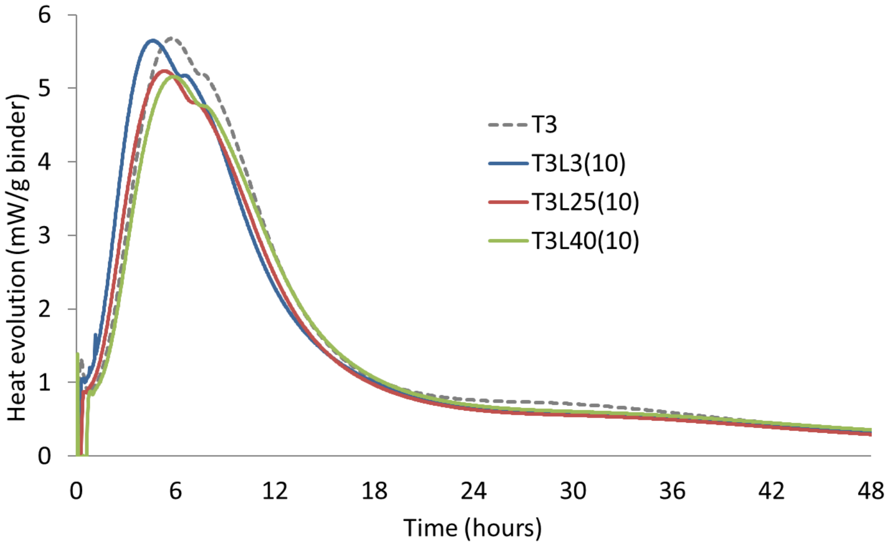
The 3 µm is finer than the cement, the 25 µm is similar, and 40 µm is coarser

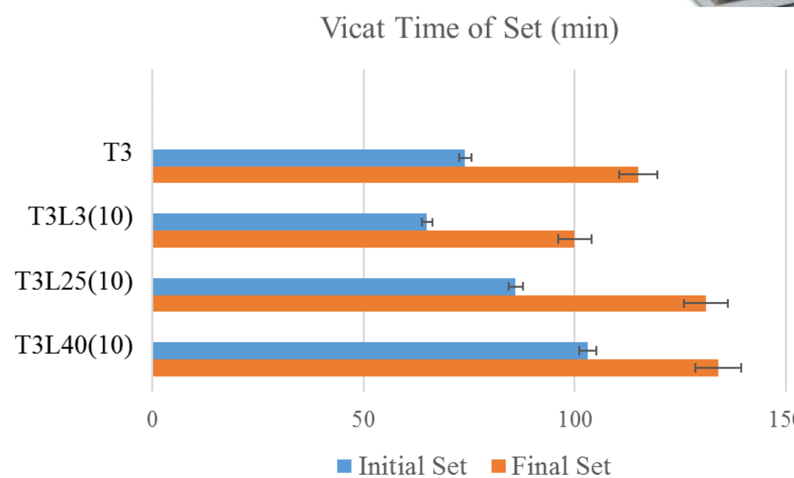
Reaction Rate and Set Time

At 10% cement substitution of:

- the 3 µm limestone accelerates hydration and set time
- the 25 µm limestone accelerated the time to peak but slows the set time
- the 40 µm takes longer to reach peak hydration and for time of set







Time to peak (@ 10% substitution)

3 µm	25 µm	40 µm
-19%	-8%	+2%

Time to set (@10% substitution)

	3 µm	25 µm	40 µm
Initial:	-12%	+16%	+39%
Final:	-13%	+14%	+17%

Concrete Workability

Concrete Mix Proportions

		0%	15%	25%
Material *lb/yd³*	cement	850	725	637
	limestone	-	125	213
	water	340	340	340
	w/b	0.40	0.40	0.40
Aggregate *lb/yd³*	#67 stone	1724	1724	1724
	natural sand	1200	1200	1200
HRWRA	*oz/yd³*	38-54	38-60	31-48
	oz/cwt	4.5-6.4	4.5-7.0	3.6-5.6

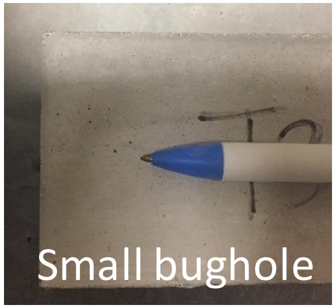
For all mixes:

