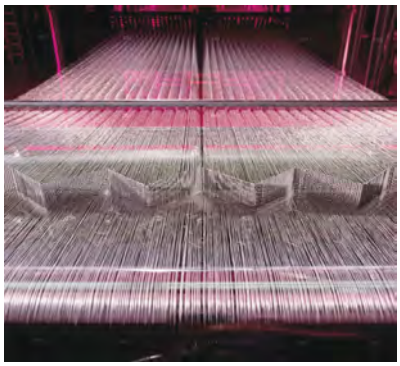
Use of Ground-Glass as Supplementary Cementitious Material in Portland Cement Concrete



Prasad Rangaraju, PhD, PE, FACI

Sustainable Materials Research and Technology (SMaRT) Laboratory

Glenn Department of Civil Engineering

Clemson University, *Clemson, SC*

NRMCA – Webinar on Concrete Innovations

November 30th, 2022

Courtesy: Some images/data from online resources are shown for demonstration purpose only.

1

Why Ground-Glass as an SCM in Concrete?

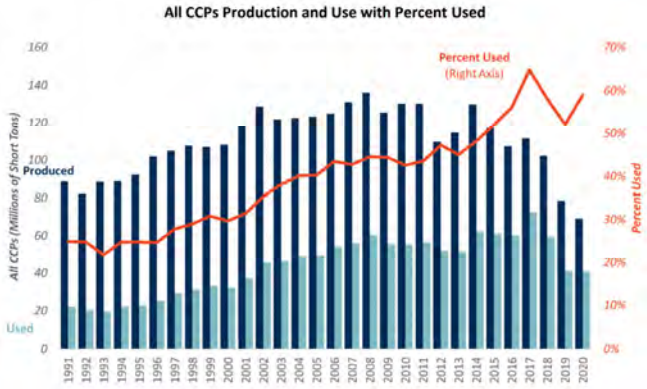
Why now?

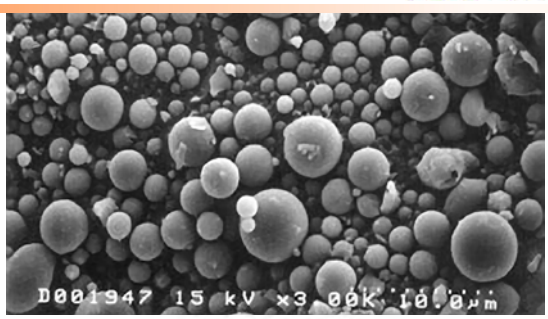


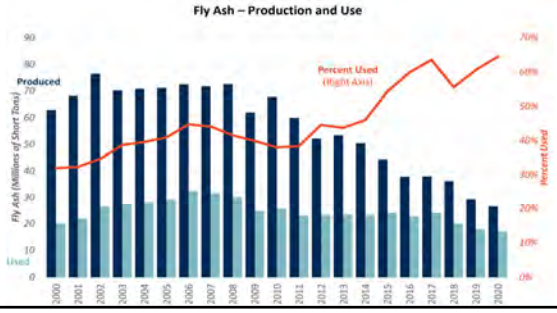

2

Traditional Supplementary Cementitious Materials (SCMs)

- Fly ash – Class F and Class C







https://acaa-usa.org/wp-content/uploads/2021/12/News-Release-Coal-Ash-Production-and-Use-2020.pdf

