NESMEA

Recycled Ground-Glass Pozzolan as Supplementary Cementitious Material

by

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OUTLINE OF THE PRESENTATION

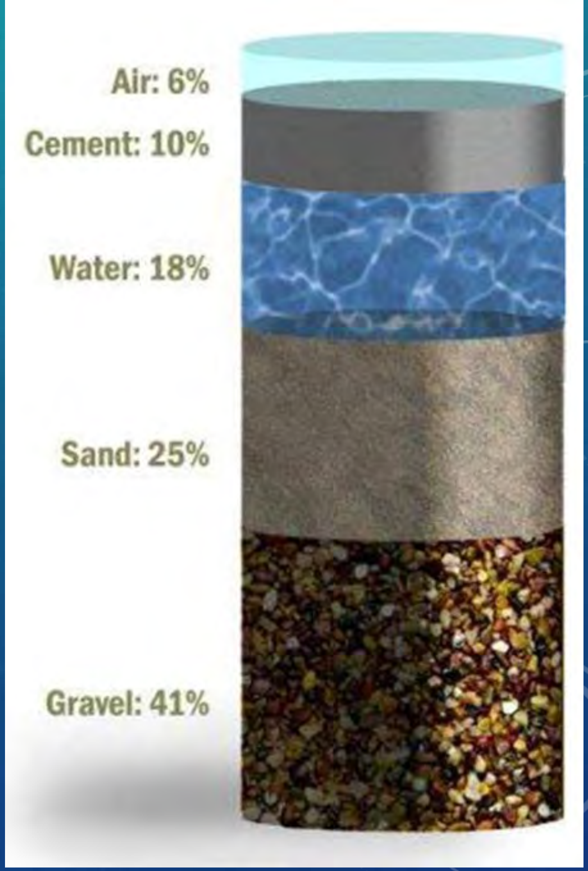
1. INTRODUCTION / RESEARCH SIGNIFICANCE AND OBJECTIVES
2. MATERIALS AND MIXTURES
3. MACROSTRUCTURE EVALUATIONS
4. MICROSTRUCTURE EVALUATIONS
5. FIELD APPLICATIONS
6. CONCLUDING REMARKS

PART I:
INTRODUCTION, RESEARCH BACKGROUND, SIGNIFICANCE

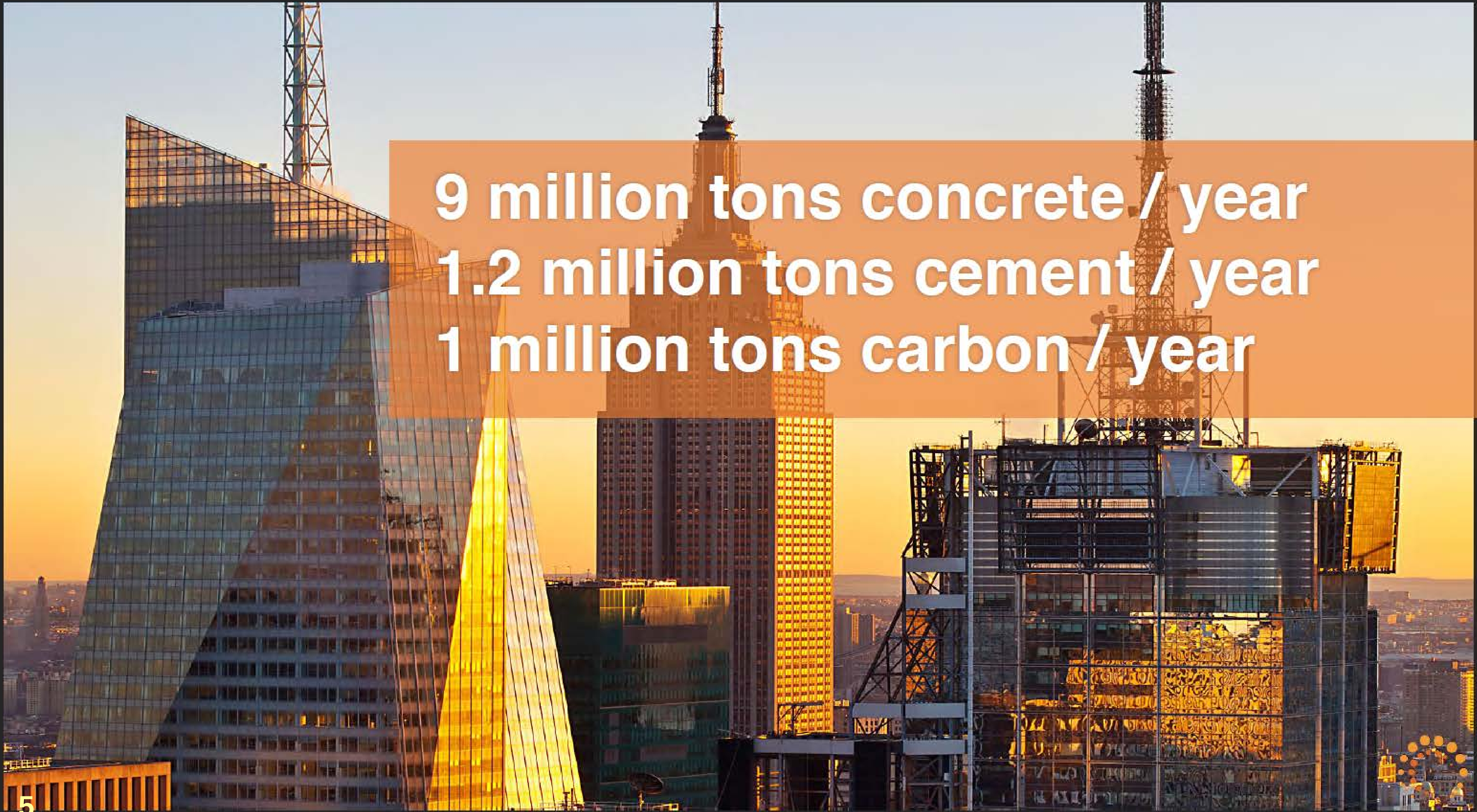
BACKGROUND:

Portland Cement (PC) Impact

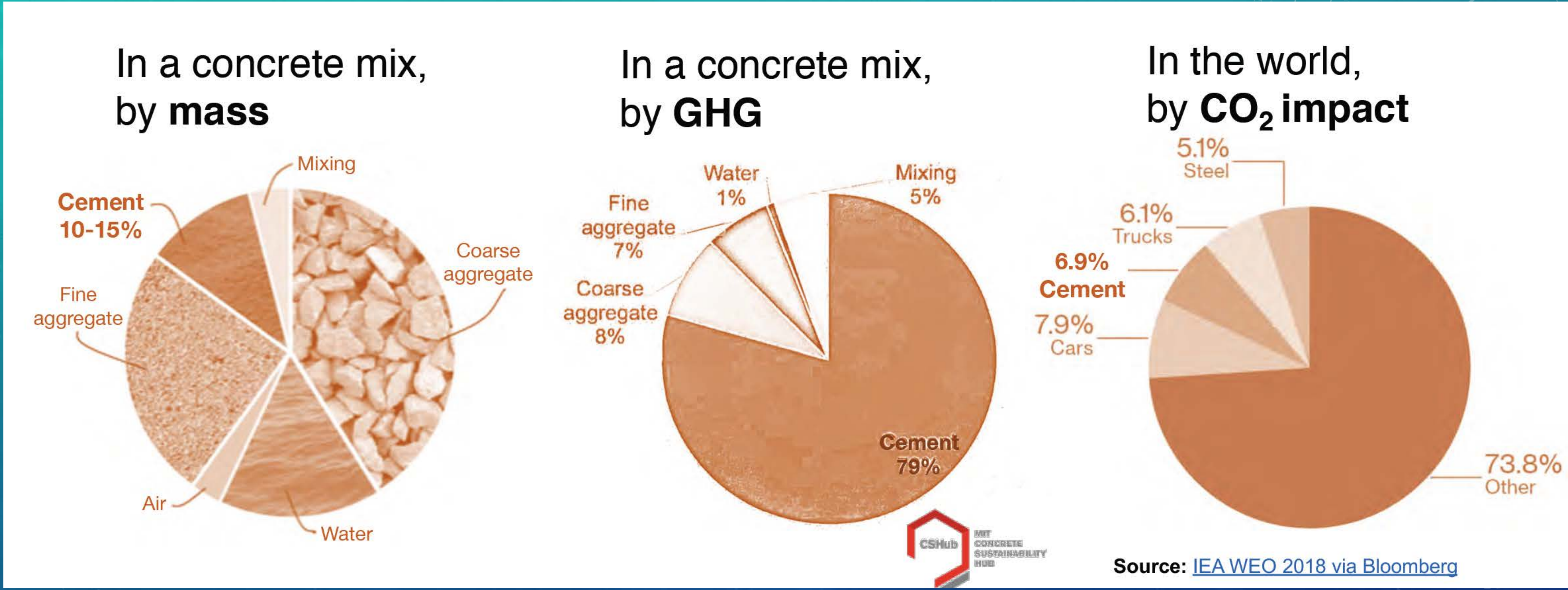
- **109 million** tons produced in US/year
- **3 million tons** used in NY/year
- **9.5 million tons** used in CA/year
- Cement industry accounts for **5-8 %** of total global energy consumption
- The energy used for production of cement accounts for more than **90%** of energy required to produce concrete
- Per EPA, **1 ton** of production results in 0.88 **tons** CO_2



Conventional concrete


9 million tons concrete / year
1.2 million tons cement / year
1 million tons carbon / year

CEMENT'S DISPROPORTIONATE IMPACTS

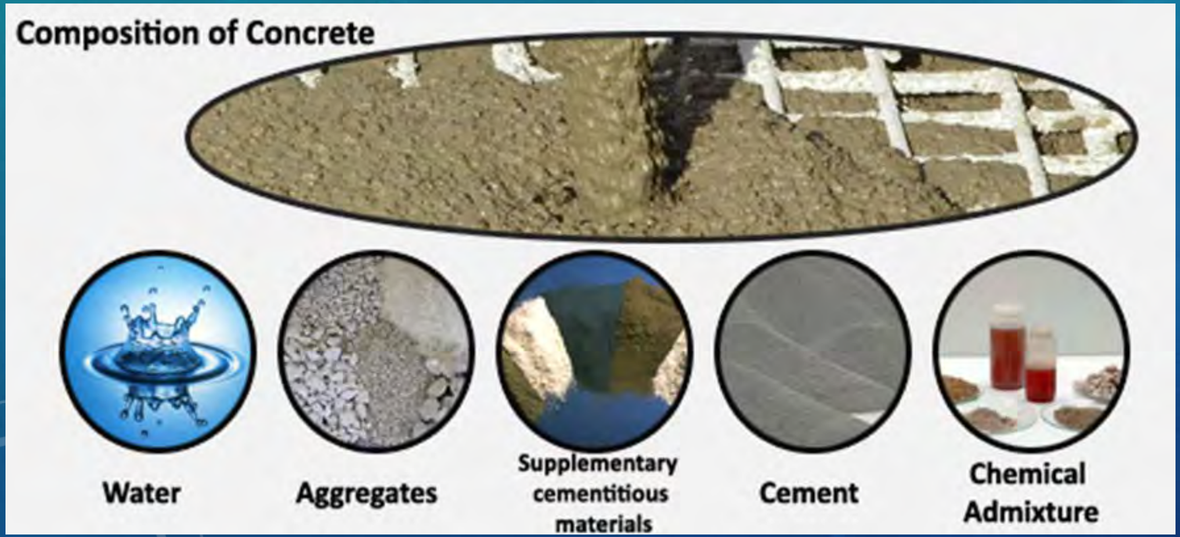


The cement industry's CO2 emissions were more than all the trucks on the road in 2017

SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMS)

Fly ash class F (residue from burning coal)
Fly ash class C (residue from burning coal)
Slag (residue from steel production)
Metakaolin (Calcined clay)
Silica Fume
Calcined shale

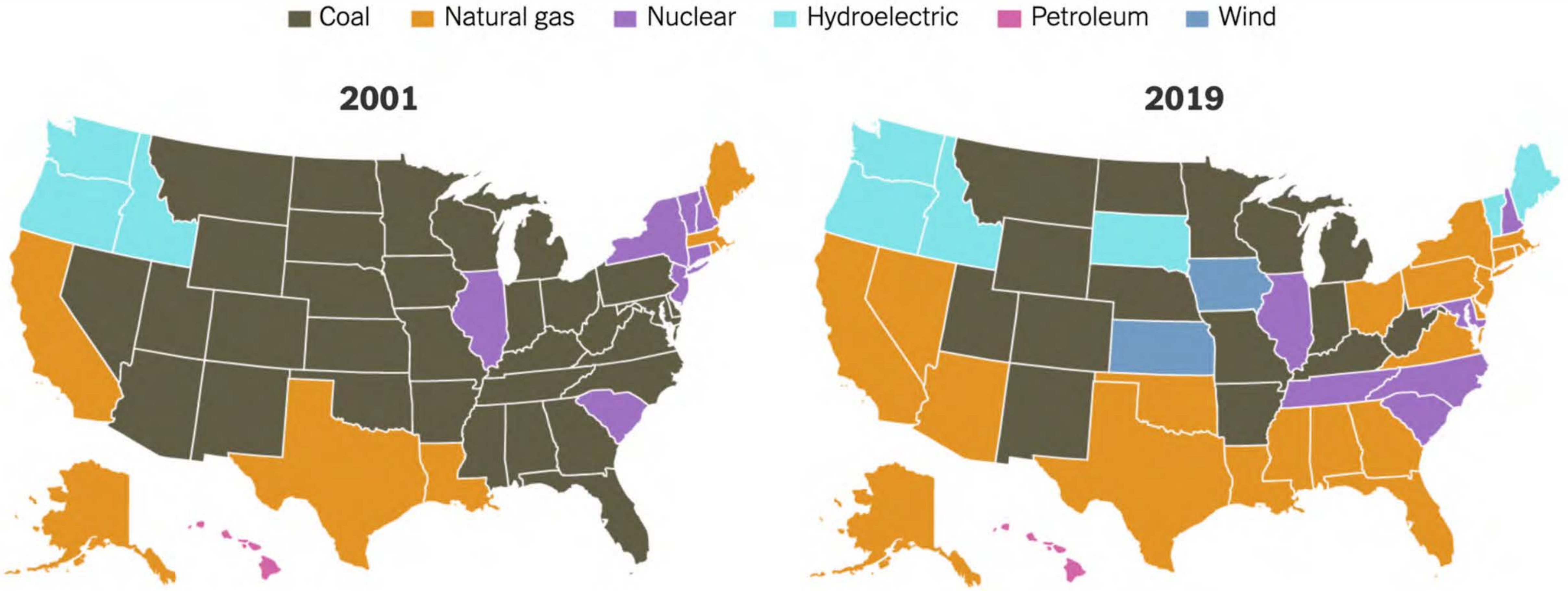
Portland Cement Association



- High Performance Concrete (HPC) reduces usage of PC by adding SCMs
- HPC has improved mechanical and durability properties and decreased maintenance cost

Is HPC necessarily sustainable ?

