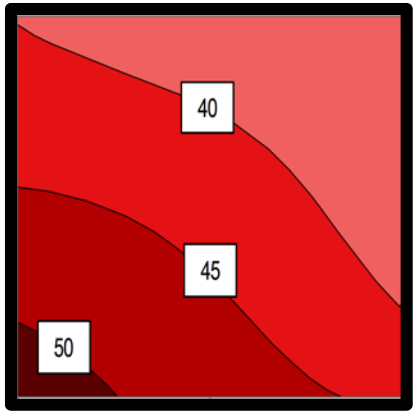
Development and Analysis of Low Embodied Carbon Concrete Mixtures for Use in Transportation Applications



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NJDOT Research Showcase
Infrastructure Breakout Session
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Research Collaborators

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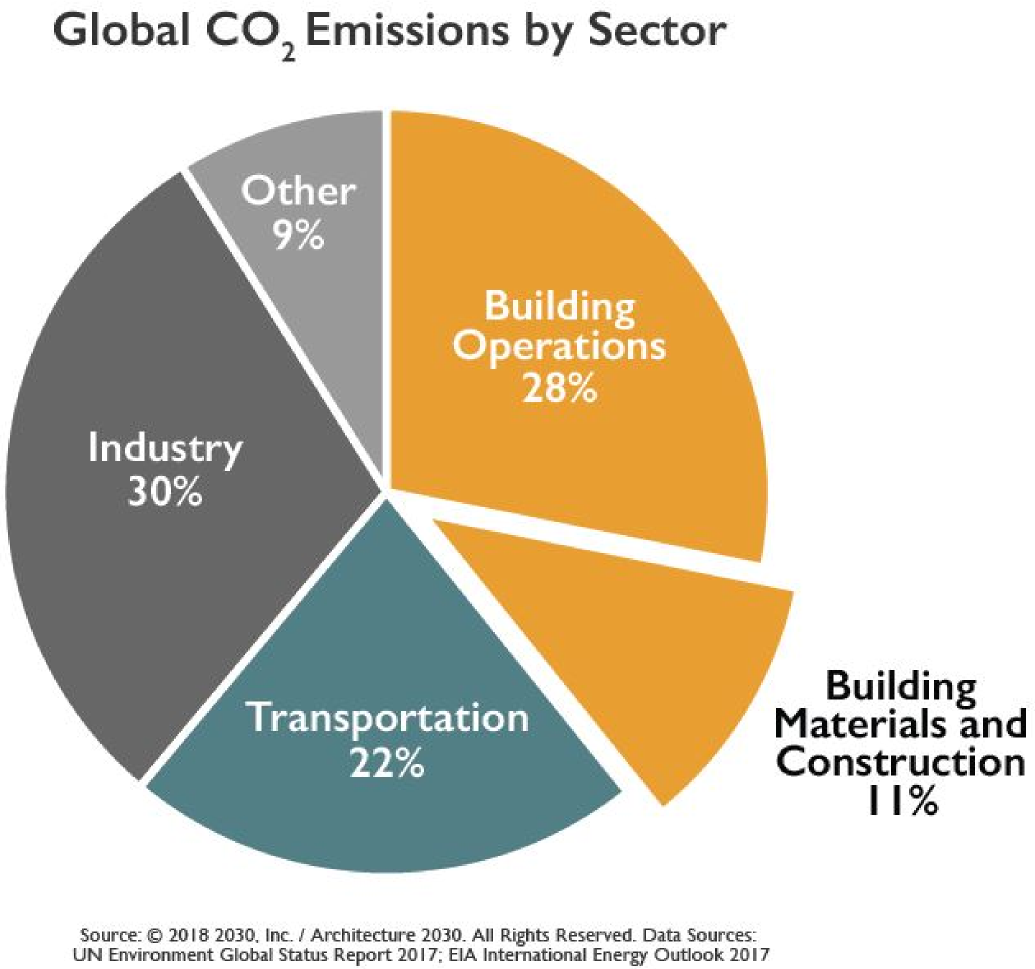
INTRODUCTION

- Building materials and construction account for 11% of global CO_2 emissions
- Concrete production is responsible for 8% of global CO_2 emissions



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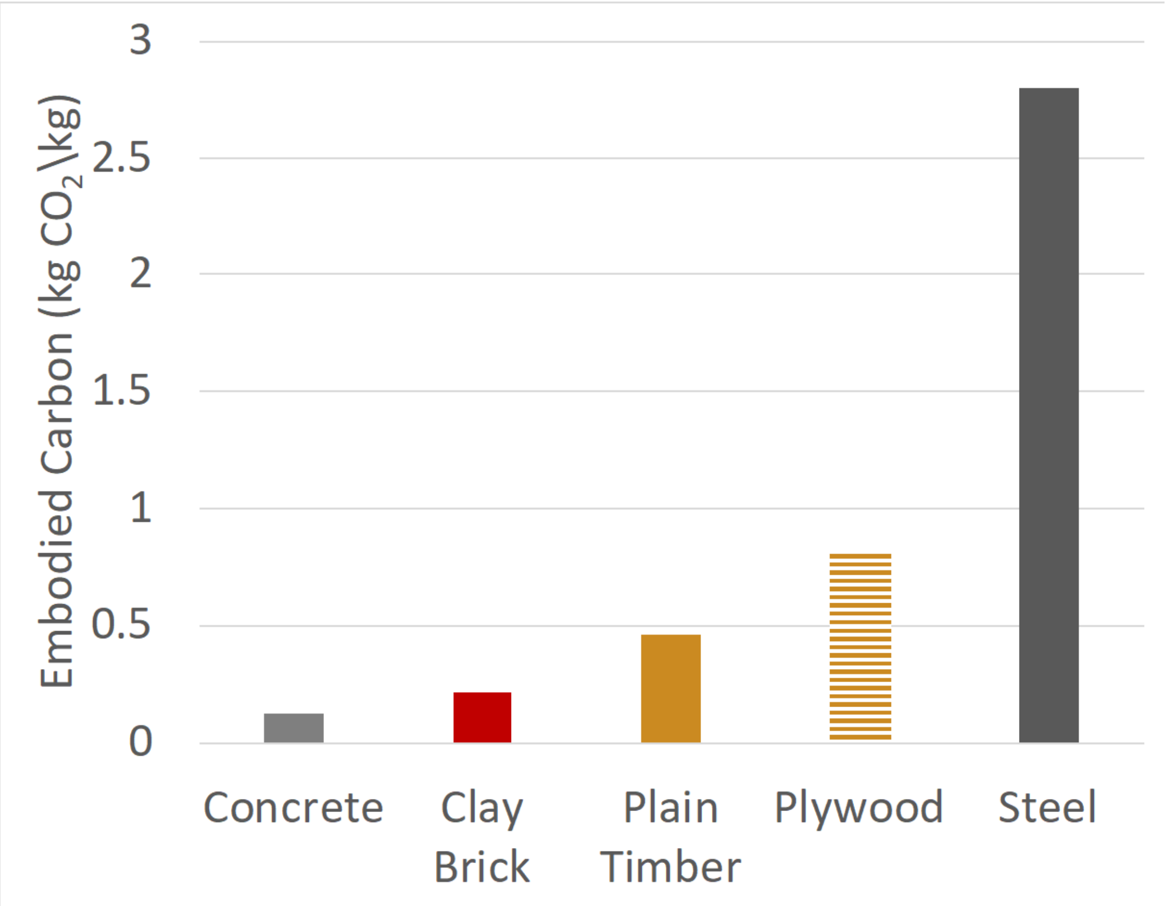
Source of Embodied Carbon