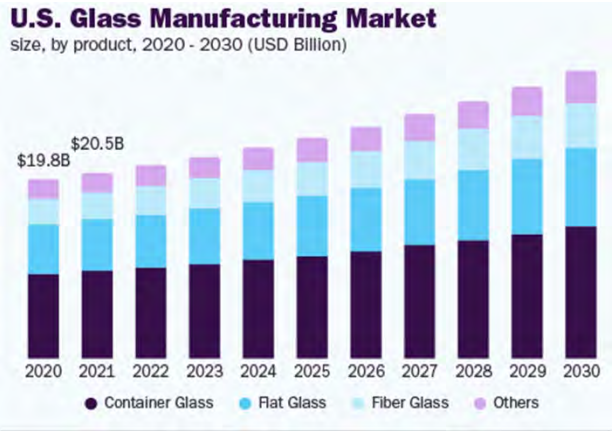
3

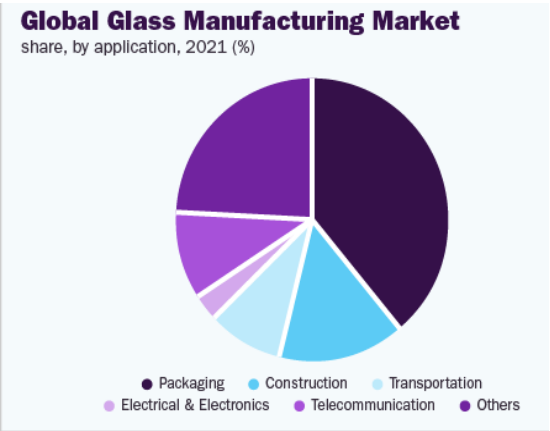
Alternative SCMs

- Natural Pozzolans (ASTM C618 – Class N)
- Calcined Clays
- Biomass ashes
- Harvested Ash, Ground Bottom Ashes and Other CCPs
- Ground Glass Pozzolans (ASTM C1866 – Type GS and GE)
- Blended Supplementary Cementitious Materials (ASTM C1697)

4

Glass Manufacturing Statistics

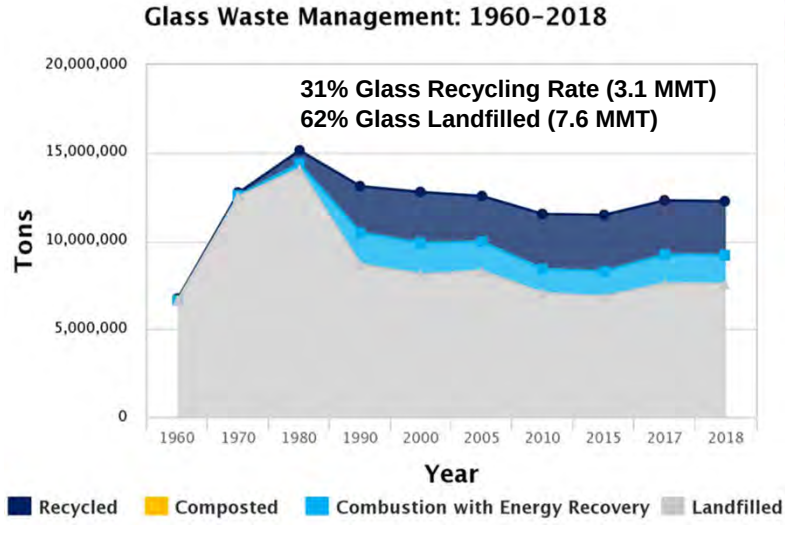




Grandviewresearch

5

Waste Generation and Management Pathways of Glass in the US



https://www.epa.gov/

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ASTM C1866 – Standard Specification for Ground-Glass Pozzolan for Use in Concrete

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.

Designation: C1866/C1866M – 20

Standard Specification for Ground-Glass Pozzolan for Use in Concrete[1]

This standard is issued under the fixed designation C1866/C1866M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

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

Type GS

Type GE

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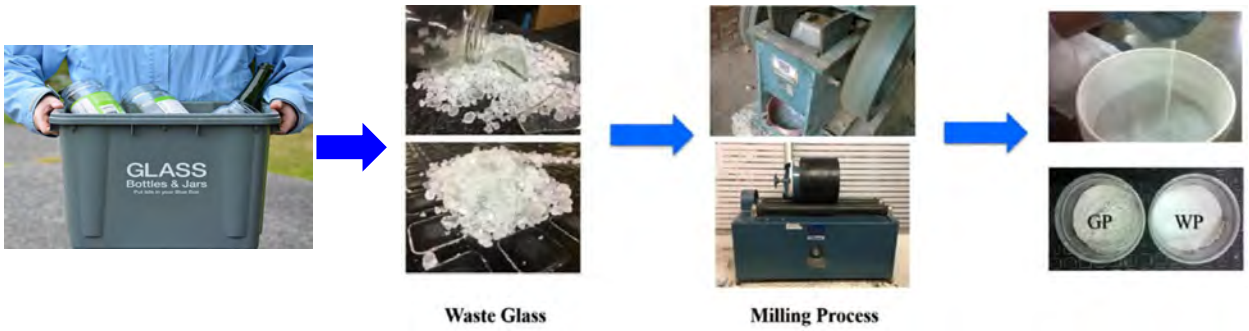
Production of Type GS Ground-Glass Pozzolan