Energy Generation Shift



Source: *How Does Your State Make Electricity?* The New York Times, 28 October 2020

Slag: Diminishing Supply, Increasing Cost

> *"Supply constraints appear to have limited domestic consumption of GGBFS in recent years. Although prices have increased, sales of GGBFS have not correlated with the increases in the quantity of cement sold since 2010."*
>
> *– USGS Slag Mineral Commodity Survey, 2021*

PROBLEMS AND NEW SOLUTIONS

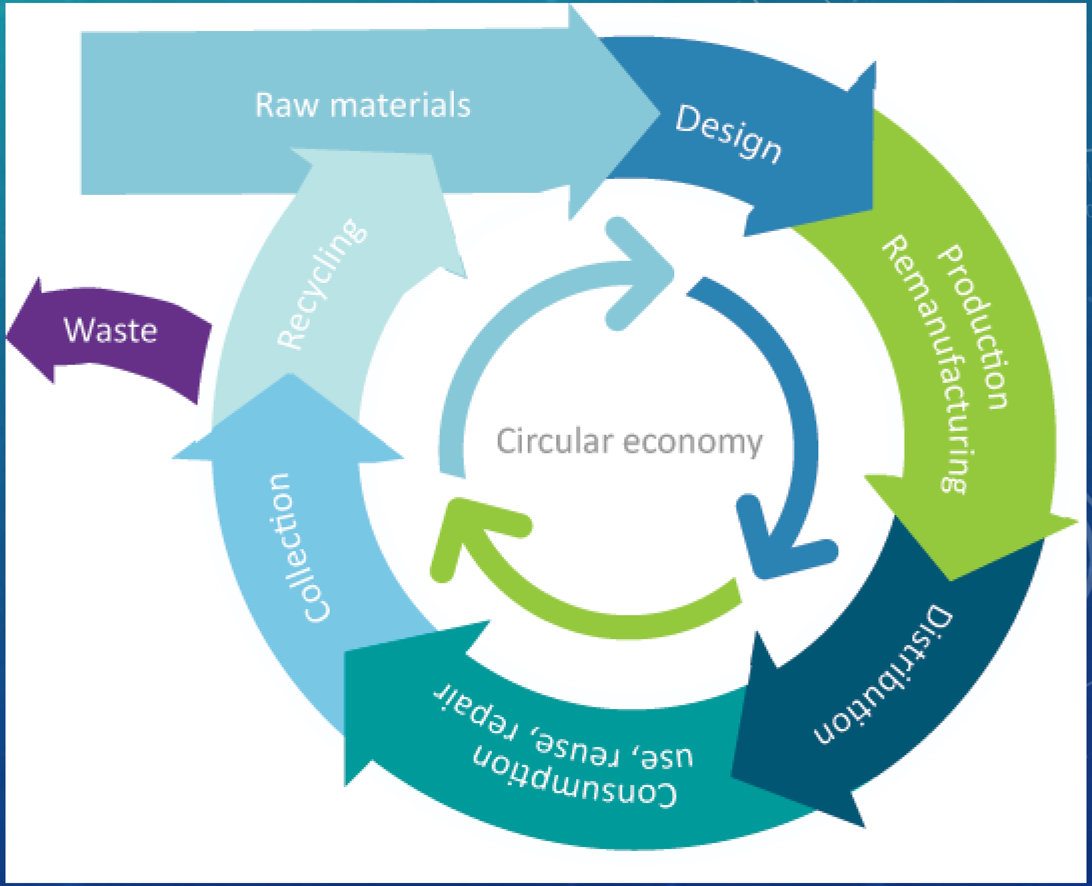
- Inconsistent fly ash supply
- Inconsistent Slag supply

Problems

There is a need for a new SCM product:

- Economic
- Sustainable
- Good performance

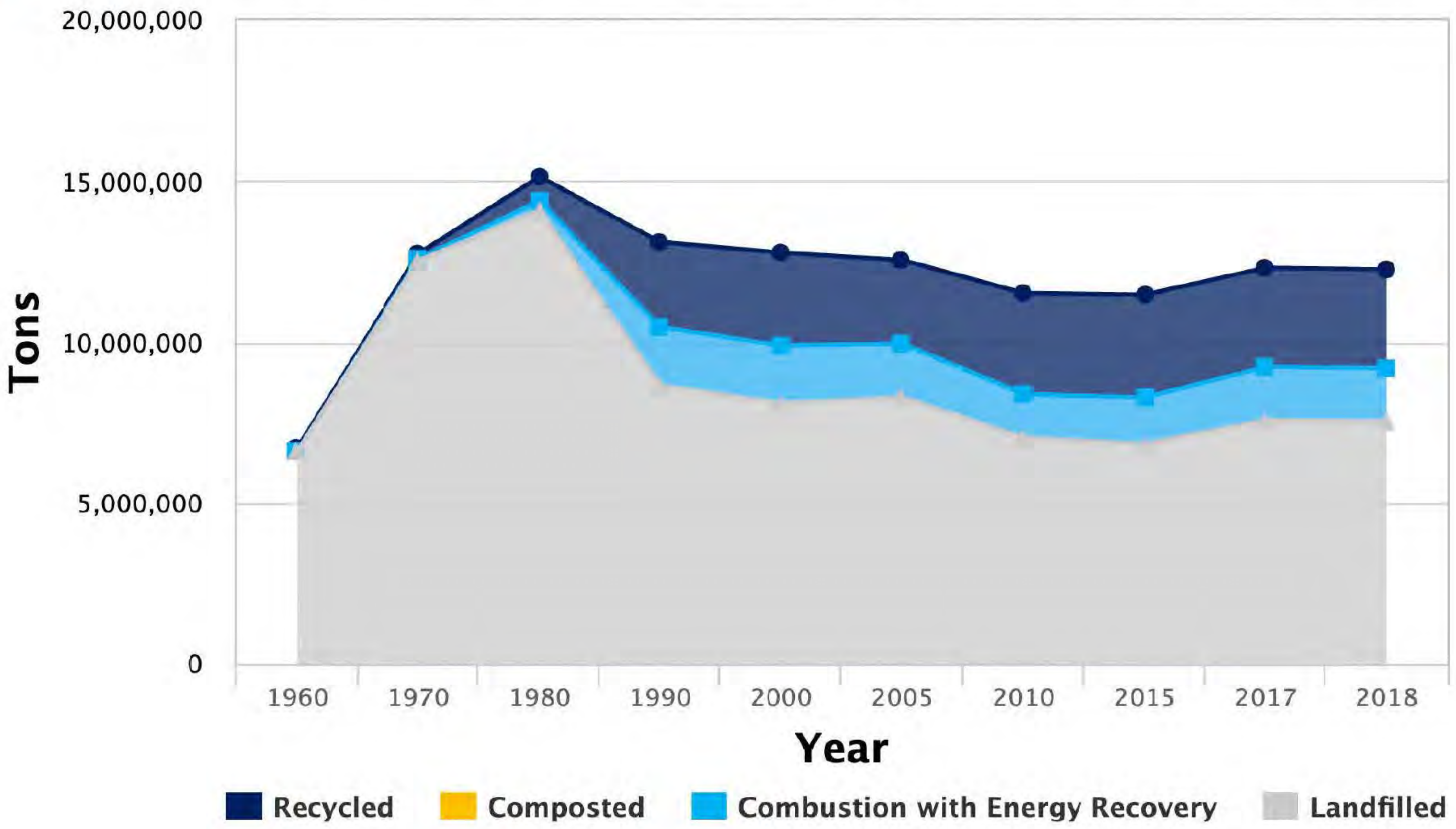
What can be done?



https://chemicalleasing-toolkit.org/node/64

Source: US EPA

Glass Waste Management: 1960-2018



Source: [EPA Facts + Figures About Materials, Waste, + Recycling | Glass: Material-Specific Data]

A NEW SCM GROUND-GLASS POZZOLAN

- **Advantages**
  - Environmentally friendly
  - Diverts glass from landfill
  - Supports local economy
  - Contributes to LEED & green initiatives
  - Contains no harmful heavy metals
  - Energy Efficient
  - Reduces need for virgin mined materials
  - GP can be used in cold weather, and in pre-cast and pre-stressed concrete

- **Disadvantages**
  - Consistency in a cleaning process of a feed stock
  - Not enough supply comparing to demand
  - Not clearly established standards

Performance of concrete with GGP ?

RESEARCH ORGANIZATION AND APPROACH

Phase 1 → Macrostructure testing evaluations → Scale 1

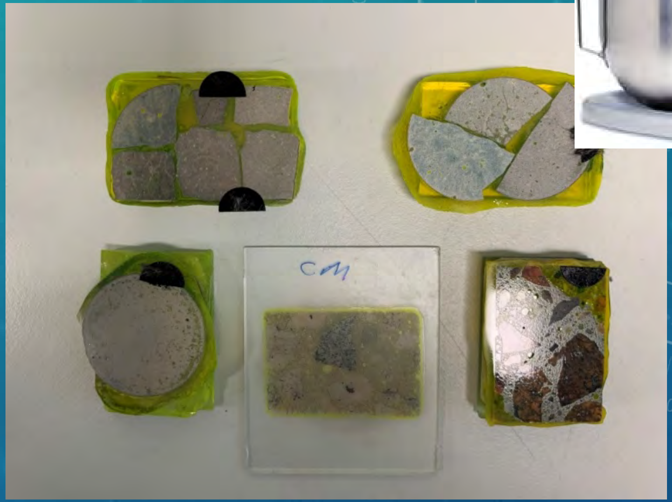
Phase 2 → Field applications + ASTM standard specifications approval → Scale 2

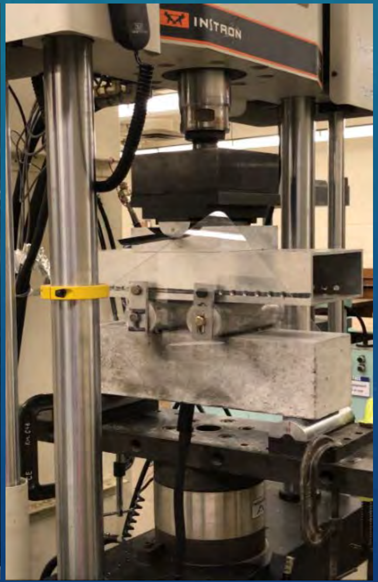
Phase 3 → Microstructure testing evaluations → Scale 3

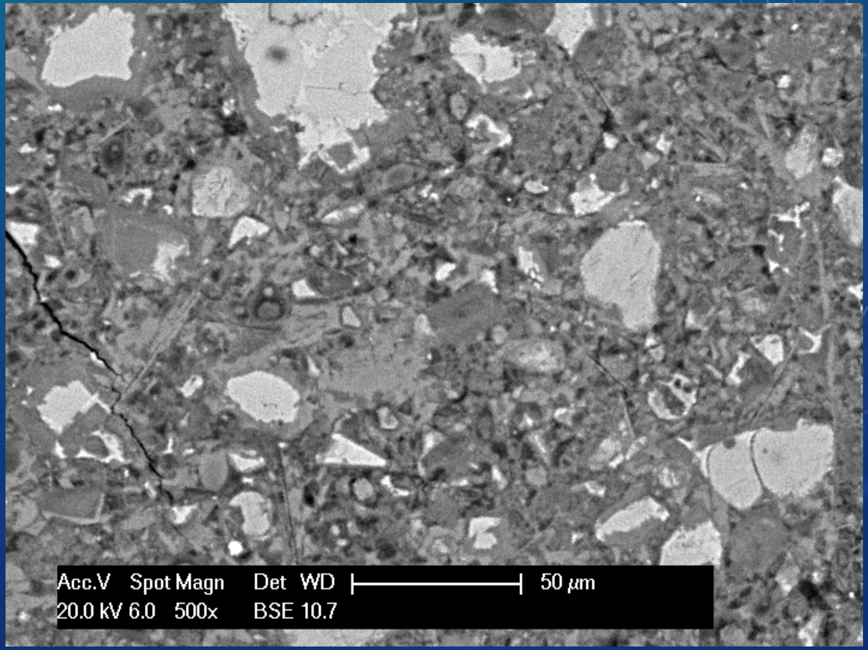
Phase 1

Phase 2

Phase 3







GENERAL CONTRIBUTIONS

- Concrete industry
- Solid waste management industry
- Large-scale field application projects
- Development of ASTM guideline (C-1866) and standard specifications for ground-glass pozzolan as SCM in concrete
- Development of DDC NYC standard specifications for using GGP in sidewalks in NYC

PART II:

MATERIALS, MIXTURE DESIGNS OF CONCRETE WITH GGP AND EXPERIMENTAL METHODOLOGY

PARTICLE SIZE DISTRIBUTION (PSD)

- Characterization of raw materials is important
- Physical and chemical properties of raw materials directly affect properties of cement paste and concrete

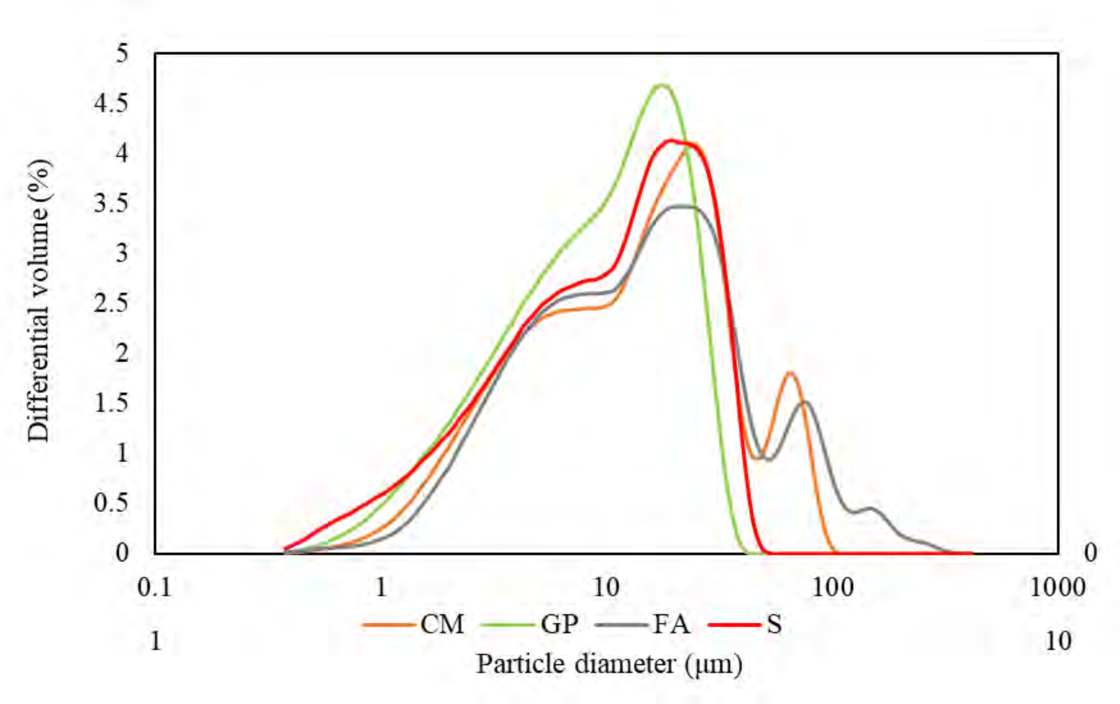


Figure 3.1 Particle size distribution (PSD)