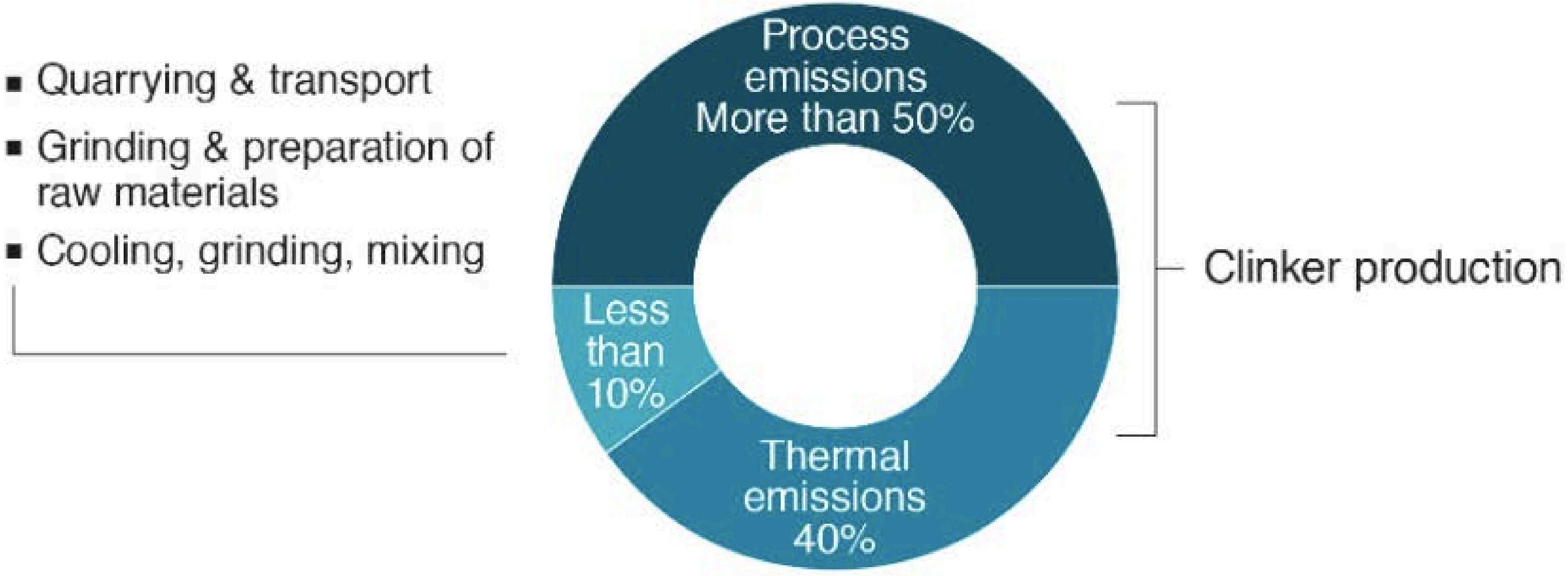
- Reinforced concrete has a low embodied carbon per unit volume
- Scale of production of concrete is the main cause of the high level of carbon emissions associated with concrete
- Over 400,000,000 yd^3 produced in US each year, or ~ 615 Hoover Dams



Data from: Scrivener et al. 2014 and Hammond and Jones 2008

Embodied Carbon in Concrete

- >90% embodied CO_2 in a portland cement mixture is from cement production
- Mostly from the processing of limestone



Embodied CO_2 Allocation by Cement Production Process

Research Program Background

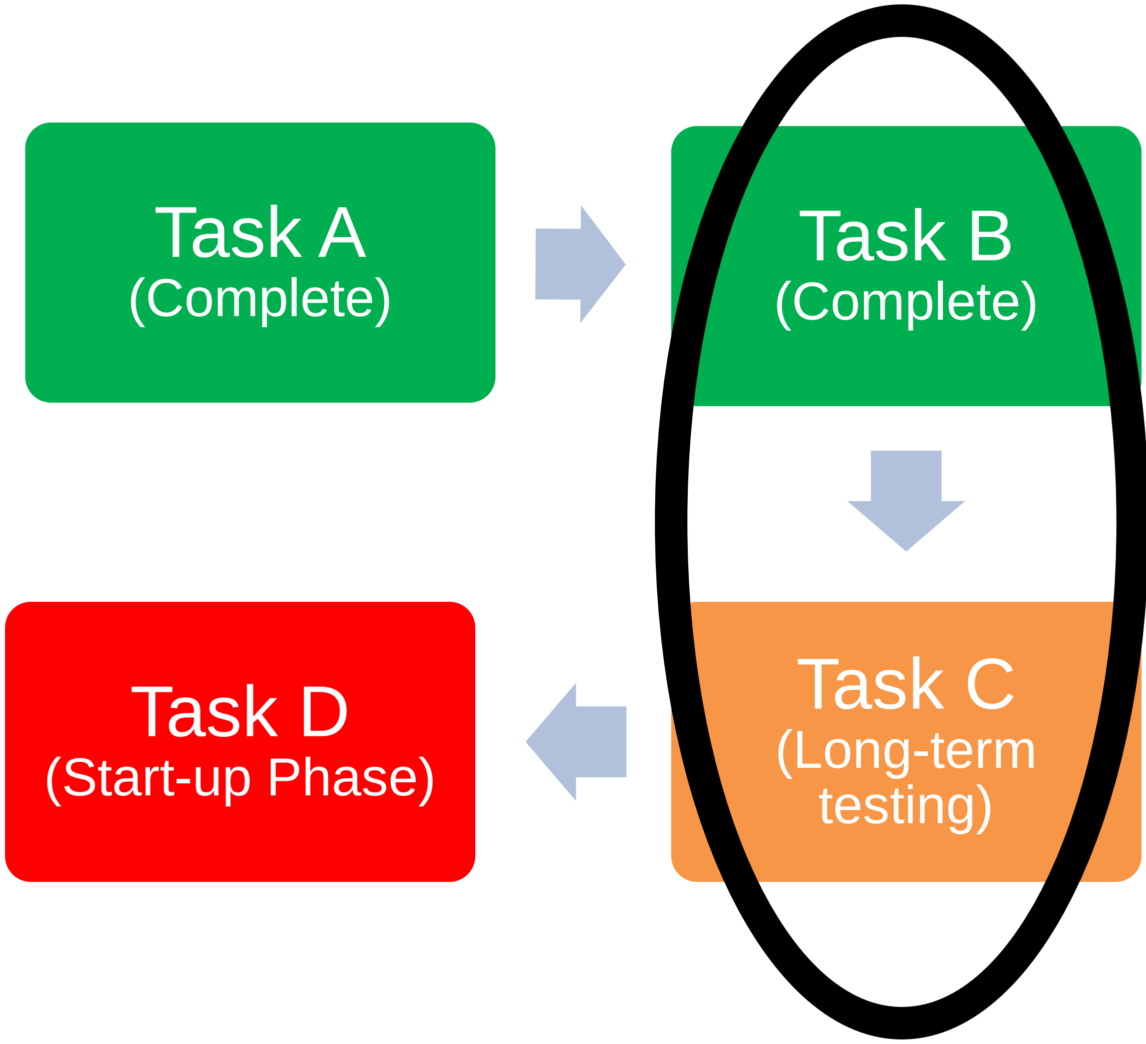
- The Port Authority is committed to meeting the goals of the Paris Climate Agreement to reduce greenhouse gas emissions by at least 35% by 2025 and 80% by 2050

- The Port Authority is a leader in sustainable construction and design, and should maintain that status

- Engaged our research team to help meet the objectives of the Low Carbon Concrete Pilot Program

Low Carbon Concrete Pilot Program

- Task A: Analyze and calculate the current state of embodied carbon in Port Authority concrete mixtures
- Task B: Determine proper application of locally available mixture design and technologies with lower embodied carbon
- Task C: Understand the performance of potential low carbon concrete materials through performance testing
- Task D: Confirm field performance of low embodied carbon concrete systems through pilot field studies and performance monitoring