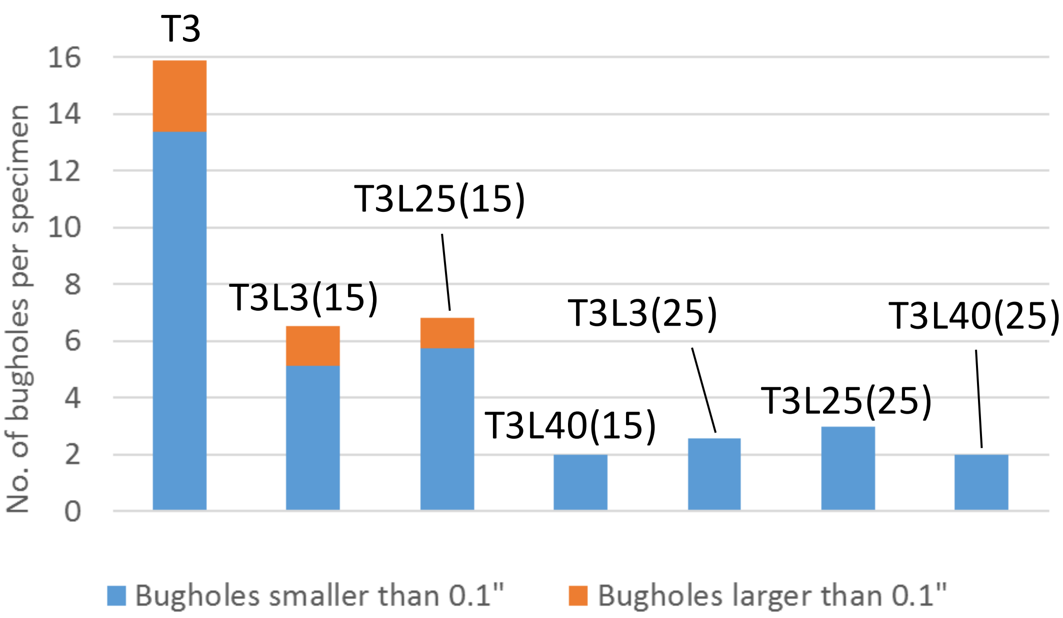
- Slump flow ranged from 20 – 27 inches
- T_{20} of 3 or 4 seconds
- Visual Stability Index (VSI) ranged from 0 to 1

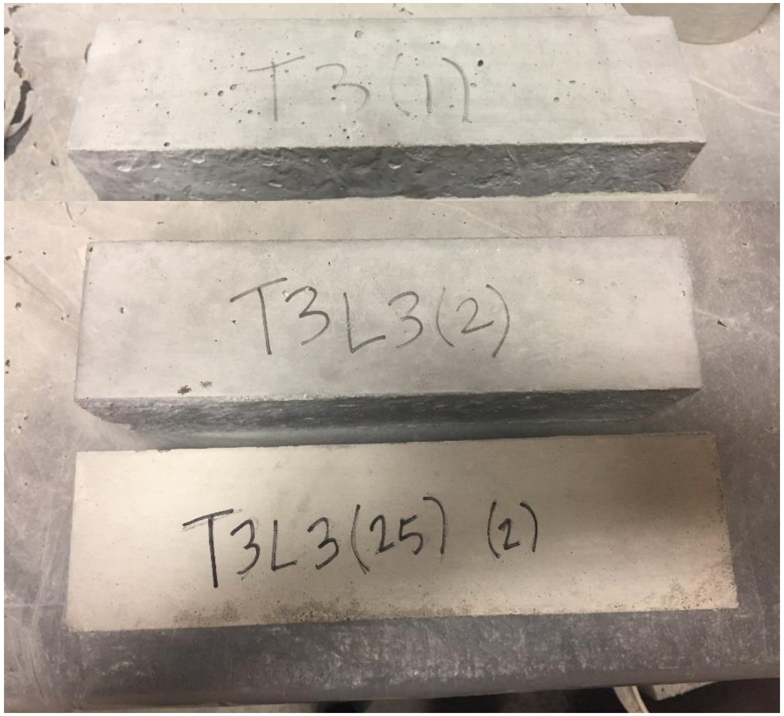
- Mixes made without limestone or with 3 µm limestone powder required more HRWRA
- Mixes made with the 40 µm limestone required less HRWRA