		CM	GP	FA	S
Volume:	%	1.0	1.0	1.0	1.0
Mean:	μm	19.8	11.8	25.9	13.9
Median:	μm	14.2	10.0	14.9	11.3
S.D.:	μm	19.1	8.4	34.2	10.7
d10:	μm	2.9	2.3	3.3	2.1
d50:	μm	14.2	10.0	14.9	11.3
d90:	μm	45.7	24.2	65.4	30.0

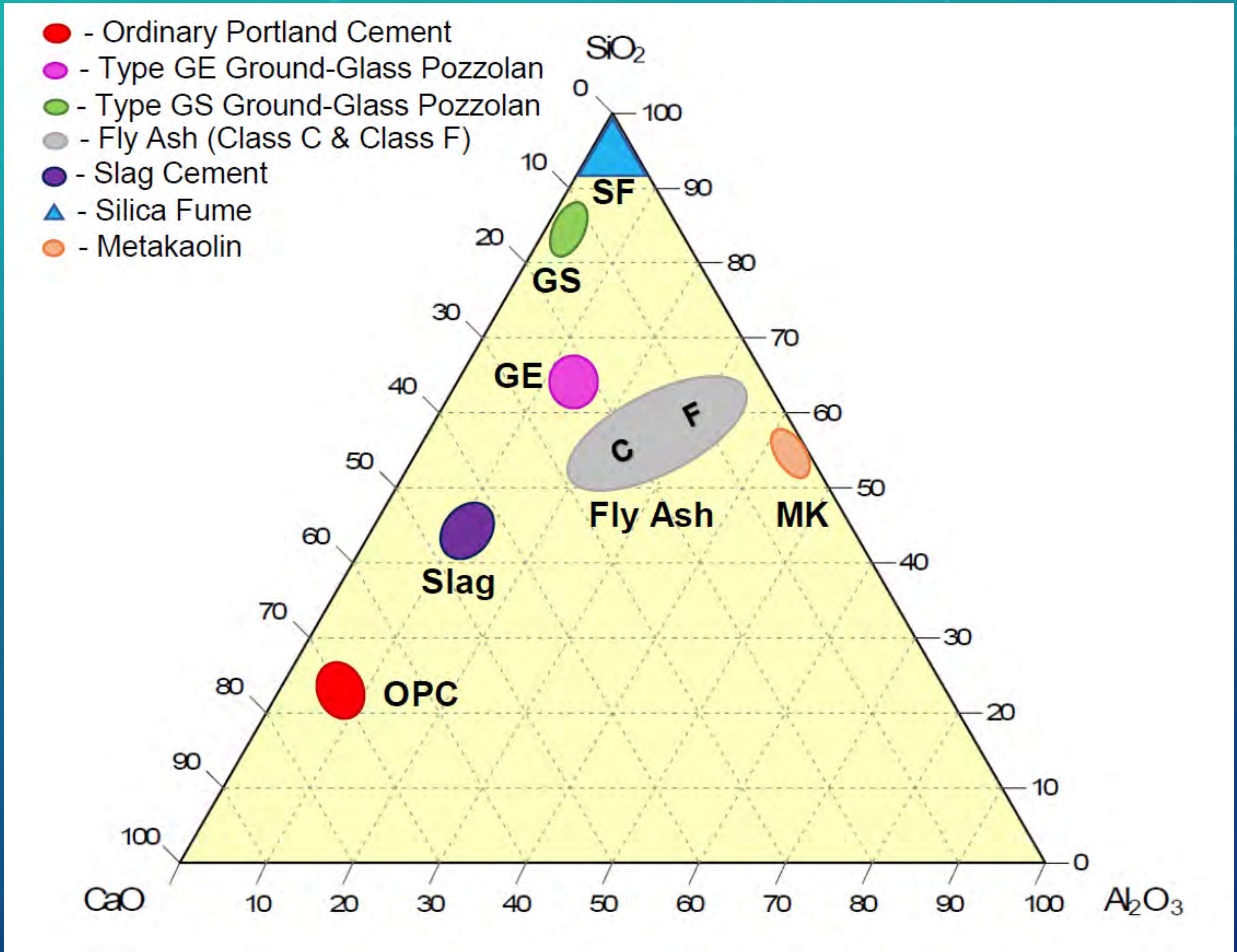
Table 3.1 Particle size distribution of raw materials

CHEMICAL COMPOSITION OF RAW MATEIRALS

Chemical composition	Glass pozzolan (GP)	Fly ash class F (FA)	Slag (S)	Portland cement (PC)
SiO_2, %	72.5	47.58	38.00	20.2
Na_2O, %	13.7	1.5	0.32	0.19
CaO, %	9.7	5.54	39.84	61.9
Al_2O_3, %	0.4	26.42	7.52	4.7
MgO, %	3.3	0.9	10.54	2.6
K_2O, %	0.1	1.9	0.38	0.82
Fe_2O_3, %	0.2	12.19	0.31	3.0
SO_3, %	0.1	1.08	0.16	3.9
Total alkalis Na_2O + $0.658K_2O$, %	13.77	2.75	0.6	0.73
LOI, %	0.4	2.5	1.2	1.5

Table 3.2 Chemical composition of raw materials from XRF analysis

TERNARY PLOT OF SCMS



https://www.concrete.org/publications/internationalconcreteabstractsportal.aspx?m=details&ID=51729296

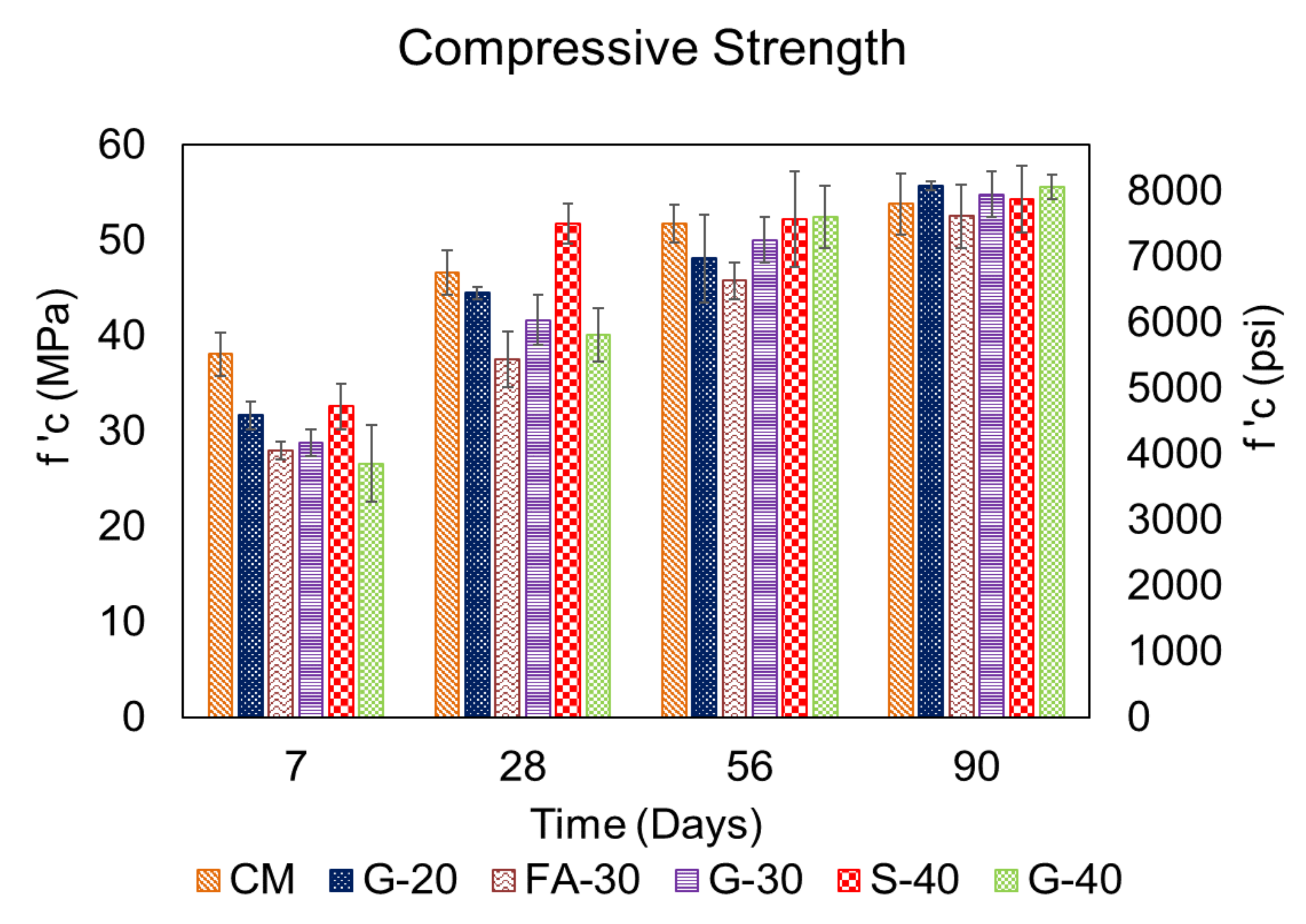
MIXTURE DESIGNS

Ingredients	CM	G20	FA30	G30	S40	G40
Cement type I/II, lb/yd³ (kg/m³)	575 (341.1)	460 272.9)	400 (237.3)	400 (237.3)	345 (204.7)	345 (204.7)
Glass pozzolan, lb/yd³ (kg/m³)	—	115 (68.2)	—	175 (103.8)	—	230 (136.5)
Class F fly ash, lb/yd³ (kg/m3)	—	—	175 (103.8)	—	—	—
Slag, lb/yd³ (kg/m³)	—	—	—	—	230 (136.5)	—
Coarse aggregate lb/yd³ (kg/m³)	2015 (1195.5)	2010 (1192.5)	1974 (1171.1)	2000 (1186.5)	2015 (1195.5)	2000 (1186.5)
Fine aggregate, lb/yd³ (kg/m³)	1079 (640.1)	1064 (631.2)	1063 (630.7)	1063 (630.7)	1065 (631.8)	1061 (629.5)
Water content, lb/yd³ (kg/m³)	233 (138.2)	233 (138.2)	234 (138.8)	235 (139.4)	236 (140)	237 (140.6)
Water-reducing admixture, oz/yd³ (mL/m³)	17 (660)	18 (695)	19 (735)	20 (775)	21 (815)	22 (850)
Air-entraining admixture, oz/yd³ (mL/m³)	16 (620)	17 (660)	29.7 (1150)	19 (735)	20 (775)	21 (810)
Water-cement ratio (w/c)	0.4	0.4	0.4	0.4	0.4	0.4
Slump, in. (cm)	4.5 (11.5)	4 (10)	4 (10)	4 (10)	4.5 (11.5)	4 (10)
Air content, %	5.9	5.2	5.6	5.2	6.2	5.8
Temperature, °F (°C)	75 (24)	75 (24)	78 (26)	73 (23)	72 (22)	72 (22)

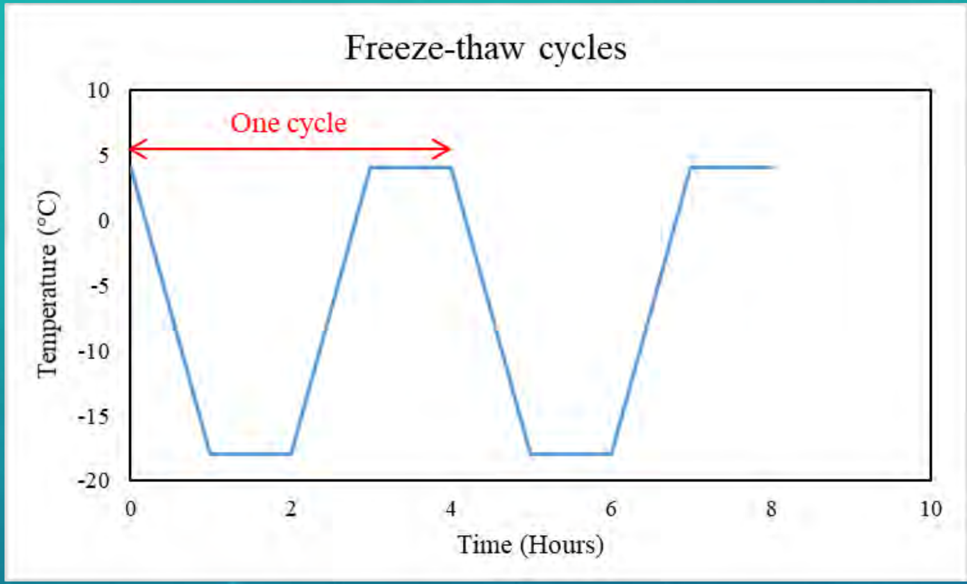
PART III:

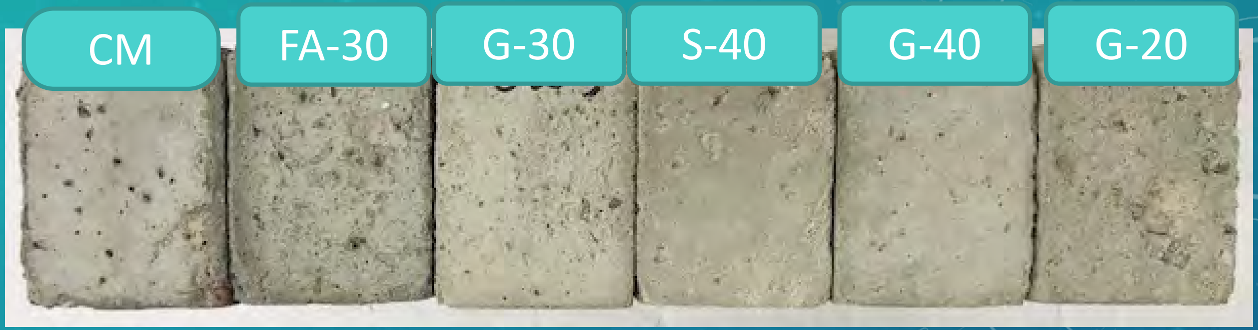
MACROSTRUCTURE CHARACTERIZATION OF CONCRETE WITH GGP

COMPRESSIVE STRENGTH

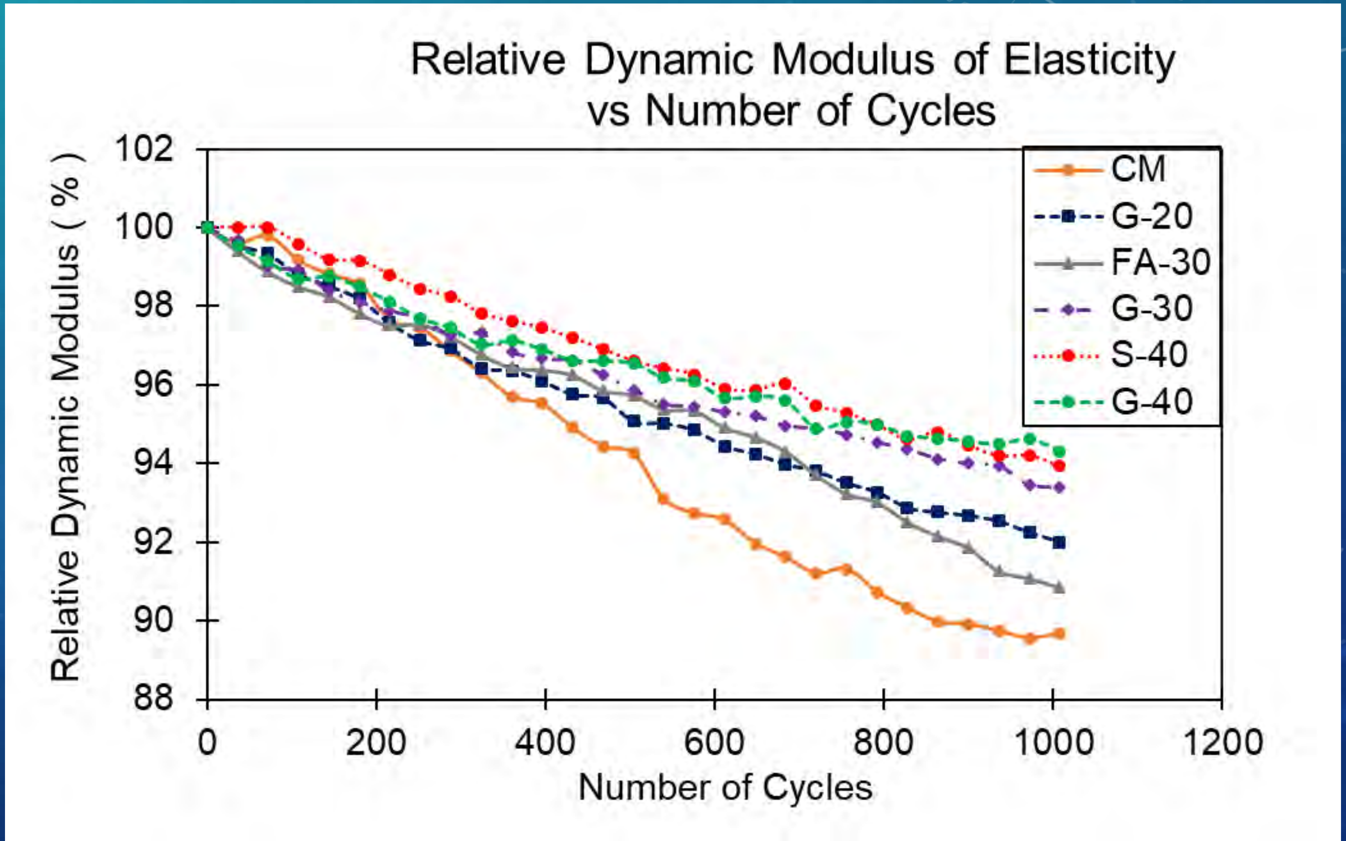


FREEZE-THAW RESISTANCE

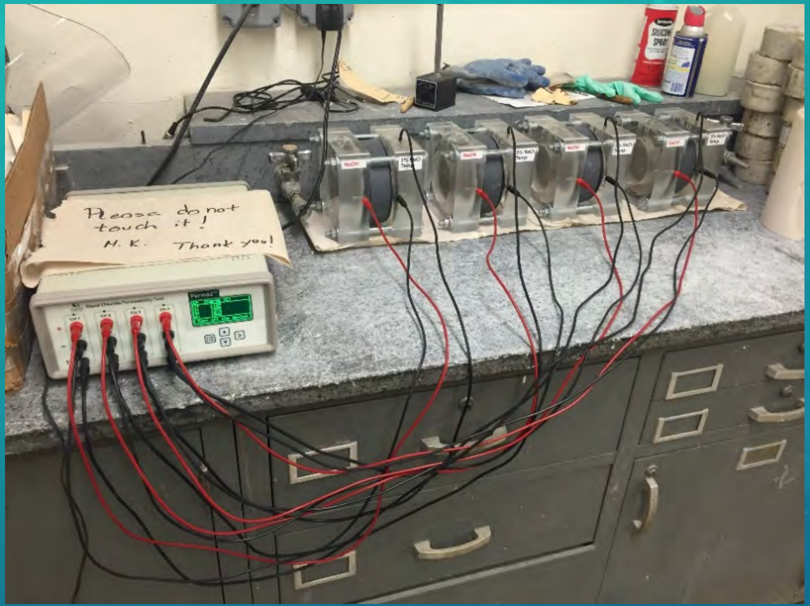




	CM	G-20	FA-30	G-30	S-40	G-40
Durability factor	0.897	0.920	0.909	0.934	0.939	0.943
Mass Loss %	1.580	0.750	1.010	0.600	0.560	0.520

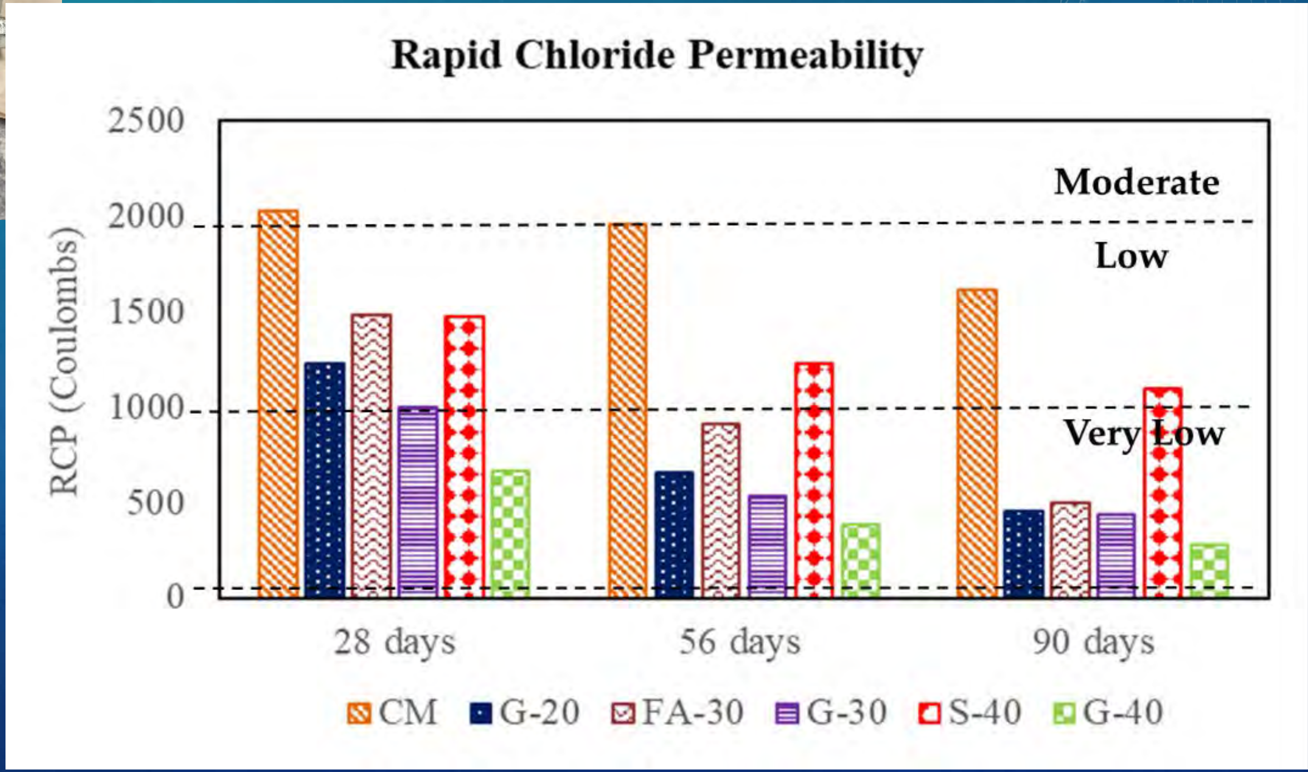


RAPID CHLORIDE PERMEABILITY (RCP)



Charge passed (coulombs)	Chloride Ion Penetrability
> 4000	High
2000 - 4000	Moderate
1000 - 2000	Low
100 - 1000	Very Low
< 100	Negligible

Mix Designs	RCP in Coulombs		
	28 days	56 days	90 days
CM	2027	1955	1617
S-40	1471	1233	1100
G-40	670	382	282
FA-30	1486	915	500
G-30	1002	533	436
G-20	1231	657	456



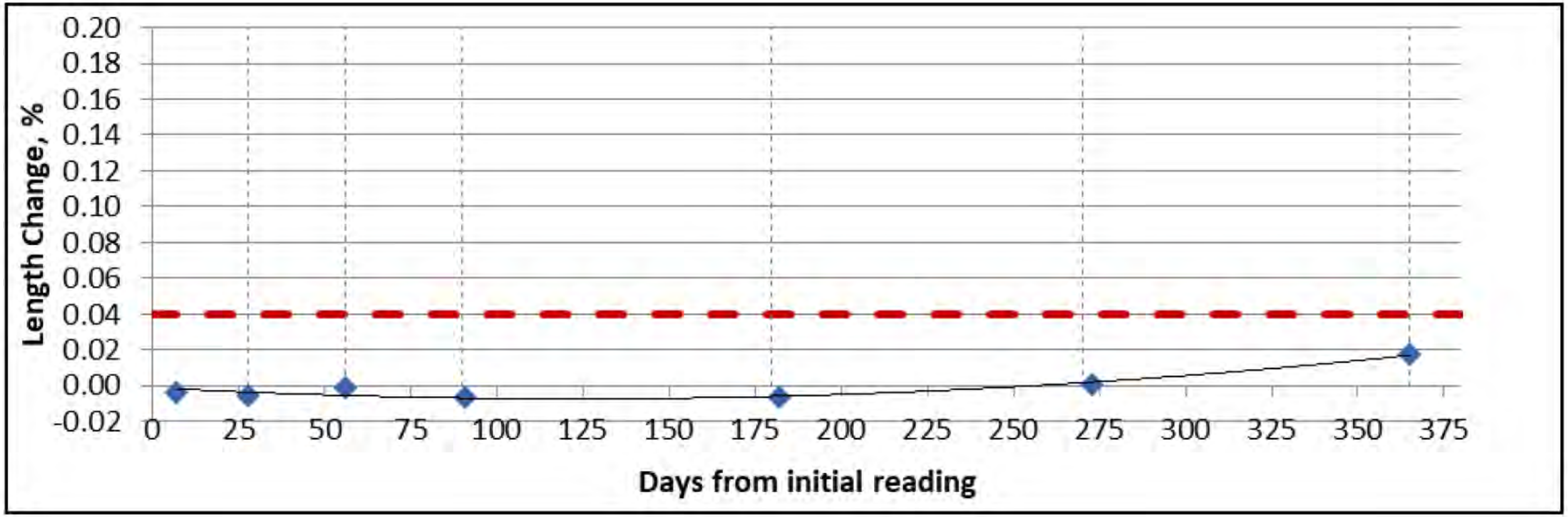
ALKALI-SILICA REACTION (ASR) ASTM C1293

SUMMARY OF TEST RESULTS

ASTM C1293

Specimen Length Change, Δ Lx (%)

Date Measured	Age, days	B-1	B-2	B-3	B-4	Average
7/6/21	7 Days	-0.002	-0.003	-0.004	-0.006	-0.004
7/27/21	28 Days	-0.003	-0.007	-0.004	-0.007	-0.005
8/24/21	56 Days	0.001	-0.002	-0.003	0.001	-0.001
9/28/21	3 Months	-0.006	-0.006	-0.006	-0.008	-0.007
12/28/21	6 Months	-0.004	-0.009	-0.009	-0.005	-0.007
3/29/22	9 Months	0.001	-0.001	0.002	-0.001	0.000
6/29/22	12 Months	0.019	0.017	0.017	0.019	0.018



ALKALI-SILICA REACTION

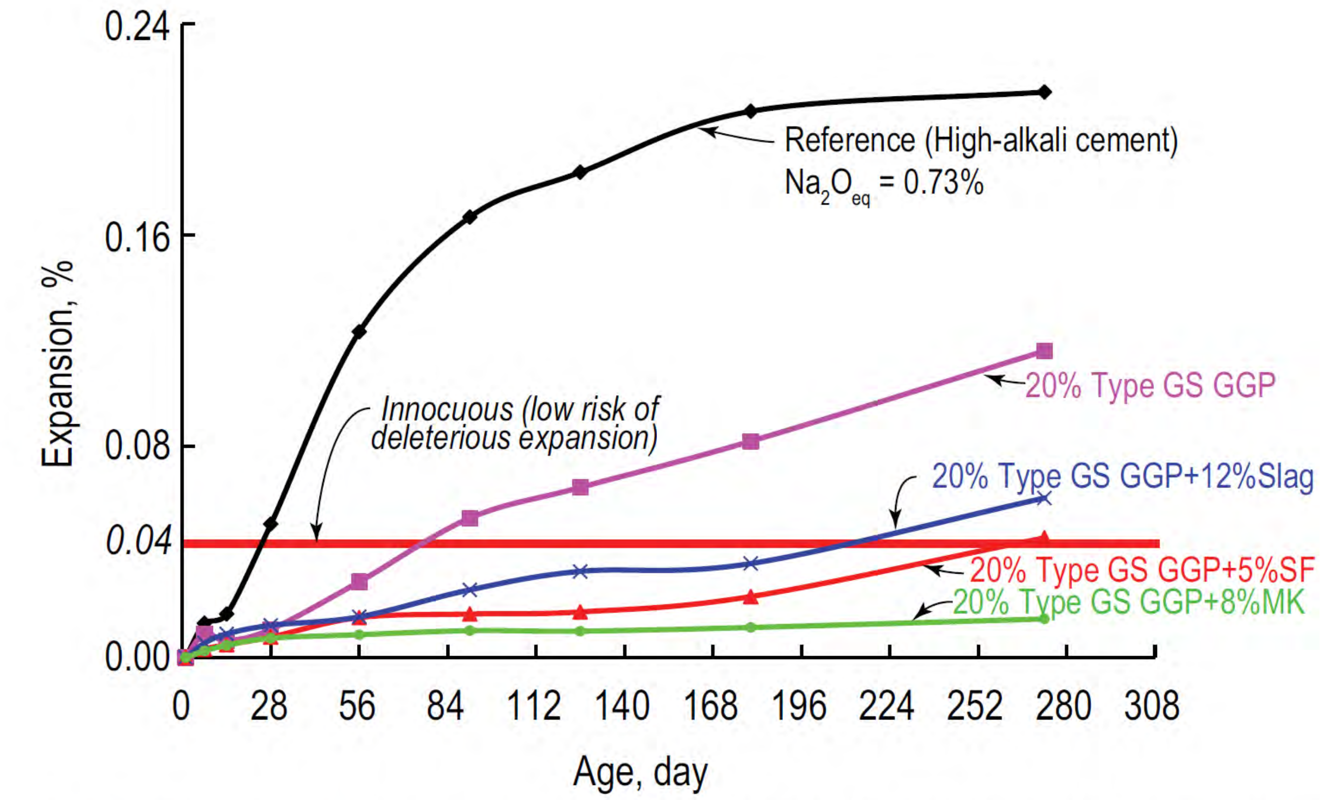


Fig. 6: Concrete prism expansion per ASTM C1293 for mixtures with Spratt aggregate, high-alkali cement, and cement replacement with Type GS GGP, silica fume (SF), and metakaolin (MK) *(figure courtesy of Arezki Tagnit-Hamou)*