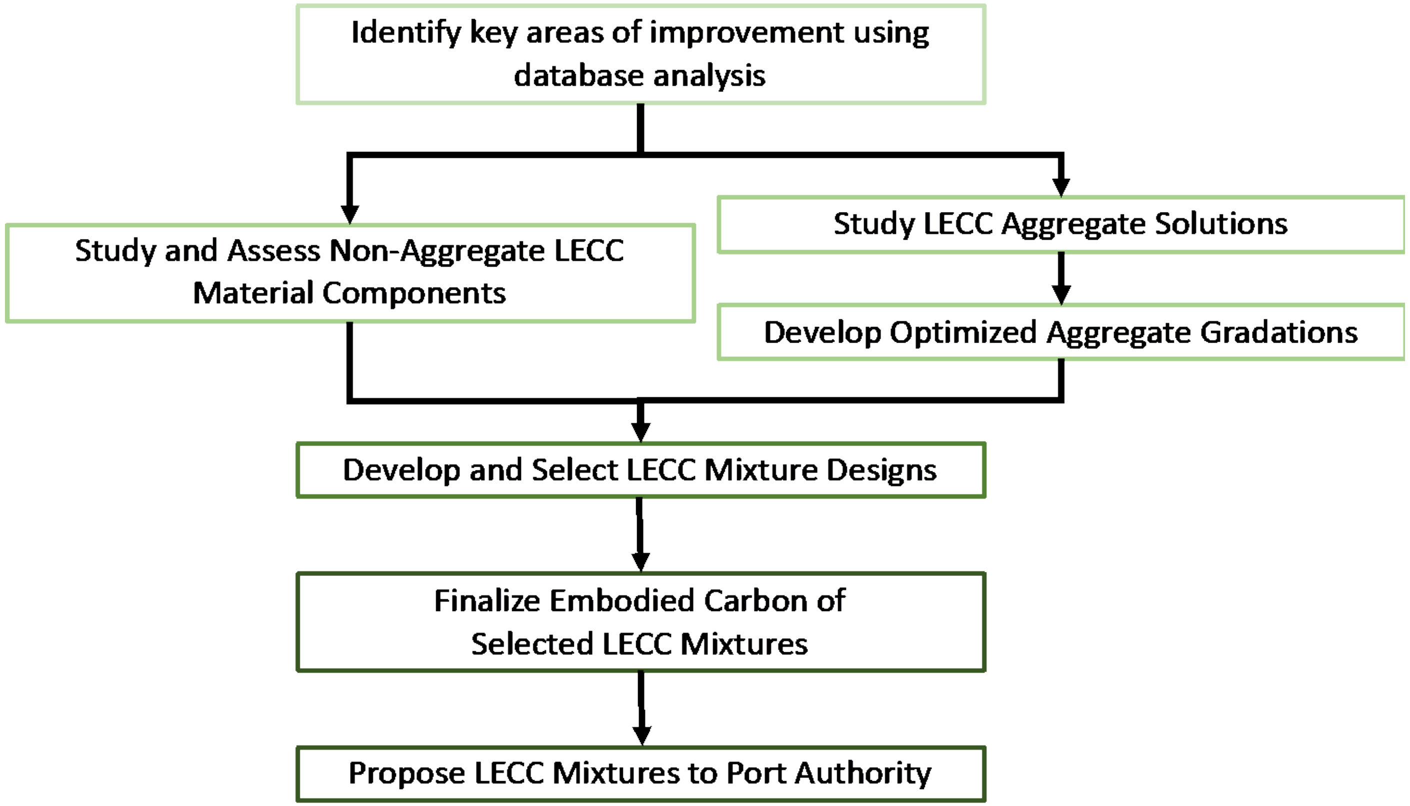


TASK B: OVERVIEW

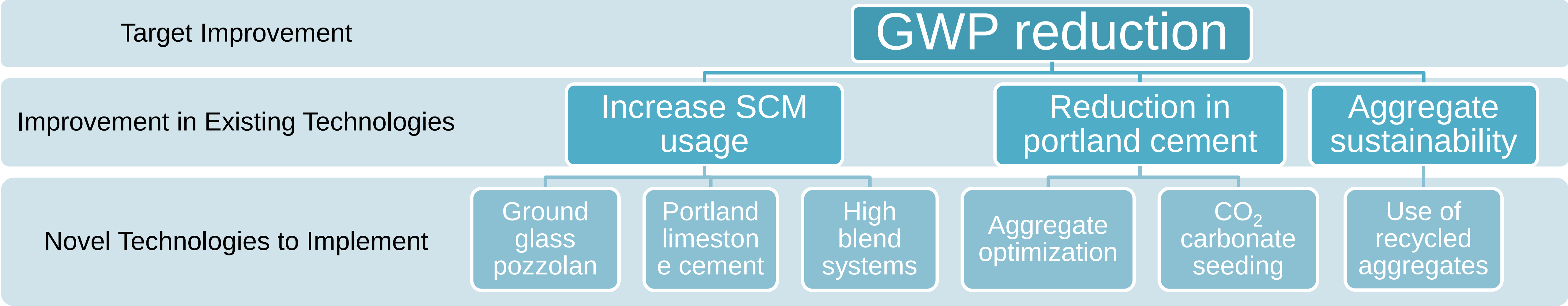
Objective

- Develop and propose 20 mixtures using LECC technology
- Determine potential GWP of proposed mixtures
- Technologies must be market ready