Surface Finish

The surface finish of concrete specimens were evaluated by counting the number of large and small bugholes present on the surface







Surface finish of concrete without limestone (top), with 15% limestone (middle) and 25% limestone (bottom)

Concrete Workability

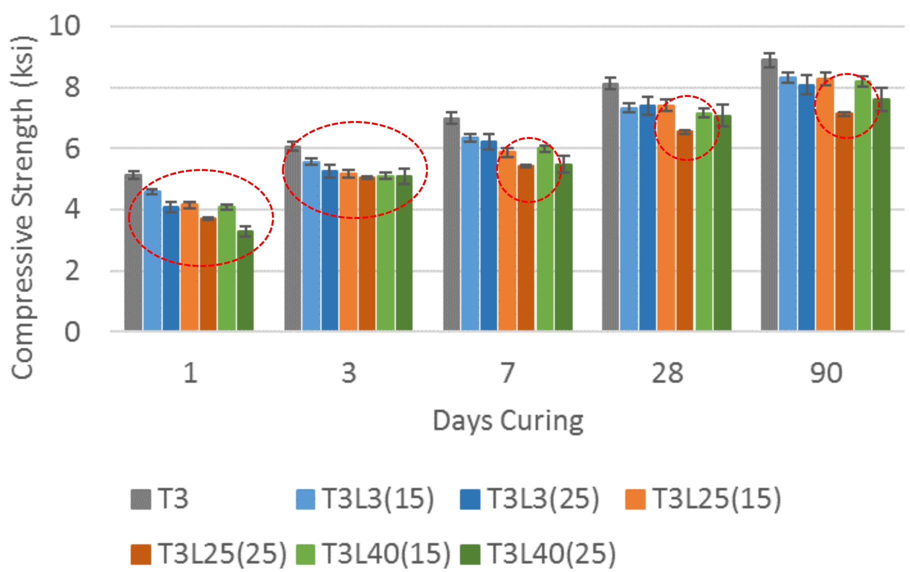
Effect of Mixer

Revolving drum mixer

High shear mixer

Compressive Strength

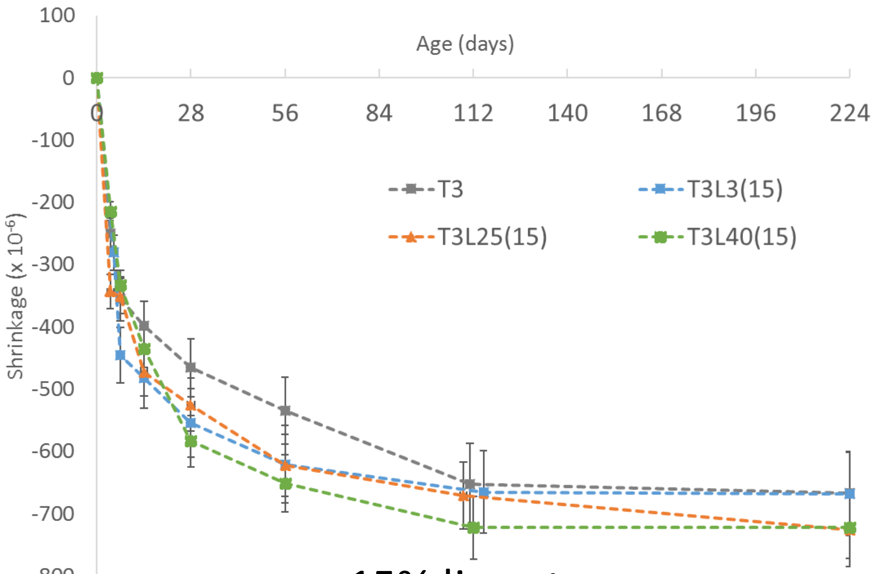
- Compressive strength was evaluated at 1, 3, 7, 28, and 90 days of curing
- After 3 days, there is little difference in strengths
- In general, the 25 µm limestone @ 25% replacement produced the lowest strengths after 7 days