SULFATE RESISTANCE

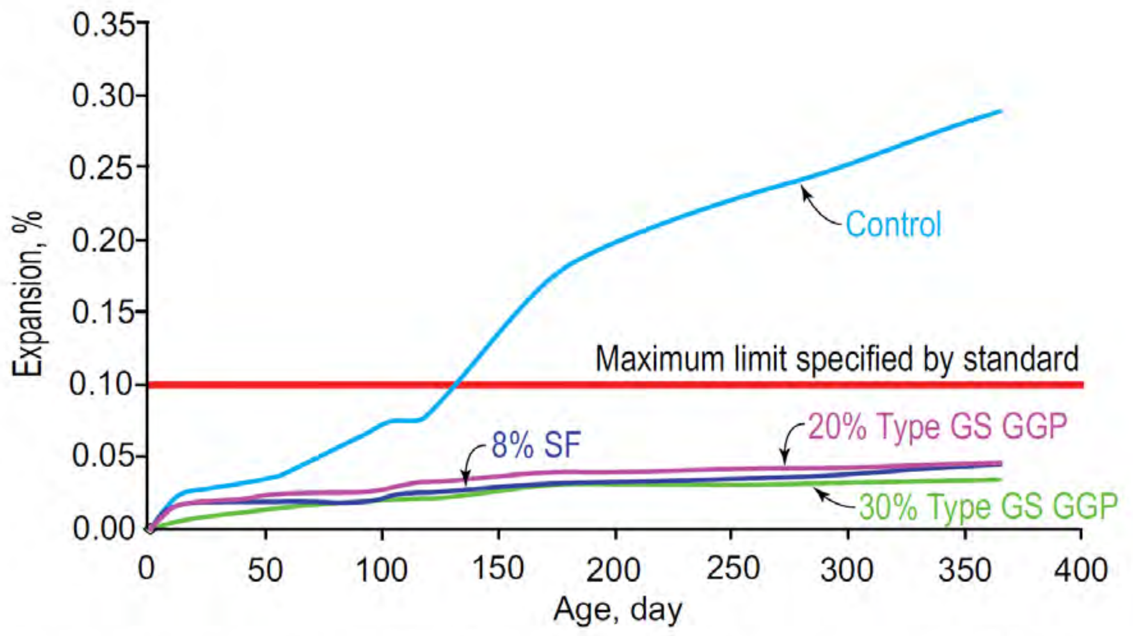
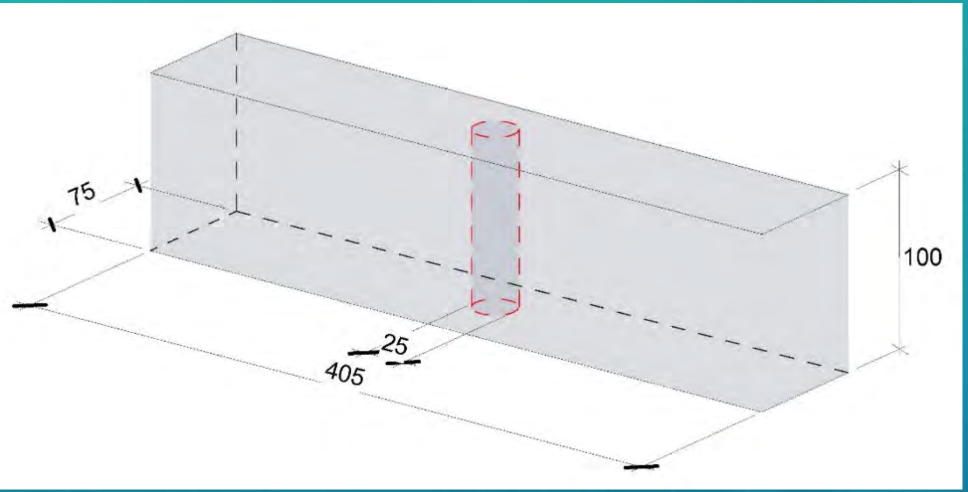


Fig. 9: Expansion per ASTM C1012/C1012M for mixtures with 20 and 30% cement replacements with Type GS ground glass *(figure courtesy of Michael D.A. Thomas)*

PART IV:

MICROSTRUCTURE CHARACTERIZATION OF PASTES AND CONCRETES WITH GGP

AIR-VOID ANALYSIS AND EVALUATION OF MICRO-CRACKS WITH MICRO COMPUTED TOMOGRAPHY (MICRO CT)



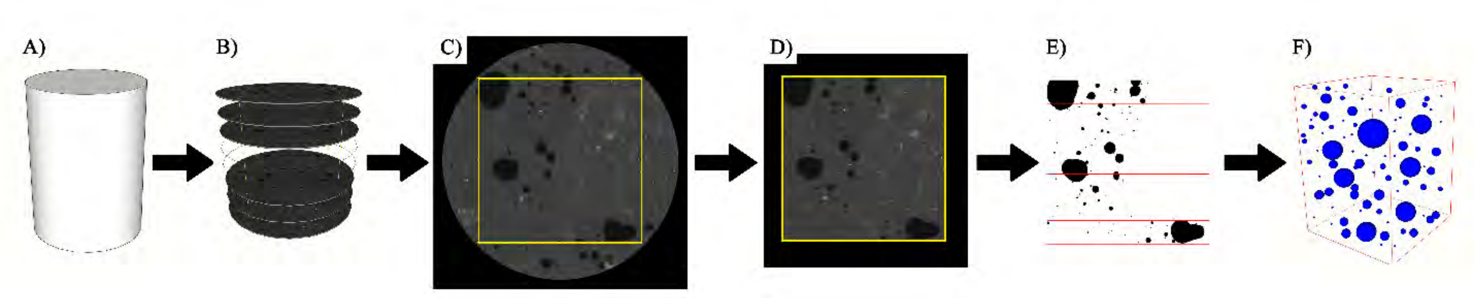


Figure 7.6. Approach 1 – Downsized linear traversed method (2-D)

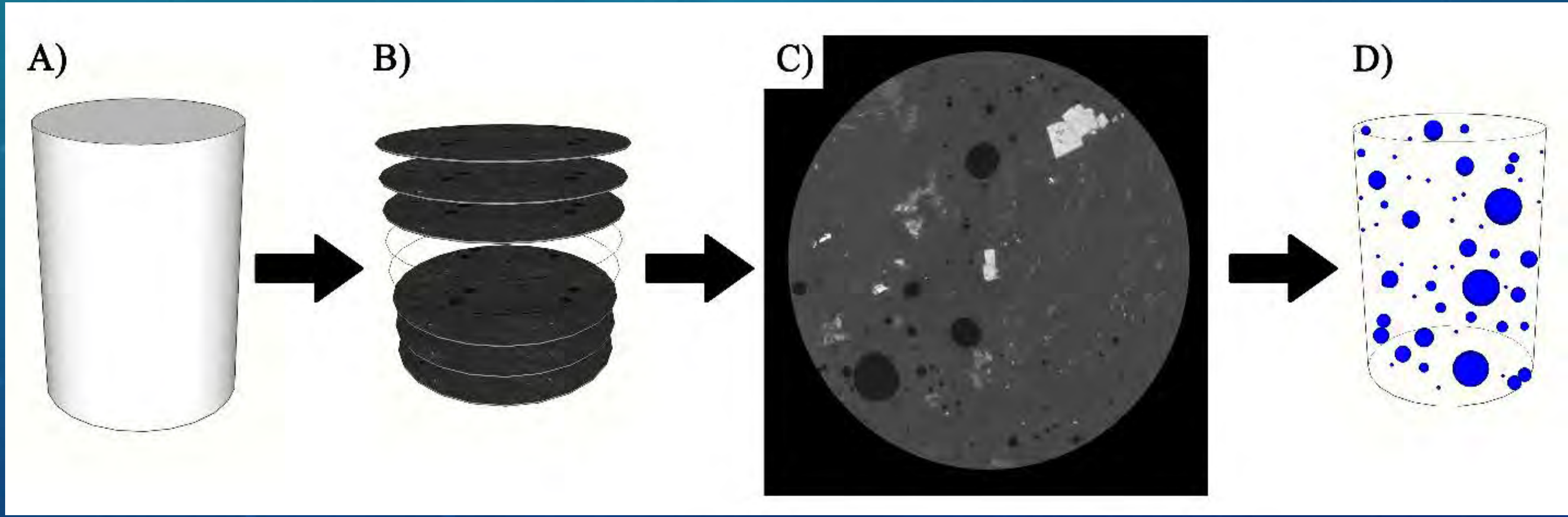


Figure 7.7. Approach 2- Threshold method of entire stack (3-D)

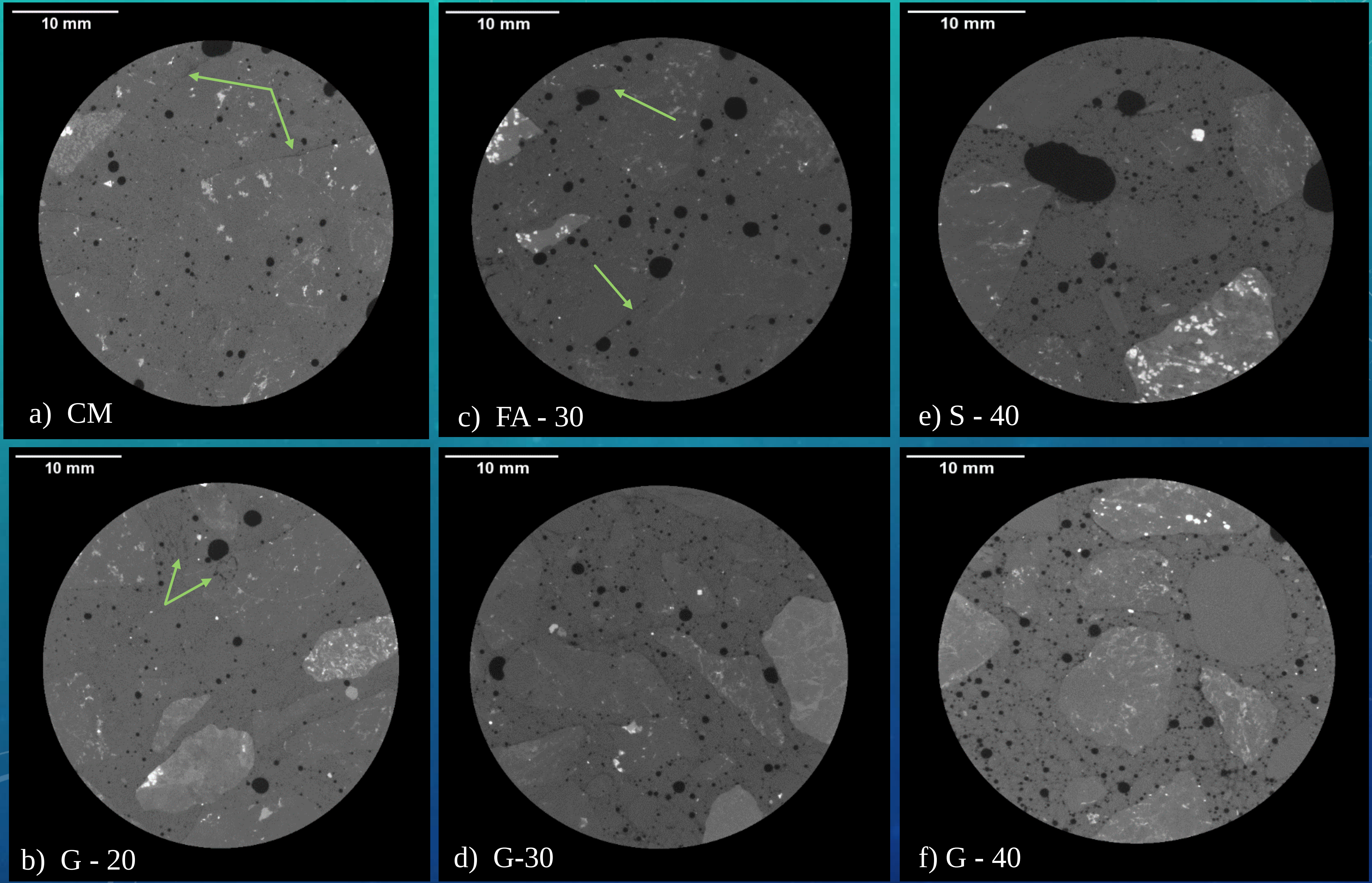


Figure 7.15
Micrographs for micro cracking analysis at 1000 FT cycles

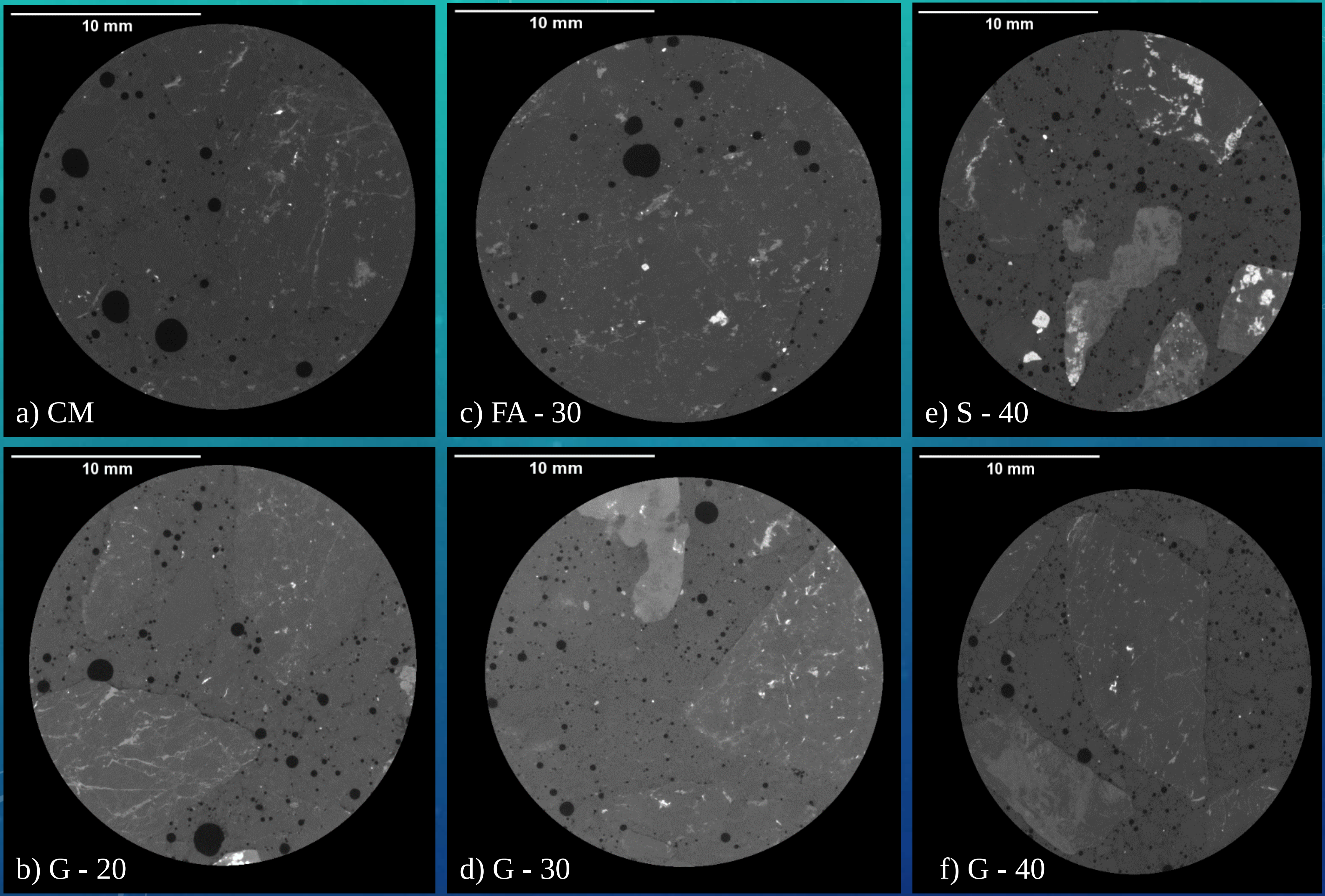


Figure 7.16
Micrographs of concretes for air void analysis not exposed to FT

%	CM	G-20	G-30	G-40	S-40	FA-30
Air voids - traverse method (2D)	2.99	2.34	2.48	4.31	5.40	2.38
Air voids – threshold (3D)	2.91	1.06	2.21	3.9	4.46	1.76
Air content – air-pressure (fresh)	5.9	5.2	5.2	5.8	6.2	5.6