Methodology

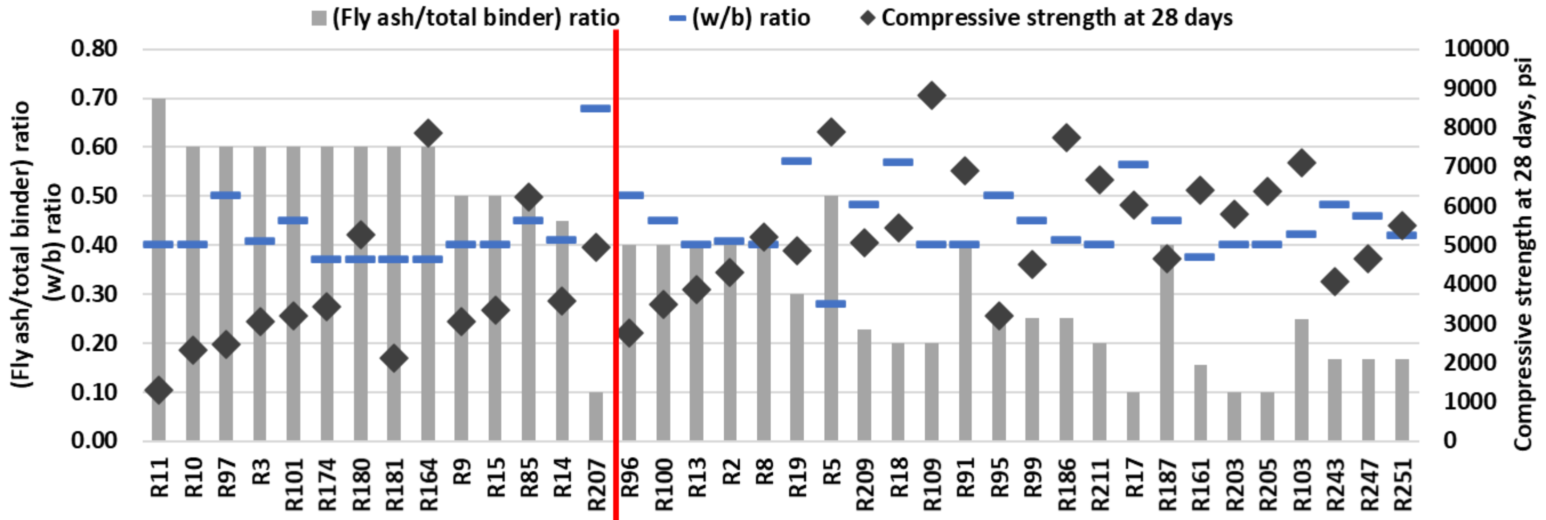


Task B: Key areas for improvement



TASK B: EXAMPLES OF INCREASING SCM USAGE

Determining allowable fly ash content

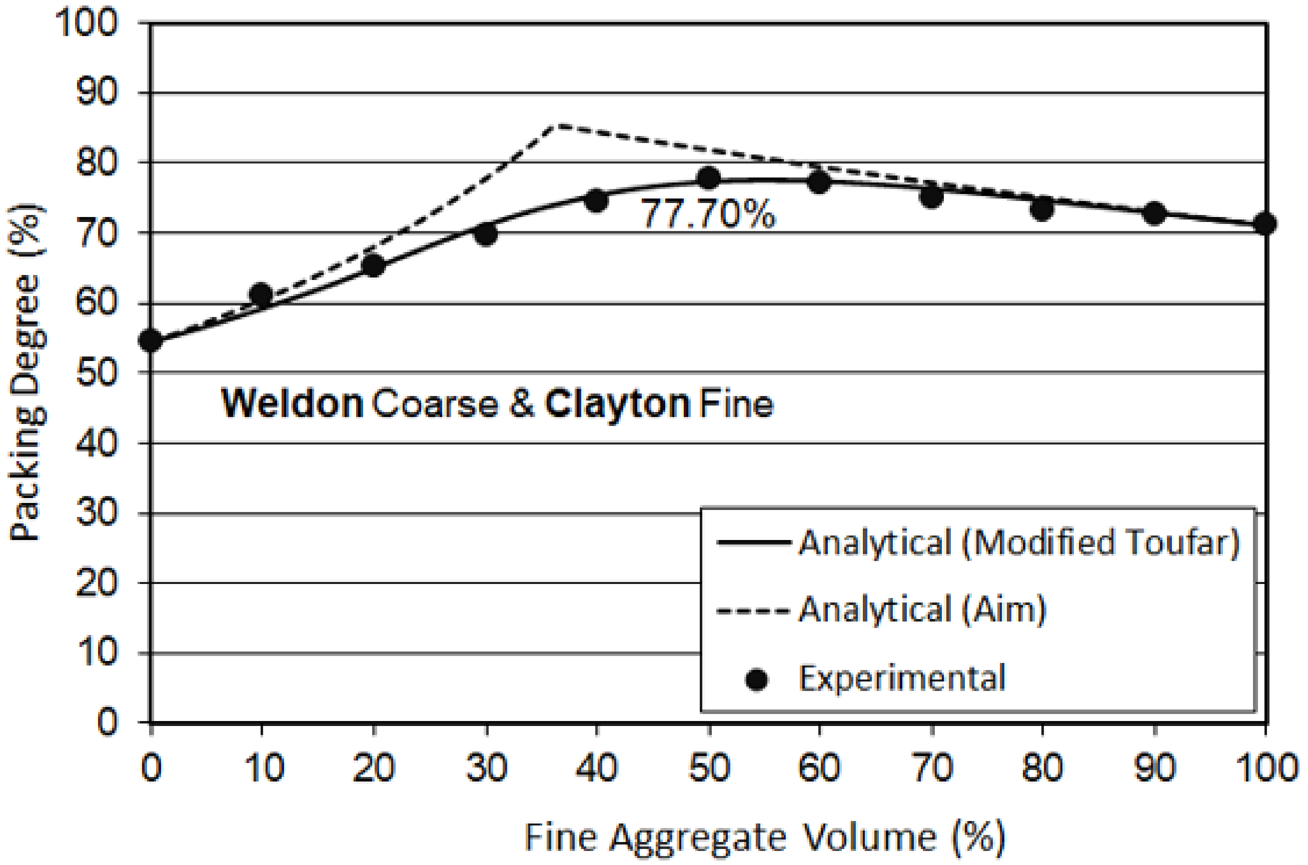


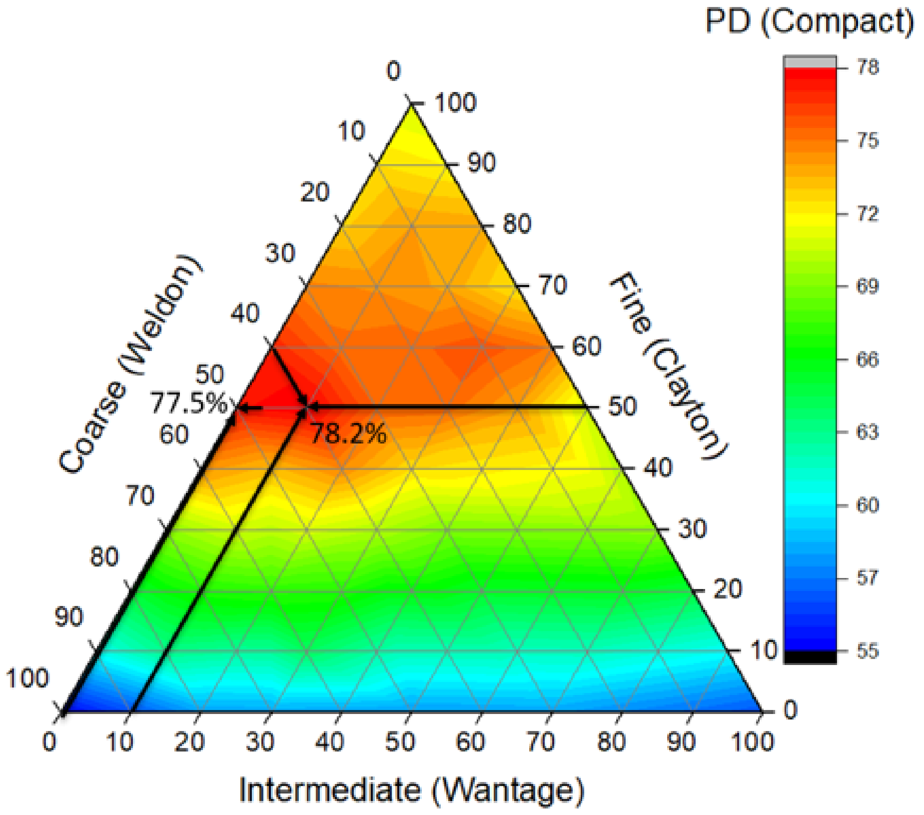
Database Mix ID	Proportion (lb/yd^3)					Ratio		Strength (psi)
	Cement	Fly ash	Coarse aggregate	Fine aggregate	Water	w/b	SCM/b	28 days Comp. strength
R85	337	337	1709	1247	303	0.45	0.5	6237
R2	405	270	1996	1153	275	0.4	0.4	4299

Mixture ID	FA_40%	FA_50%
Portland Cement Content (lb/yd^3)	360	300
Fly Ash Content (lb/yd^3)	240	300
w/b	0.4	0.4
SCM Content	40%	50%