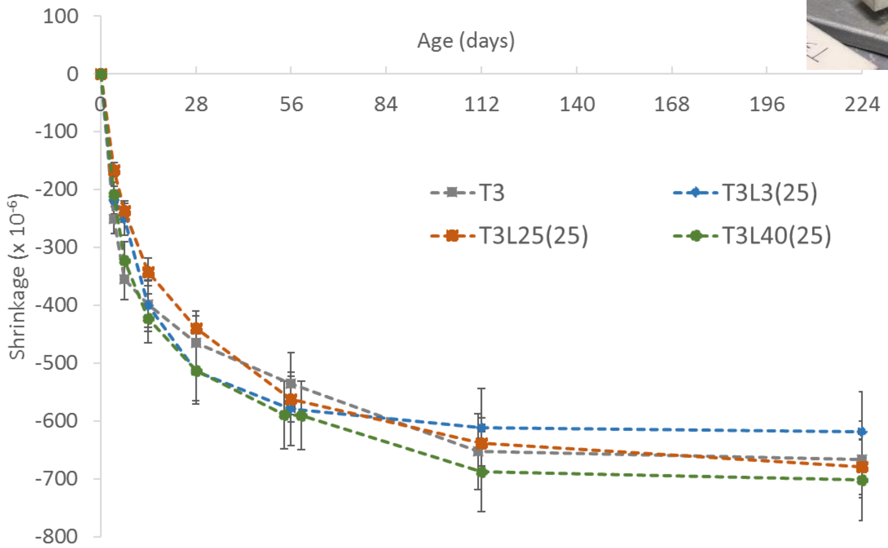
Drying Shrinkage

Specimens were allowed to air dry after 24 hours curing in fog room:

- The drying shrinkage of mixes ranged from 480 to 580 microstrains at 28 days
- There is little variability in the amount of drying shrinkage among the mixes
- Specimens with more limestone (25%) experienced less shrinkage (15%)



15% limestone

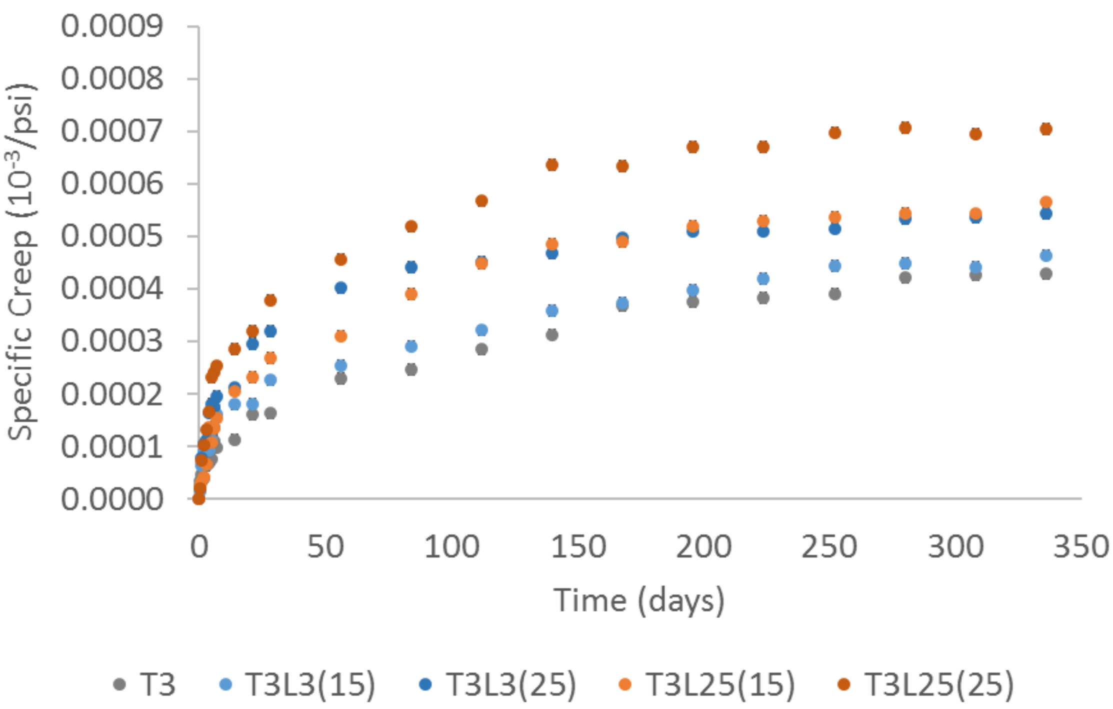


25% limestone

Specific Creep

Specific creep = (basic creep + drying creep) / applied load

- The T3 mix and T3L3(15) show the lowest amount of creep strain
- The T3L3(25) and T3L25(15) had similar creep strains
- The T3L25(25) mix show the highest amount of creep strain