Table 7.3 Summary of air voids content obtained with different methods

	CM	G-20	G-30	G-40	S-40	FA-30
α (1/mm)	11.88	20.66	24.24	23.78	26.17	21.33
P %	20.730	20.82	20.91	21.00	20.87	21.00
A %	2.99	2.34	2.48	4.31	5.40	2.38
R	6.93	8.92	8.44	4.87	3.86	8.83
L (mm)	0.452	0.292	0.242	0.192	0.148	0.281

Table 7.4 Air void parameters for all concretes

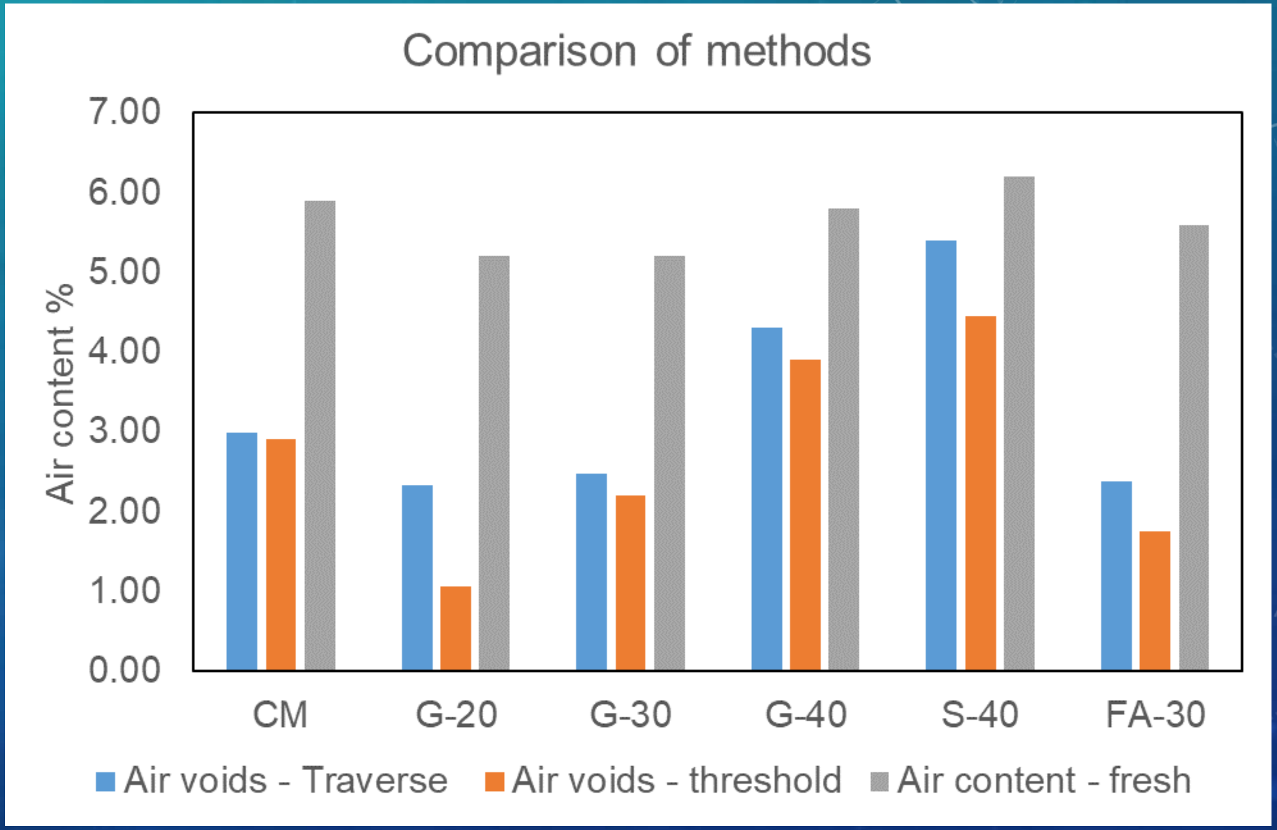


Figure 7.18 Comparison of different methods for air void content

PART V:

APPLICATION OF CONCRETE WITH GGP, CONTRIBUTIONS AND CONCLUDING REMAKRS

RESEARCH DESIGN AND APPROACH

- Performing slump/spread, air content, and setting time tests on fresh concrete (in lab and in the field) to determine :
  - Workability
  - Pump-ability
  - Placing
  - Finishing
- Installation of Maturity Sensors in both field concrete and cylinder samples to develop strength-prediction curves.
- Testing of mechanical properties

SIGNIFICANT CONTRIBUTIONS

- Field application projects for sidewalk and building construction:
  - Sidewalk construction in Jamaica, Queens, in collaboration with NYC-DDC
  - Complex of five twenty-three story residential buildings in Halletts Point - Queens, as part of a collaboration with Durst Organization sponsored by Building Products Ecosystems
  - Parking lot at Queens Borough Hall in collaboration with NYC-DDC
  - Google campus in California
  - Facebook campus in California- renovation
- Development of ASTM standard specifications for ground-glass pozzolan ASTM C1866

SIDEWALK CONSTRUCTION

Jamaica, Queens DDC, May 2016 - Placing G20 concrete developed and tested by CCNY

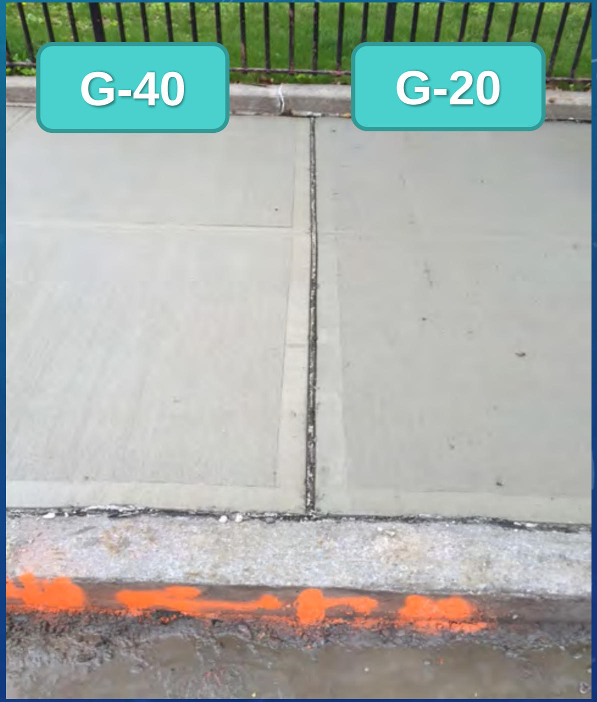


Figure 9.1.-Sidewalk for G20 and G40 - Jamaica, Queens, NY, May 2016

SIDEWALK CONSTRUCTION

Field Mix Designs	G-20 T-1	G-20 T-2	G-40 T-1	G-40 T-2	Control Mix 3200 psi-FA30
Cement , lb/yd^3	457	461	345	345	400
GP, lb/yd^3	115	115	230	230	0
Fly Ash, lb/yd^3	0	0	0	0	162
# 57, lb/yd^3	1935	1935	1955	1960	1940
Sand, lb/yd^3	1250	1255	1200	1205	1255
Water. Gal	23.6	23.6	23.5	23.5	25.6
Water lb. , lb/yd^3	196.95	196.95	196.12	196.12	213.64
SIKAMENT 686	16.8 oz/cyd	22.4 oz/cyd	16.8 oz/cyd	22.4 oz/cyd	19.2
SIKA AER	1.2 oz/cyd	1 oz/cyd	0.6 oz/cyd	0.6 oz/cyd	7 oz/cyd
Air %	7	7	6.5	7	7
Slump (in)	2.5	4.5	2.75	5	4
w/c	0.344	0.342	0.341	0.341	0.38

Table 9.1. Actual mix designs used for the Sidewalk in South Jamaica, Queens

Fresh properties	G-20 T-1	G-40 T-1	FA-30 T-1	G-20 T-2	G-40 T-2	FA-30 T-2
Slump in	2.5	2.75	4	4.5	5	4
Air content %	7	6.5	7	7	7	7