Task B: Example of Cement Reduction

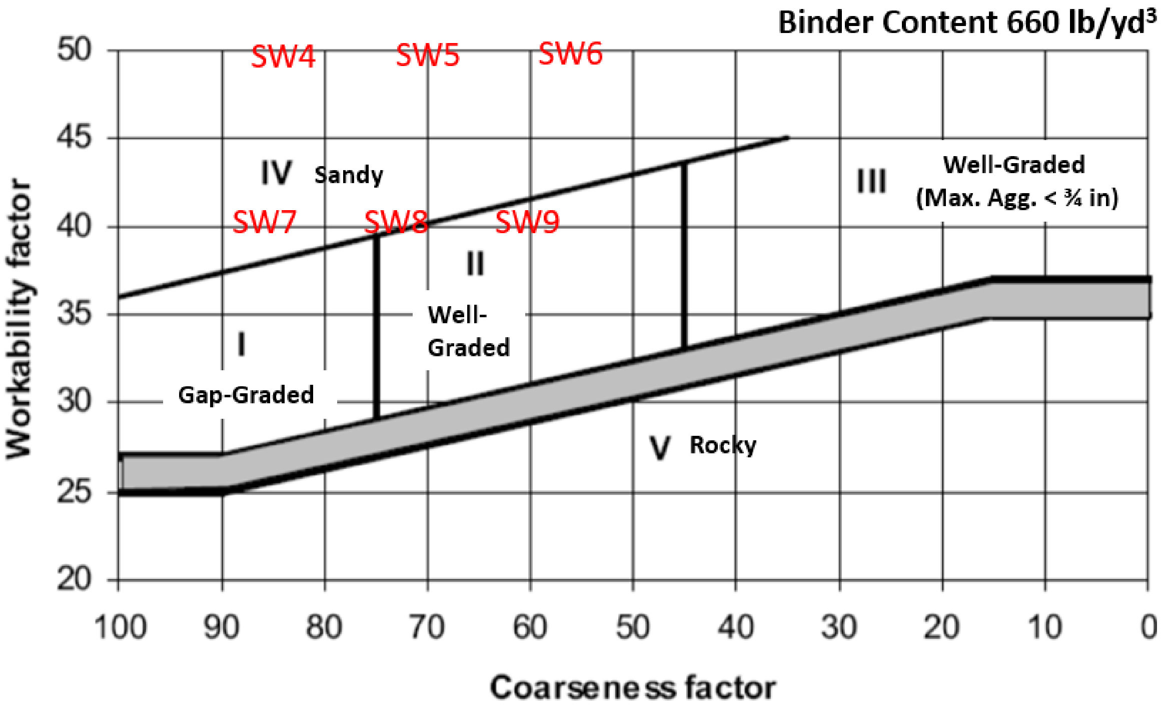
Optimizing aggregate particle packing

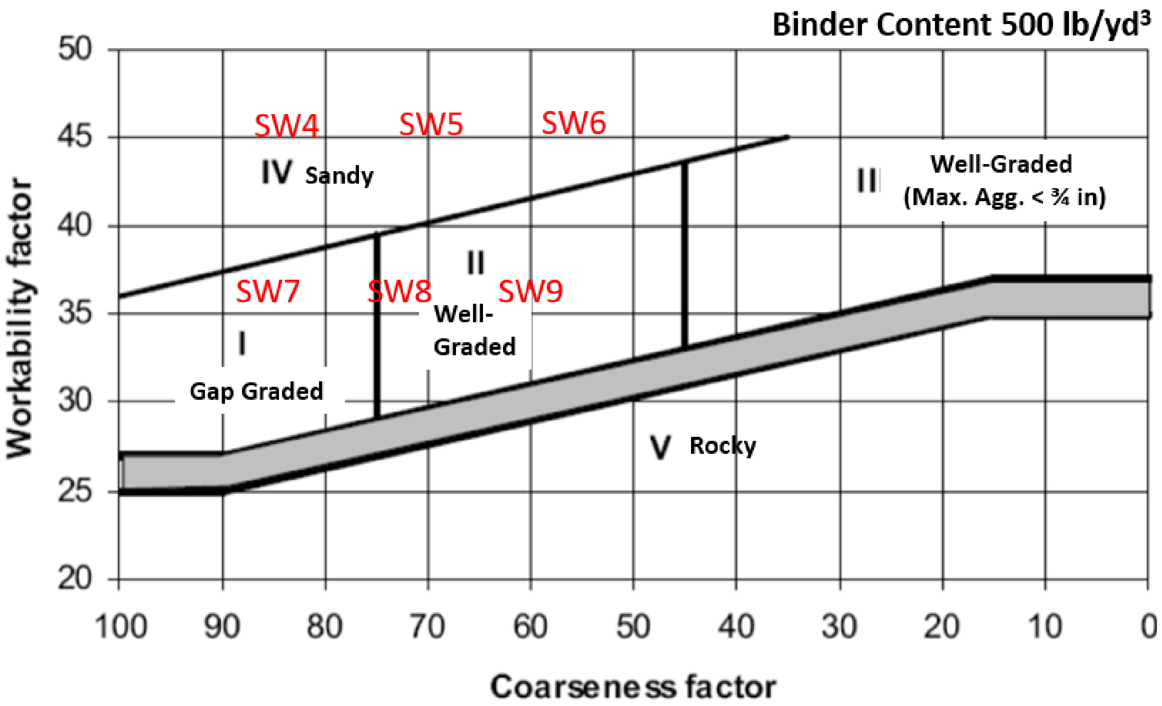




Task B: Example of Cement Reduction

Optimizing aggregate particle packing

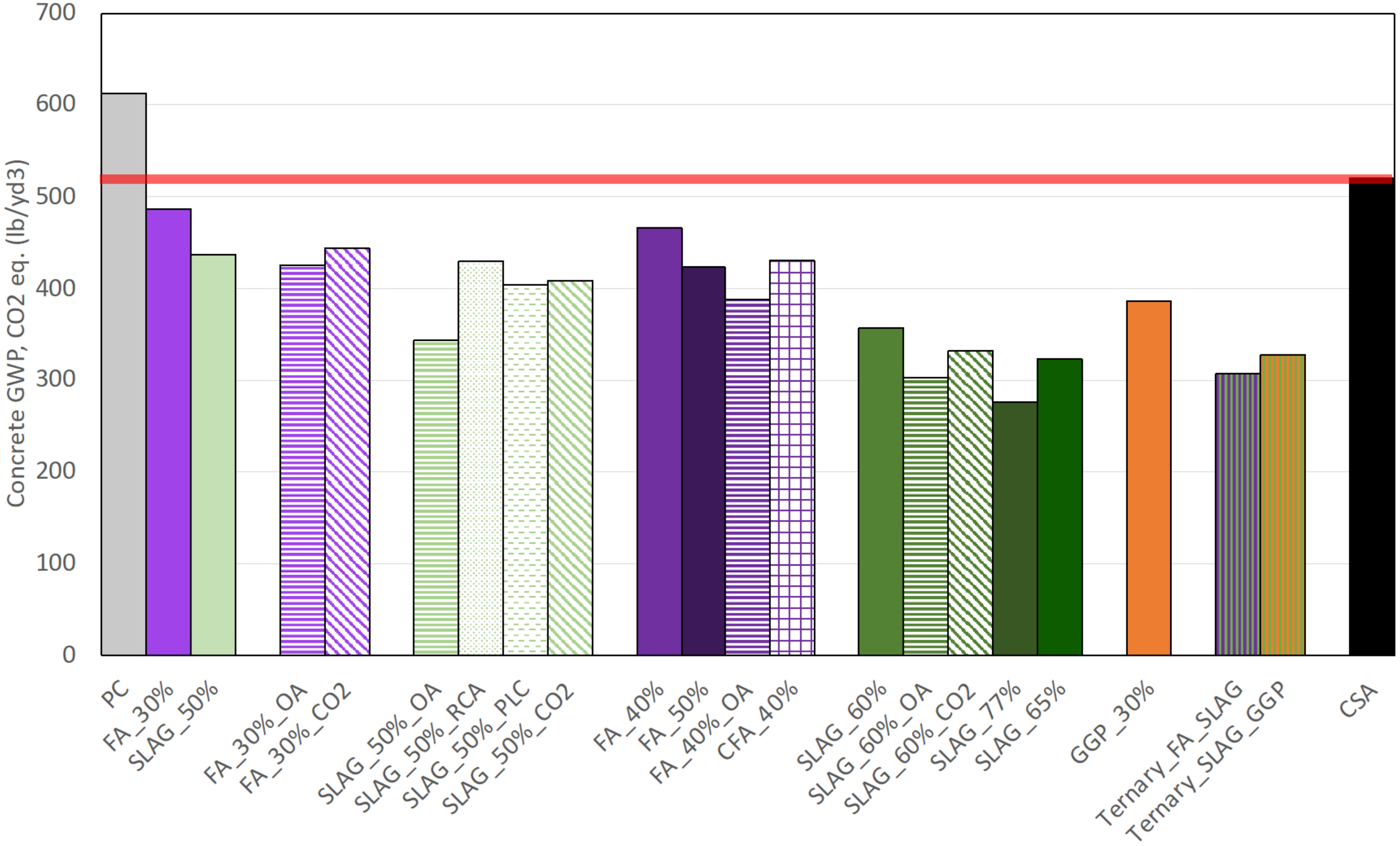




Task B: Proposed Mixtures

- Higher SCM contents provide the biggest GWP improvements

- Aggregate optimizations provide significant GWP reductions



TASK C: ANALYSIS AND TESTING OF MIXTURES

Objective

- Complete laboratory testing to assess suitability of proposed low-carbon concrete mixtures for use in Port Authority projects
- Recommend potential mixtures for pilot testing in field trials

Methodology

Cast trial mixtures to final mixture designs

Cast finalized mixtures and measure fresh properties
- Workability, Setting time, Air content

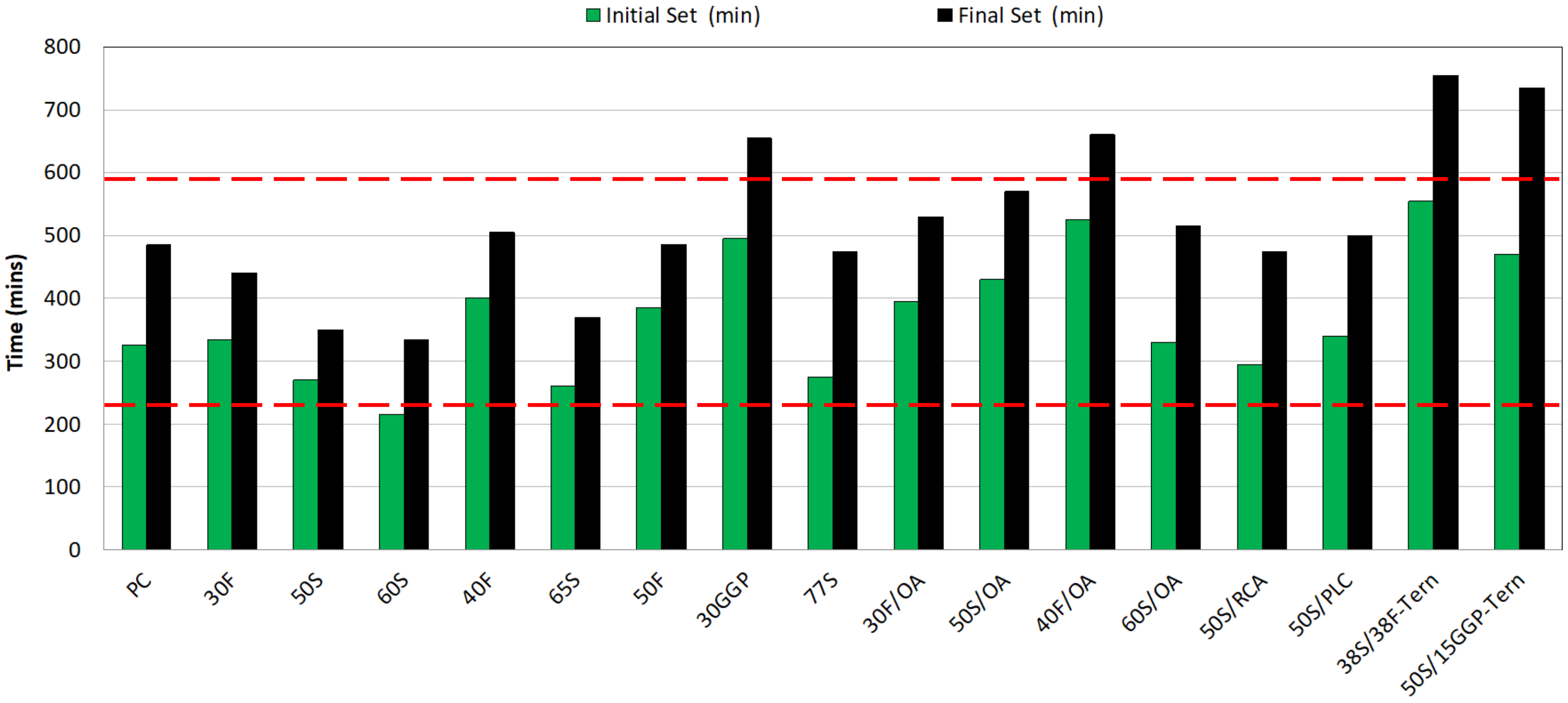
Measure hardened properties of systems
- Strength
- Freeze-thaw resistance, Drying shrinkage, Permeability