40% f'_{cm3}

Creep cylinders in compression frame

Conclusions

Using limestone powder as partial cement replacement at 15 and 25% is viable for self-consolidating concrete mixes and allows for the tailoribility of concrete mixes

<u>Effect of limestone median particle size:</u>

- 3 µm - accelerates hydration and set time – leading to higher early strength (1 day), less shrinkage and lower creep rate – but produce less workable mixes which require higher doses of HRWRA
- 25µm - has a dilution effect, moderate change in set time, slower compressive strength development, but has good workability
- 40 µm - slows down hydration, has slower compressive strength development, but produces mixes with greater workability and surface finish

The 25 µm limestone powder at 25% cement replacement showed the greatest dilution effect – the lowest compressive strength and the highest creep rate, and is not recommended for use

Acknowledgements

PCI

METROMONT

Tindall

IMERYS
TRANSFORM TO PERFORM

LafargeHolcim

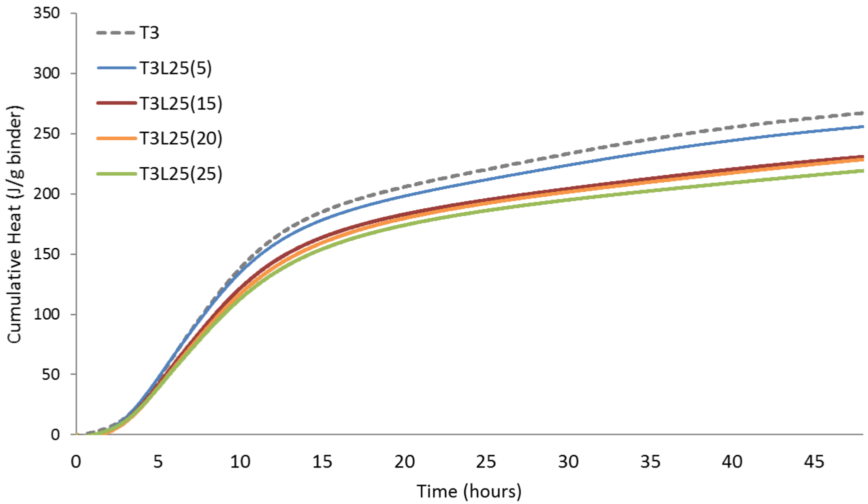
+ undergraduate assistants

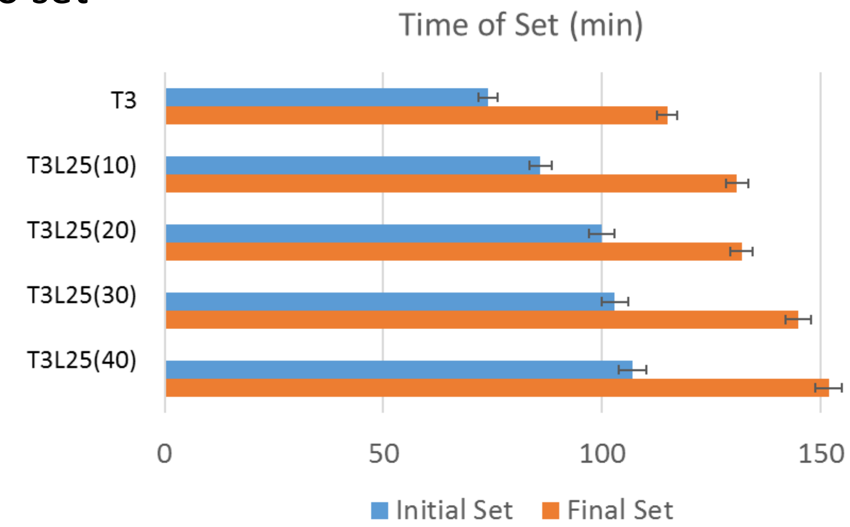
Thank you and questions?

Cumulative Heat and Set Time

As the amount of cement substitution increases, cumulative heat reduces and:

- all three limestone decrease total heat
- the 3 µm limestone has minimal effect on set time
- the 25 and 40 µm limestone takes longer to set





Total heat: for each 10% substitution

3 µm	25 µm	40 µm
-5%	-7%	-9%

for each 10% substitution

	3 µm	25 µm	40 µm
Initial:	-3%	+11%	+35%
Final:	+3%	+8%	+32%