Table 9. 2. Fresh properties of concrete

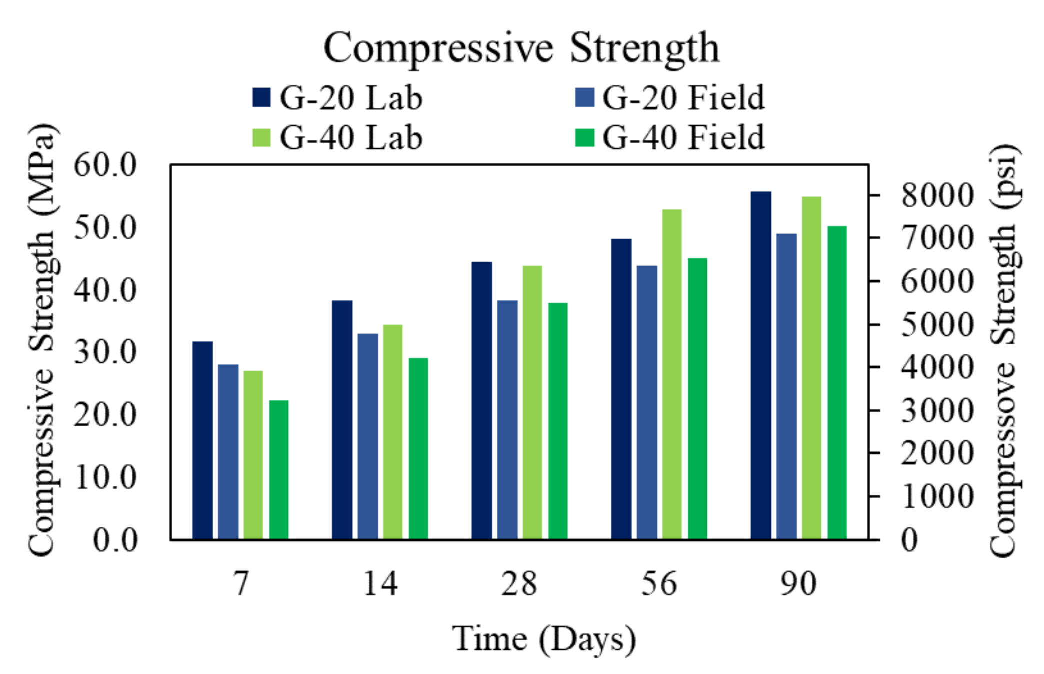


Figure 9.4. Compressive strength for G-20 and G-40

PREDICTING COMPRESSIVE STRENGTH BY MATURITY METHOD

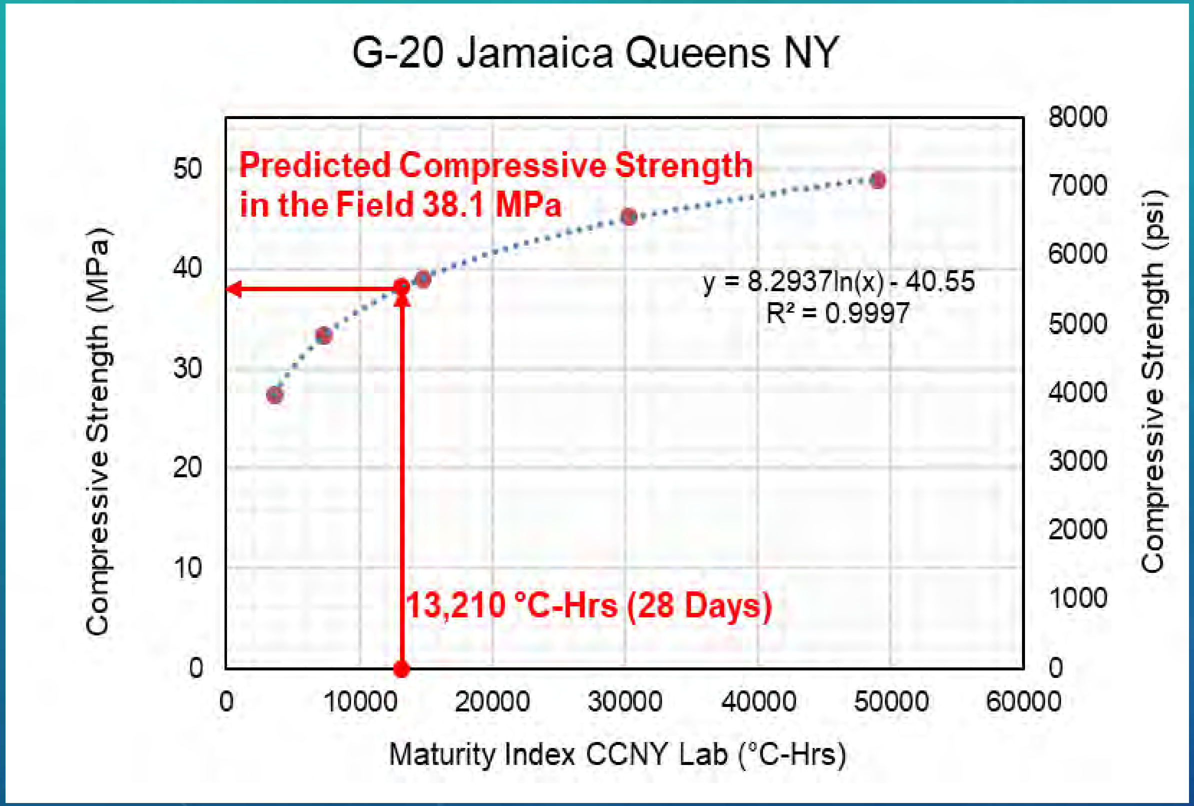


Figure 9.5. Predicted strength by maturity curve for each truck for G-20

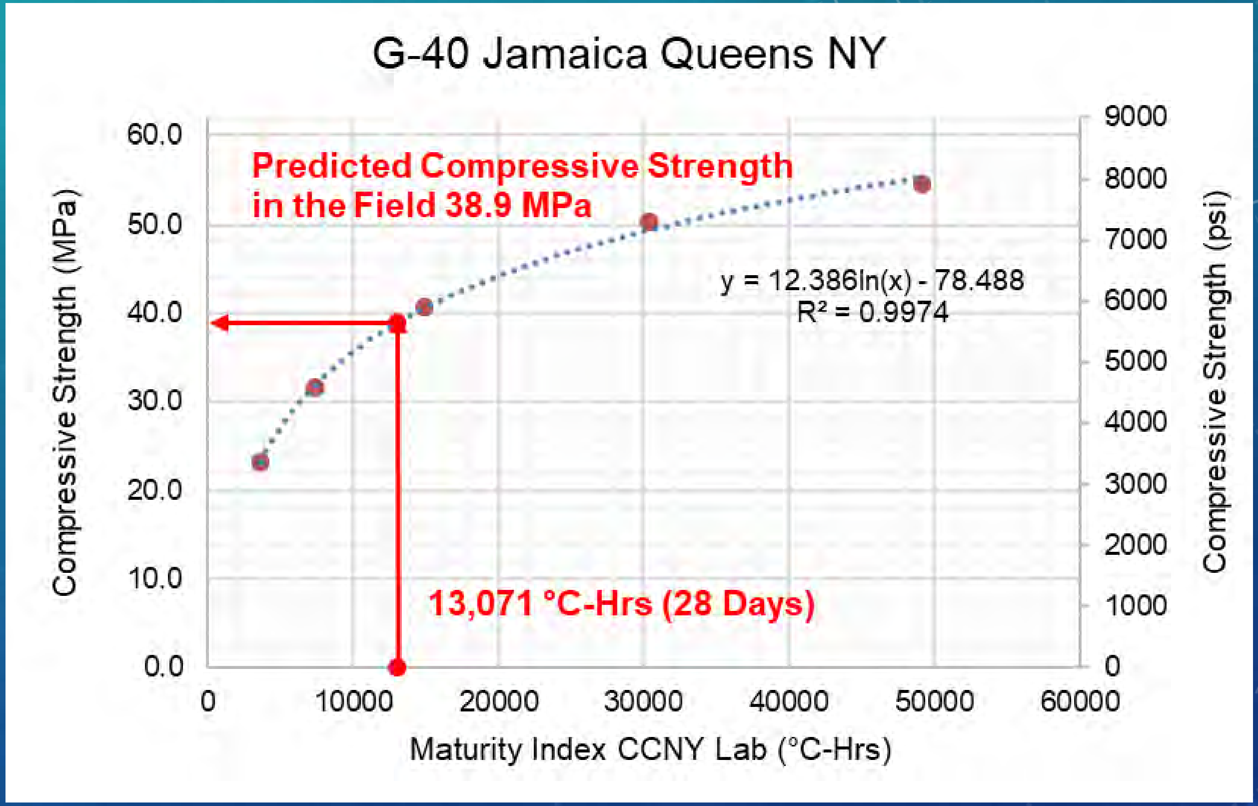


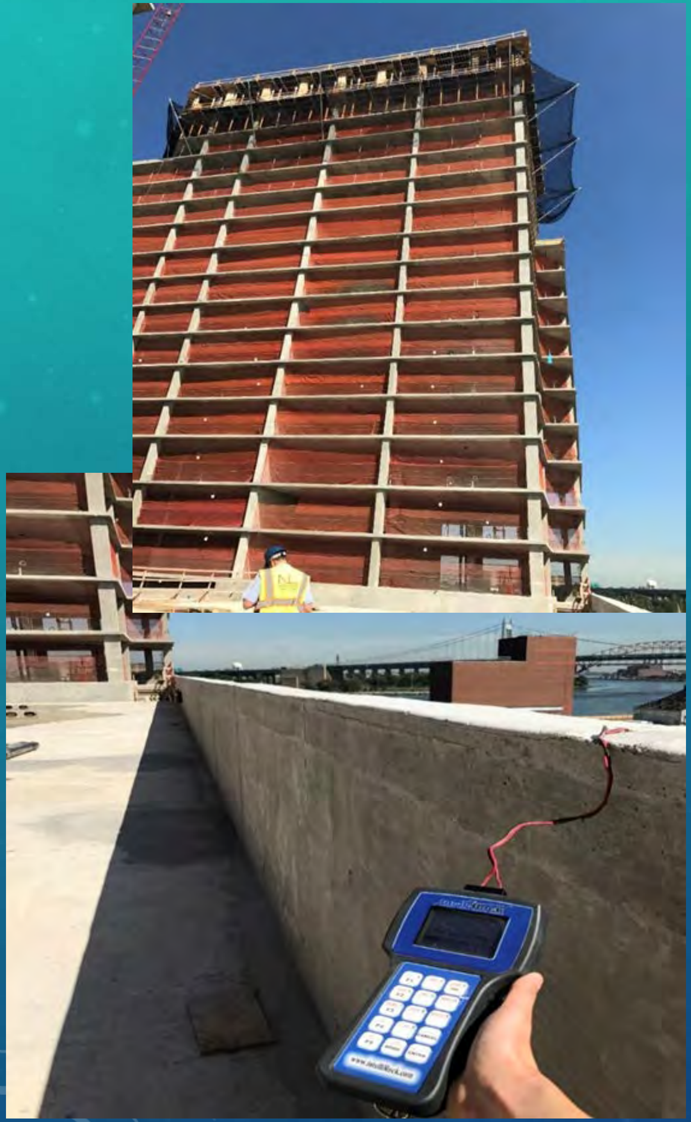
Figure 9.6. Predicted strength by maturity curve for each truck for G-40

HALLETTS POINT COMPLEX– RESIDENTIAL BUILDING

Halletts Point 1 Project- Slabs, Columns and Walls

Self-consolidating concrete 8,000 psi (55 MPa) with 35% cement replacement by GP

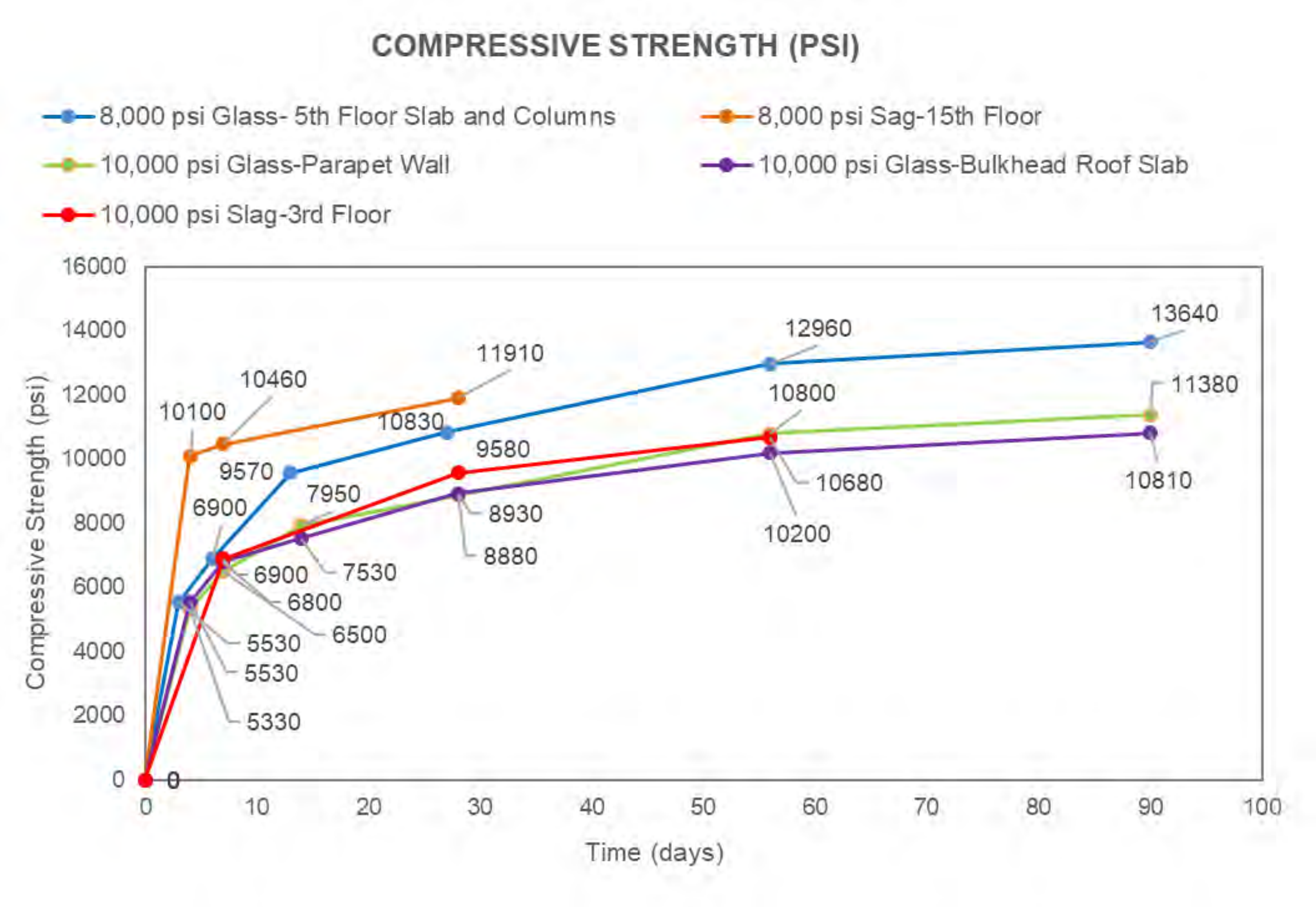
HALLETTS POINT 1 - SLABS, COLUMNS AND WALL



Parapet wall at 8th floor and Bulkhead roof slab, 10,000 psi (~70 MPa) self-consolidating concrete

COMPRESSIVE STRENGTH-8,000 PSI (55 MPA) AND 10,000 PSI (70MPA) SELF-CONSOLIDATING CONCRETE

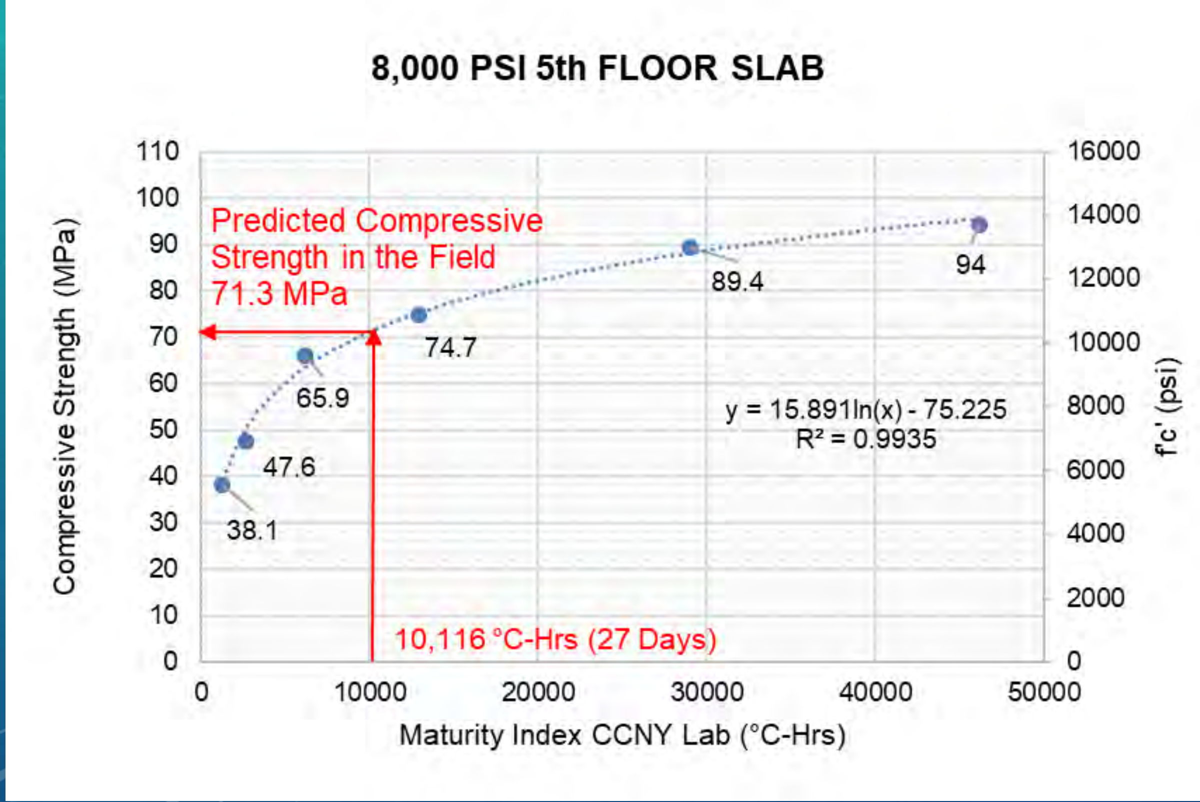
Samples prepared in **the** field and tested in the lab