Analyze performance and recommend trial systems for field testing

TASK C: FRESH PROPERTIES TESTING – SETTING TIME

Setting Time – Construction timelines and labor requirements

- Acceptable initial setting times for all mixtures
- Final set times ran long on systems with fly ash and ground glass pozzolan
- Could use accelerators to shorten the setting time of slow setting systems



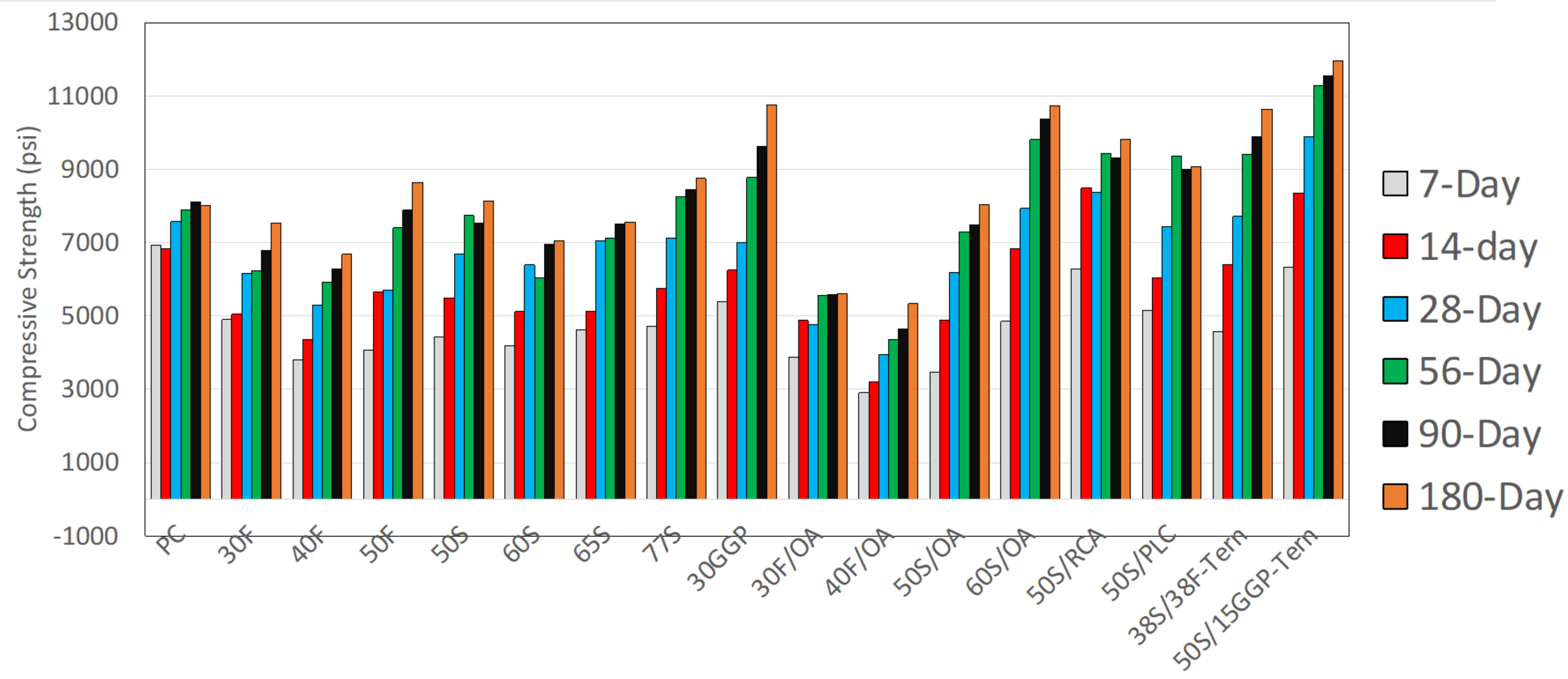
10 hours – Recommended upper limit for final setting time

3.5 hours – Recommended lower limit for initial setting time

Task C: Mechanical Performance

Compressive Strength

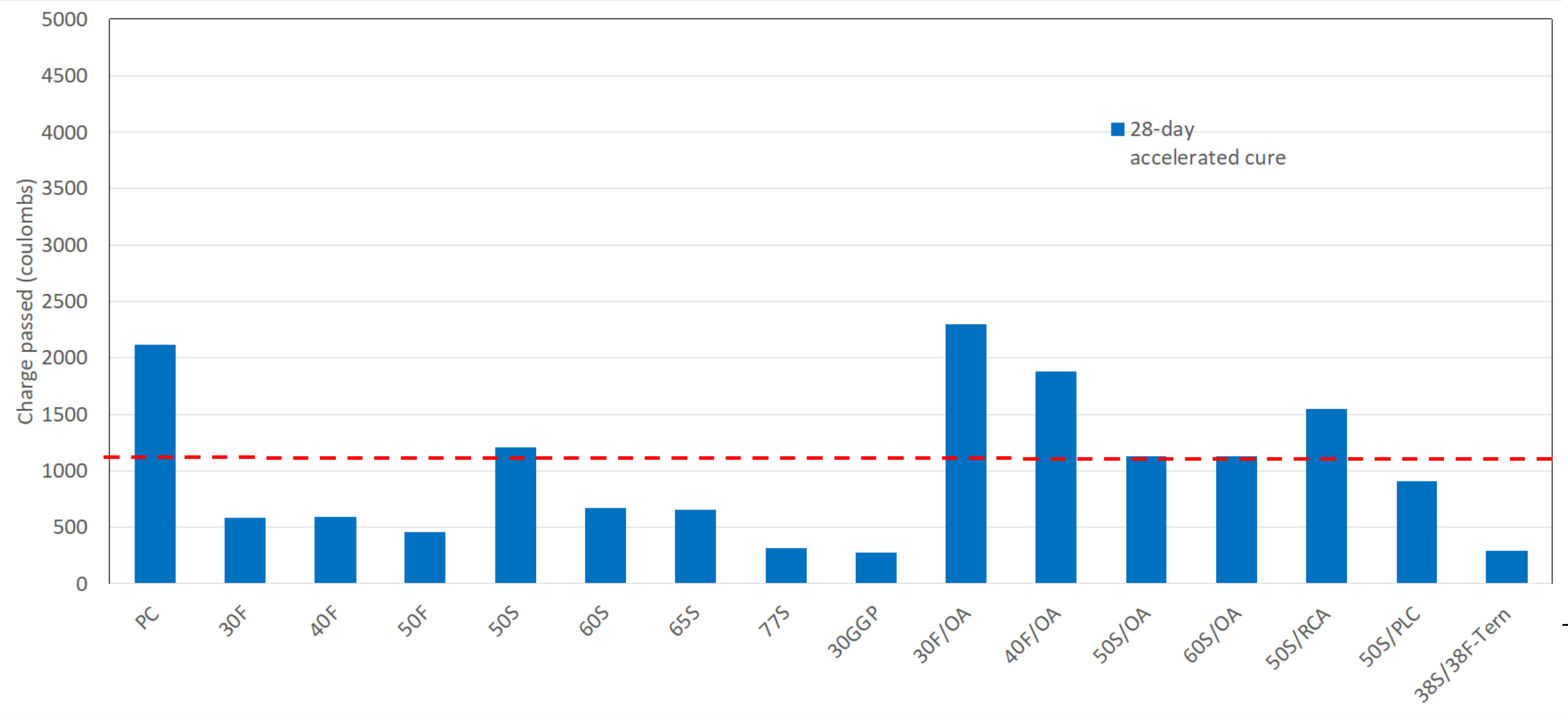
- All systems met a minimum of 4000 psi compressive strength by 28 days
- Fly ash and ground glass pozzolans may cause issues for rapid construction
- GGP, high slag, and ternary blendshad highest long-term compressive strengths



TASK C: DURABILITY PERFORMANCE

Permeability – Reinforced concrete exposed to seawater or deicing salts

- Lower quality limit of 1200 coulombs passed (maximum) after accelerated curing at 28 days
- More charge passed indicates likelihood of faster corrosion
- Several systems performed well.