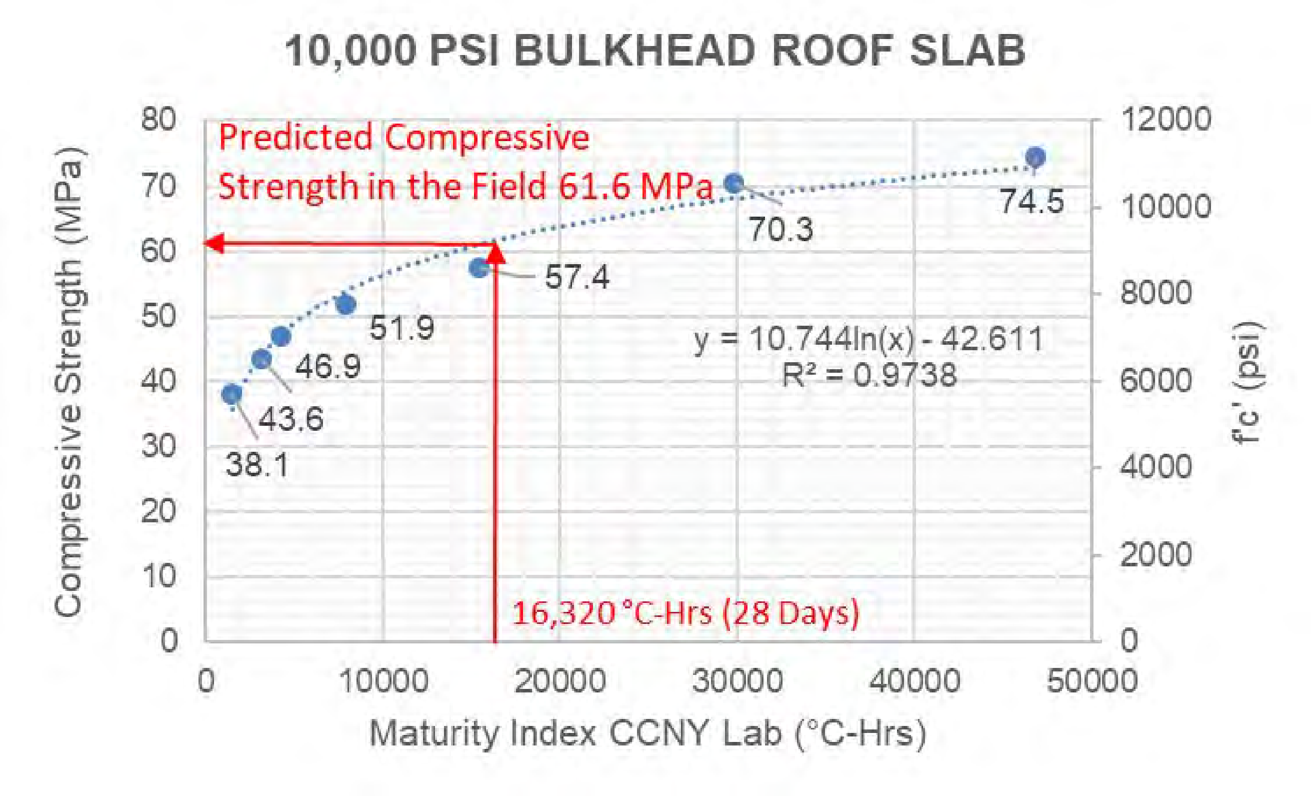


At 6 days

At 27 days

PREDICTING COMPRESSIVE STRENGTH BY MATURITY METHOD





climate earth

Results for Pozzotive

"The GWP impacts for a metric tonne of Pozzotive is 56kg CO_2e. This compares to the US industry average GWP for Portland cement of 1,040kg CO_2e."

Pozzotive® Screening LCA – Pre-Production

Beacon Falls, CT Production Facility

HLP Mock-up Mix Designs [1] with GGP [2] + Slag	Mix Design Strength Total Cementitious	Global Warming Potential (GWP) of Concrete Mixes [3] in kg CO2e/m3				HLP Mock-up GWP Reduction (below 100% Cement)	
		100% Cement Comparison	50% Cement 50% GGP + Slag HLP Mock-up	50% Cement 50% Slag Comparison	50% Cement 50% Fly Ash Comparison		
50% Cement **35% GGP** 15% Slag	**6,000 psi Mix** 650 Total Cementitious	509	312	322	308	38.70%	
50% Cement 50% GGP	**8,000 psi Mix** 750 Total Cementitious	559	326	343	327	41.70%	**Direct GWP Comparison** (Each SCM [4] Mix @ 50% Cement Replacement)
50% Cement **25% GGP** 25% Slag	**10,000 psi Mix** 850 Total Cementitious	627	373	383	364	40.50%	
50% Cement **25% GGP** 25% Slag	**12,000 psi Mix** 950 Total Cementitious	695	410	421	398	41%	

GWP Impacts (kg CO2e) of Cement + SCMs [5] per 1 metric tonne	Cement	GGP	Slag	Fly Ash
	1,040	55.9	146.6	0 [6]

[1] Mix Designs provided by US Concrete, approved by Severud.

[2] Ground-Glass Pozzolan

[3] GWP calculations executed by Climate Earth, on materials as supplied to US Concrete batch plants.

[4] Supplementary Cementitious Material, or cement replacement

[5] Cement, Slag, + Fly Ash GWP Impacts are all Industry Average. GGP GWP Impact is Product-Specific to Pozzotive made @ Urban Mining's Beacon Falls facility. None factor in transport to US Concrete NYC batch plants.

[6] Includes no processing of stored fly ash, which is increasingly necessary due to changes in availability/supply.

CONCLUDING REMARKS

- This research contributed to macrostructure evaluation of concrete with GGP for mechanical and durability properties
- Significant contributions were provided for microstructure evaluations to corroborate the macroscale findings
- Based on this research field projects were implemented for sidewalk and high-rise building constructions
- This research also contributed to the development of ASTM standard for GGP in concrete that were approved in 2019 (ASTM C1866)

CONCLUDING REMARKS

GGP meets ASTM standards

Test results show that GGP is superior to other SCMs (it shows significantly lower chloride permeability and linear shrinkage)

GGP does not cause ASR, and when it is used with highly reactive aggregate, it suppresses expansion ~ 50%

GGP can effectively reduce use of cement in concrete up to 50%, and effectively reducing embodied CO_2 in concrete

Designation: C1866/C1866M – 20

ASTM INTERNATIONAL

Standard Specification for Ground-Glass Pozzolan for Use in Concrete

1. Scope

1.1 This specification covers ground-glass pozzolans for use in concrete where pozzolanic action is desired. This specification applies to ground glass from sources that consist of container glass, plate glass, or E-glass.

1.2 The standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. If required results obtained from another standard are not reported in the same system of units as used by this standard, it is permitted to convert those results using the conversion factors found in the SI Quick Reference Guide.[2]

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

C125 Terminology Relating to Concrete and Concrete Aggregates

C150/C150M Specification for Portland Cement

C204 Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus

C311/C311M Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete

C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

C1069 Test Method for Specific Surface Area of Alumina or Quartz by Nitrogen Adsorption

C1293 Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction

C1567 Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

C1778 Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete

2.2 *ACI Standards:*[4]

318-2019 Building Code Requirements for Structural Concrete and Commentary

2.3 *CSA Standards:*[5]

A3003 Chemical Test Methods for Cementitious Materials for Use in Concrete and Masonry (Contained in CSA A3000 Cementitious Materials Compendium)

A3004-A4 Glass Content by the modified McMaster method (Contained in CSA A3000 Cementitious Materials Compendium)

3. Terminology

3.1 *Definitions:*

3.1.1 For definition of terms used in this specification, refer to Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *container glass, n*—recycled soda-lime-silica glass material that is derived from bottles, jars, and other glass

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.24 on Supplementary Cementitious Materials.
Current edition approved Feb. 15, 2020. Published March 2020. DOI: 10.1520/ ...C1866M-20.
...and Style for ASTM Standards, www.astm.org/COMMIT/
...visit the ASTM website, www.astm.org, or ...org. For *Annual Book of ASTM* ...ment Summary page on

[4] www.concrete.org/store.aspx

[5] https://store.csagroup.org/

Ground-Glass Pozzolan for Use in Concrete

Members of ASTM Subcommittee C09.24 summarize industry context behind new ASTM standard specification

by Amanda Kaminsky, Marija Krstic, Prasad Rangaraju, Arezki Tagnit-Hamou, and Michael D.A. Thomas

The construction sector is continually seeking new sources of supplementary cementitious materials (SCMs) to augment the portland cement, fly ash, slag cement, and silica fume used in modern concrete mixtures. Extensive research and testing have shown that several types of ground glass will perform well as a pozzolan in concrete. Supported by those results, ASTM Subcommittee C09.24, Supplementary Cementitious Materials, has drafted ASTM C1866/C1866M-20, "Standard Specification for Ground-Glass Pozzolan for Use in Concrete." The new specification was published earlier this year, after 3-1/2 years of balloting by the committee. This article provides much of the background information and industry context that accompanied the balloting.

Motivation

Glass production is a major source of greenhouse gases. While recycling can reduce the environmental impact,[1] 8.4 million tons (7.6 million tonnes) of container glass is landfilled annually in the United States (almost triple the amount that is recycled).[2] A significant resource is therefore being discarded. A preliminary, third-party life-cycle ...ssessment of one ground-glass pozzolan (GGP) producer's ...tput[3] indicates that the global warming potential (GWP) ...act for 1 ton (0.9 tonne) of GGP is 56 kg (123 lb) CO_2e. ...comparison, the U.S. industry average GWP for portland ...nt is 1040 kg (2293 lb) CO_2e. Thus, the GWP calculated ...ecent New York City project concrete mixture with 50% ...replacement with GGP would be about 40% less than ...[?] for a concrete mixture with cement only.

...urces and Chemistry

...the glass produced in the world is one of the ...pes:

- ...glass (used in packaging)—This material is generally soda-lime glass produced in flint (clear), green, blue, or amber colors and formed by air pressure in molds;
- Plate glass (used as glazing in buildings and automobiles)—This material is also generally soda-lime glass produced in clear or tinted colors and formed by floating on molten tin; or
- E-glass (used as reinforcement in fiber-reinforced polymers)—This material is low-alkali glass formed by extrusion through a bushing to form filaments that are rapidly drawn to a fine diameter before solidifying.

Table 1 summarizes the chemistry of these glass types and other pozzolanic or cementitious materials used in concrete, and Fig. 1 contextualizes GGP versus ordinary portland cement (OPC) and other SCMs. Although the chemistry of E-glass is quite different from the chemistry of container or plate glass, all three glass types have been shown to be suitable for use as a pozzolan in portland cement concrete. Also, because of the controlled processes used to manufacture these glass types, each has a very uniform chemistry worldwide, as demonstrated by the standard deviation reported in Table 2 for container glass chemistry.

The subcommittee members agreed that the three glass sources listed in ASTM C1866/C1866M are produced in sufficient quantities to provide viable resources for concrete production. The subcommittee also agreed that ground glass could be used safely. Glass production is regulated to limit toxic materials content, and the glasses listed in the standard are not included on the U.S. Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA) lists of hazardous wastes.[9] Further, the glass pozzolan sources are composed of amorphous silica. Unlike crystalline silica, amorphous silica has not been found to produce cancer in lung tissue.[10,11] However, as with all nonhazardous dusts, the U.S. Occupational Safety and Health Administration (OSHA) provides permissible exposure levels (PEL) for amorphous

ACI CONSTRUCTION AWARD (2020)

ACI MATERIALS JOURNAL TECHNICAL PAPER

MS No. M-2018-348.R1

Field Application of Recycled Glass Pozzolan for Concrete

by Marija Krstic and Julio F. Davalos

The inconsistent supply of fly ash and relatively high cost of slag as supplementary cementitious materials (SCMs) in the Northeastern United States is of concern to the concrete industry. Fly ash is a by-product from coal-burning plants that are shutting down or converting to natural gas, and slag is a residue from steel production mainly outside of the United States. With the goal of contributing significantly to the implementation of sustainable high-performance concrete, this study focuses on the evaluation of mixture designs using recycled post-consumer glass as SCM for concrete, for three mixtures with 20, 30, and 40% glass pozzolan as cement replacements, as well as two other comparable mixtures with 30% fly ash and 40% slag. Following laboratory characterizations for fresh and hardened properties, the mixtures with 20 and 40% glass pozzolan were selected for implementation in a sidewalk project in Queens, NY. The field work involved evaluations of mixture production, placement, finishing, curing, compressive strength, and development of maturity curves from data loggers in concrete. This study offers great potential for benefitting the concrete and glass recycling industries.

Keywords: cementitious materials; field application; glass pozzolan; maturity curves; post-consumer glass; sidewalk construction; strength and stiffness evaluations.

INTRODUCTION

Concrete is one of the most used materials in the world due to its versatility, durability, sustainability, and favorable cost.[1] The production of cement as the binding material in concrete is energy-intensive and has raised environmental concerns because 1 ton of cement produces 1 ton of CO_2 (5 to 8% contribution to total global CO_2 emissions).[2-4] In the United States, approximately 90 million tons of cement are used annually (CO_2 emissions equivalent to 300 million cars).[3] To overcome environmental impacts and produce high-performance concretes, which are commonly used today, supplementary cementitious materials (SCMs) such as fly ash and slag are used to partially replace cement in concrete mixtures. Fly ash is a residue from the combustion of coal burning plants and has been the most commonly used pozzolan for concrete, but recently its availability in the United States has decreased significantly.[5] Approximately 25% of coal burning power plants have shut down and many are converting to cheaper and cleaner natural gas.[6,7] Compounding this problem, granulated blast-furnace slag, a residue from the production of steel, is relatively expensive and generally produced outside the United States (Canada 31%, Japan 33%, Spain 16%, Germany 5%, and other 15%).[8] Thus, there is a need for an alternate SCM to overcome the scarcity of fly ash, particularly in the Northeastern region of the United States, and post-consumer glass can be effectively and economically transformed into value-added pozzolanic material for concrete. In New York, 3 million tons of cement are used annually for concrete,[3] and at a typical 30% SCM cement replacement, this potentially represents 1 million tons (907,000 tonnes) per year of glass pozzolan (1 million tons CO_2 reduction) using 6 billion post-consumer bottles and creating a $1 billion USD market.

The glass recycling industry faces significant challenges and economic hardship processing glass, particularly mixed color glass, which has no real market, and is generally used as low-cost granulated filler or drainage material. Glass is heavy (approximately 20% of total solid waste), harsh on processing equipment, and costly to recycle. In the United States, approximately 11.5 million tons (10.4 million tonnes) of post-consumer glass (or 80 lb [36.3 kg] per person) is generated annually, with only approximately 26.4% being recycled. In New York City, 140,000 tons (126,980 tonnes) is collected annually and approximately 50% is recycled.[9] Worldwide, glass represents 6% of approximately 2 billion tons (1.8 billion tonnes) per year of solid waste.[10] And although the recycling of glass in the United States has increased more than four times in the last 20 years, most of the glass is landfilled, exacerbating the management and disposal of solid waste. At the same time, the scarcity and cost of SCMs in the United States is of concern to the concrete industry. Mixed-color waste glass from the bottle and jar industry is an inert material that when milled to micro-level particles does not change its chemical composition and provides favorable pozzolanic reactivity[2,11] Thus, these two concerns—the lack of market for recycled glass and dwindling supply of fly ash—present a unique and transformative opportunity for benefiting both the glass recycling and the concrete production industries through the development and implementation of glass pozzolan for concrete.

Over the last few decades, several efforts have been directed to incorporate waste glass into concrete mixtures. An overview of the literature of the last 15 years showed that early applications of glass were in the form of granular material. Glass was crushed and used as recycled coarse and fine aggregates in concrete for nonstructural applications, as well as for other construction materials such as paving blocks and architectural tiles. Most studies reported that the replacement of natural aggregates with crushed waste glass of up to 20% increased the compressive strength, and 10% was suggested as most effective.[12-19] However, there were concerns with the potential negative effect of glass on alkali-silica reaction (ASR), due to high silica content in course glass particles. Recent studies[20-23] that investigated mechanical, physical, and chemical properties of concrete with different particle

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- Peter Gasparini, Independent consultant

THANK YOU FOR YOUR ATTENTION!

QUESTIONS AND SUGGESTIONS ARE WELCOME ☺

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