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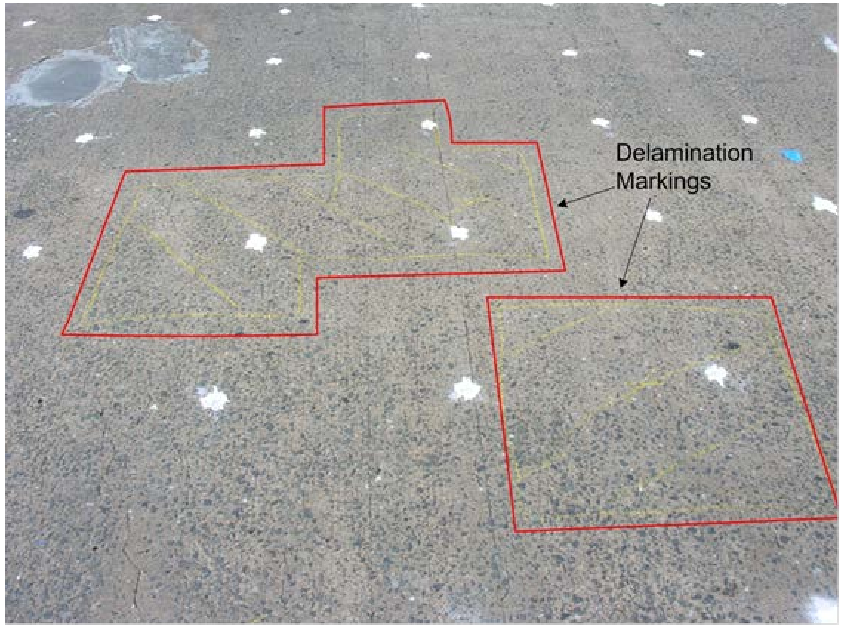
TASK C: OVERALL SYSTEM PERFORMANCE

Performance Criteria	Mixtures																	
	PC	30F	40F	50F	50S	60S	65S	77S	30GGP	30F/OA	40F/OA	50S/OA	60S/OA	50S/PLC	50S/RCA	38S/38F-Tern	50S/15GGP-Tern	CSA
Initial Setting Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	n/a
Final Setting Time	✓	✓	✓	✓	✓	✓	✓	✓	X	✓	X	✓	✓	✓	✓	X	X	n/a
28-Day Compressive Strength	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓
Flexural Strength	✓	X	X	X	✓	✓	✓	✓	✓	X	X	X	✓	✓	✓	✓	✓	X
Shrinkage (0.04% limit)	X	X	✓	✓	X	X	X	✓	✓	✓	✓	X	X	X	X	X	X	✓
Freeze-Thaw Resistance	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓	✓	✓	✓	✓	✓	X
Permeability (Accelerated Cure)	X	✓	✓	✓	X	✓	✓	✓	✓	X	X	✓	✓	✓	X	✓	✓	✓
Number of Criteria Met	5	5	6	6	5	6	6	7	5	4	3	5	6	6	5	5	5	3

NEXT STEPS

- Pilot program
  - 3 field trials of tested mixtures
  - Exterior concrete exposed to deicing salts
  - Long-term monitoring of systems
    - Cracks
    - Scaling
    - Delamination
    - Corrosion



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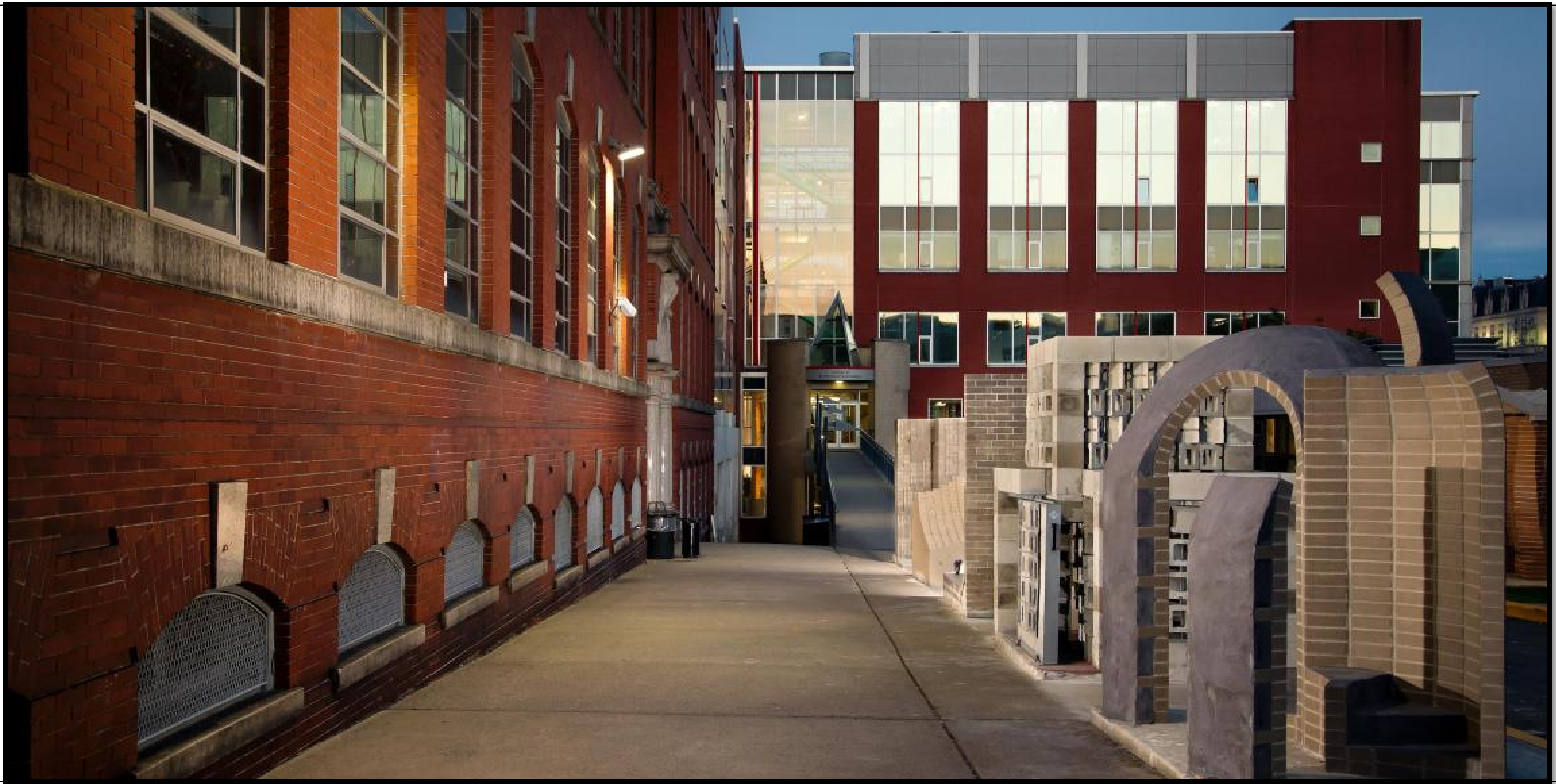
Thank You/Questions



Extra Slides for Question Period

Mixtures Tested for Performance

Technologies Assessed

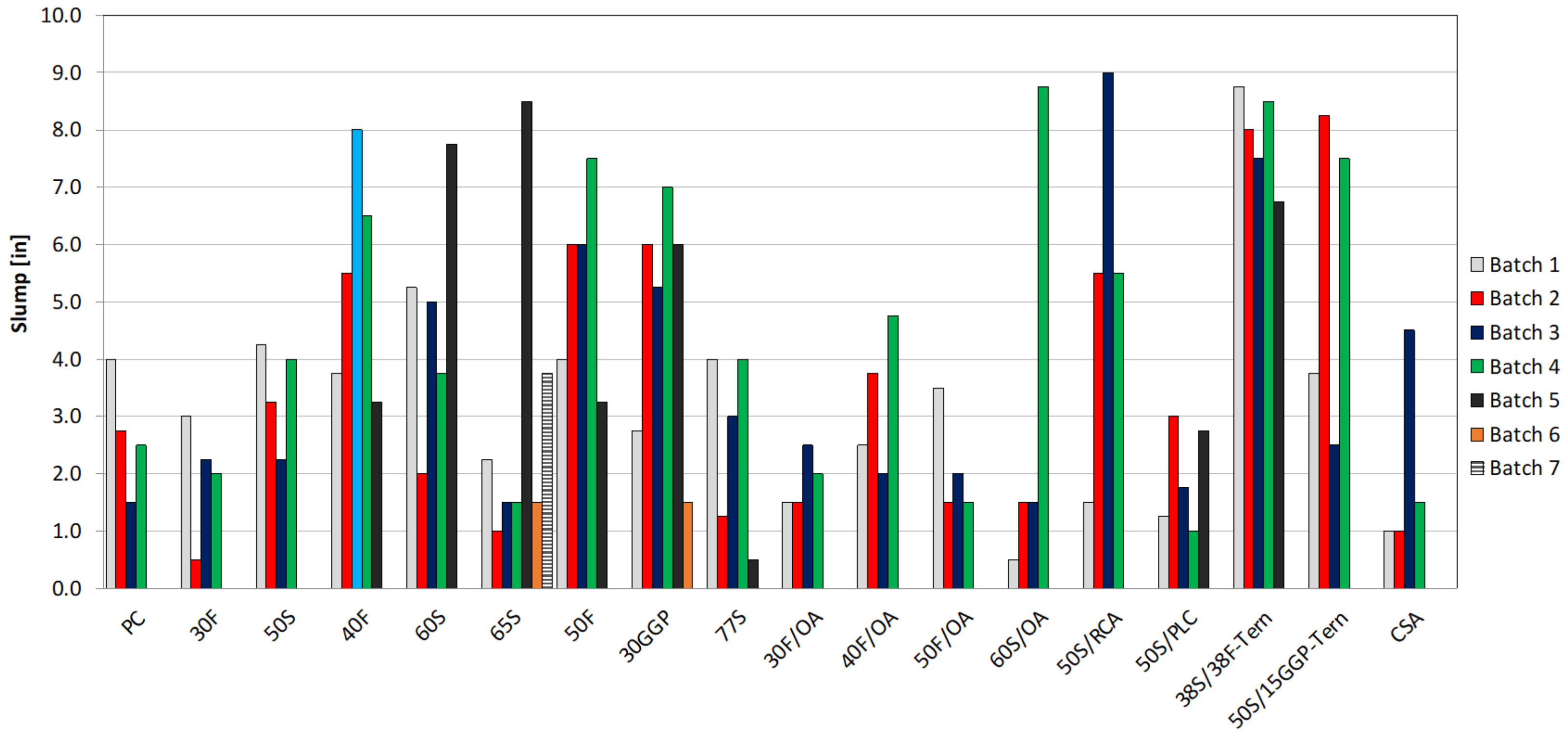
1. High SCM replacements
   - Using slag and fly ash
2. Ground glass pozzolan
3. Portland-limestone cement
4. Blends utilizing two SCMs
5. Cement reduction through optimized aggregate particle packing
6. Recycled aggregates
7. Rapid setting cements
8. Carbon dioxide mineralization (pending)

Mixture ID	Short ID	Description	Mixture ID	Short ID	Description
PC	PC	Baseline 100% portland cement binder mixture	FA_40%_OA	40F/OA	50% fly ash binder mixture utilizing particle packing theories to increase the volume of aggregates
FA_30%	30F	Baseline 30% fly ash binder mixture	SLAG_60%	60S	60% slag binder mixture
SLAG_50%	50S	Baseline 50% slag binder mixture	SLAG_60%_OA	60S/OA	60% slag binder mixture utilizing particle packing theories to increase the volume of aggregates
FA_30%_OA	30F/OA	30% fly ash binder mixture utilizing particle packing theories to increase the volume of aggregates	SLAG_60%_CO2	60S/CO2	60% slag binder mixture with mineralized carbon dioxide
FA_30%_CO2	30F/CO2	30% fly ash binder mixture with mineralized carbon dioxide	SLAG_77%	77S	77% slag binder mixture
SLAG_50%_OA	50S/OA	50% slag binder mixture utilizing particle packing theories to increase the volume of aggregates	SLAG_65%	65S	65% slag binder mixture
SLAG_50%_RCA	50S/RCA	50% slag binder mixture utilizing recycled concrete as coarse aggregates	GGP_30%	30GGP	30% ground glass pozzzolan binder mixture
SLAG_50%_PLC	50S/PLC	Binder mixture made up of 50% slag and 50% portland limestone cement	Ternary_FA_SLAG	38S/38F-Tern	Ternary binder system using 38% slag, 38% fly ash, and 25% portland cement
SLAG_50%_CO2	50S/CO2	50% slag binder mixture with mineralized carbon dioxide	Ternary_SLAG_GGP	50S/15GGP-Tern	Ternary binder system using 50% slag, 15% ground glass pozzolan, and 35% portland cement
FA_40%	40F	40% fly ash binder mixture	CSA	CSA	Rapid setting mixture using 100% calcium sulfoaluminate cement binder
FA_50%	50F	50% fly ash binder mixture			

Fresh Property Performance of Concrete Systems

❖ Workability (slump) – Constructability and labor implications

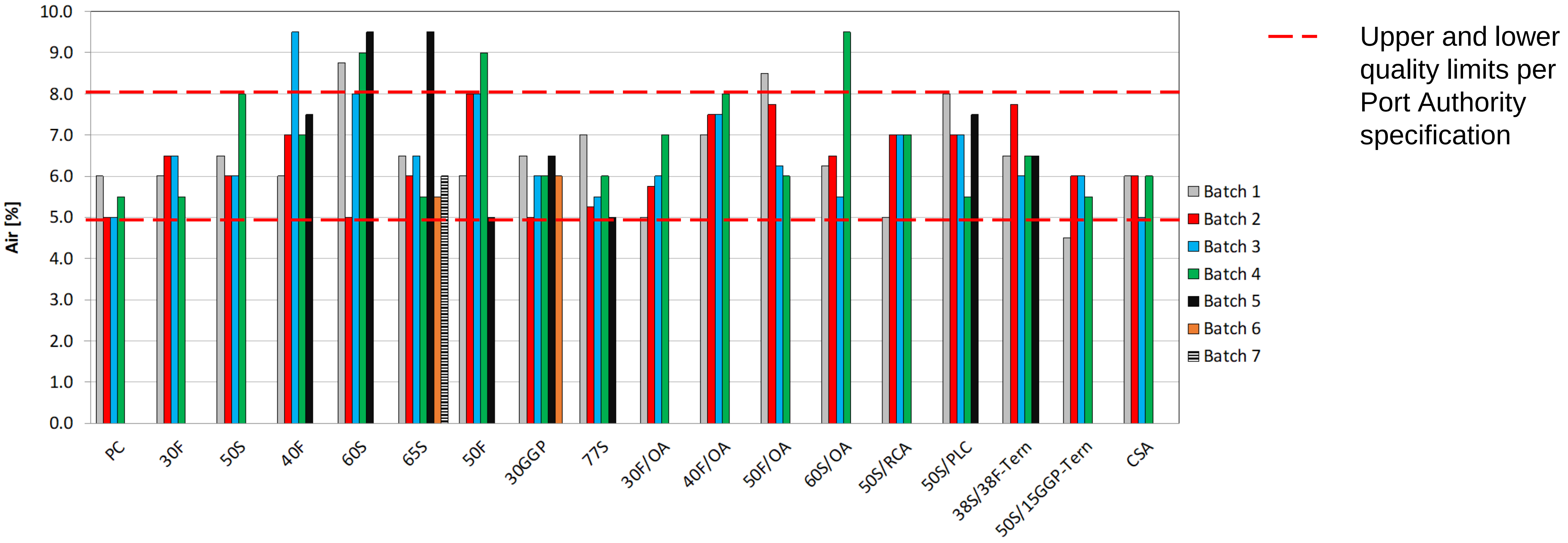
- Workability varied significantly across systems and within separate batches for each system
- Higher SCM content typically needed additional superplasticizer
- Good workability achieved
- Laboratory dosage rates may not yield same results in field



Fresh Property Performance of Concrete Systems

❖ Air content – Protection against freezing and thawing

- Each batches of all systems met Port Authority LQL for air content (5%) but some exceeded the UQL (8%) for a ¾ in. nominal aggregate (#57 stone)
- Targeted air content was difficult to achieve particularly with slag mixtures (common issue)
- Laboratory dosage rates do not reflect field dosage rates



Durability Property Performance of Concrete Systems

❖ Drying shrinkage – Long-term performance indicator –

- Cat. I (rapid setting) – LQL: 0.03% maximum
- Cat. II, II, IV, V - LQL: 0.04% maximum
- No systems conformed to cat. I LQL
  - None are rapid setting
- Several mixtures met 0.04% maximum shrinkage LQL
- Port Authority should examine other options for reducing shrinkage in LCC systems
  - Shrinkage reducing admixtures
  - Internal curing
  - Longer curing

Mixture ID	Free Shrinkage at 28 Days (%)	Port Authority Spec Limit Exceeded	
		Cat. I	Cat. II, III, IV, V
PC	0.0407	X	X
30F	0.0425	X	X
40F	0.0390	X	
50F	0.0385	X	
50S	0.0570	X	X
60S	0.0462	X	X
65S	0.0527	X	X
77S	0.0387	X	
30GGP	0.0343	X	
30F/OA	0.0400	X	
40F/OA	0.0387	X	
50S/OA	0.0548	X	X
50S/RCA	0.0572	X	X
50S/PLC	0.0588	X	X

Durability Property Performance of Concrete Systems

❖ Freeze-thaw resistance – Exterior concrete requirement

- Requirement: Systems withstand 300 cycles of accelerated freezing and thawing
- Most systems met freeze-thaw requirements
- Ground glass pozzolan may be sensitive to type of air entrainer used despite adequate air
- Further studies needed to understand failures

Mixture ID	Relative Dynamic E Below 80% of Starting Value	Number of Cycles at Failure	Air Content of Batch (%)
PC			5.5
30F			5.5
40F			7.0
50F			8.0
50S			8.0
60S			9.0
65S			5.5
77S			7.0
30GGP	X	60 Cycles	6.0
30F/OA	X	280 Cycles	5.8
40F/OA			7.0
50S/OA			7.0
50S/RCA			7.0
38S/38F-Tern			7.8