- Typically, post-consumer glass is collected through Material Recovery Facilities (MRFs)
- On average, per capita consumption of glass on an annual basis is 75 lbs.
- A city with a population of 3,000,000 will produce about 100,000 tons of glass



Riviera et al., Advanced Powder Technology, 2018

8

Typical Chemical Composition of SCMs

Typical composition of three principal glass types an

Compound	Soda-lime glass		Type GE
	Type GS		
	Container glass	Plate glass	E-glass
SiO_2	71.0	71.2	59.9
Al_2O_3	1.82	0.36	12.5
Fe_2O_3	0.61	0.44	0.37
CaO	10.9	9.33	21.4
MgO	0.94	3.86	2.91
Na_2O	13.0	13.2	0.77
K_2O	0.52	0.04	0.06
SO_3	<0.1	<0.1	<0.1
LOI	<0.5	<0.1	<0.1
Amorphous silica*	~100	~100	~100

*Amorphous silica values are percentages of total silica content in the

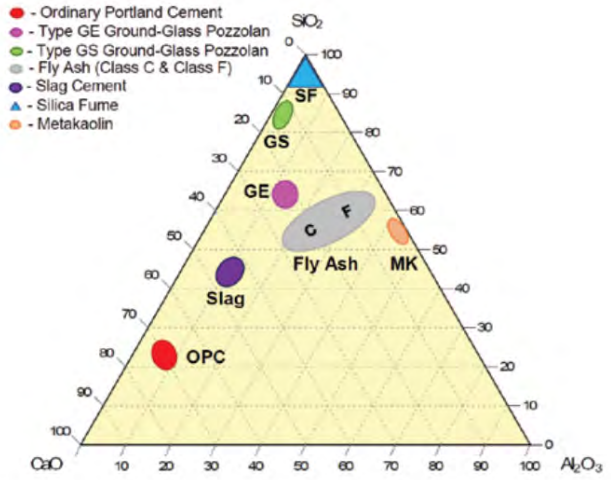


Fig. 1: Ternary plot contextualizing GGPs versus OPC and other SCMs (Note: For ternary plots, values are in wt.%, and they are normalized to the sum of SiO_2, Al_2O_3, and CaO)[4-8]

(figure courtesy of Marija Krstic)

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ASTM C1866 Chemical Requirements for Ground Glass Pozzolans

TABLE 1 Chemical Requirements

	Classification	
	Type GS	Type GE
Silicon dioxide (SiO_2), min %	60.0	55.0
Aluminum oxide (Al_2O_3), max %	5.0	15.0
Calcium oxide (CaO), max %	15.0	25.0
Iron oxide (Fe_2O_3), max %	1.0	1.0
Sulfur trioxide (SO_3), max %	1.0	1.0
Total equivalent alkalies, Na_2O_{eq}, max %[A]	15.0	4.0
Moisture content, max %	0.5	0.5
Loss on ignition, max %[B]	0.5	0.5

TABLE 2 Optional Chemical Requirements[A]

	Classification	
	Type GS	Type GE
Amorphous Content[B], min %	95	95

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Impact of Loss on Ignition (LOI) of GGPs on Air Content of Fresh Concrete

- LOI in GGPs (Type GS) is typically due to Non-Glass Residue (NGR).
- NGR typically contains paper, plastic, metals, solid and liquid organic content.
- Companies employ proprietary methods (ex: grinding, washing, separation techniques, etc.) to reduce the NGR to below 0.5% to meet ASTM C1866 requirements on LOI.

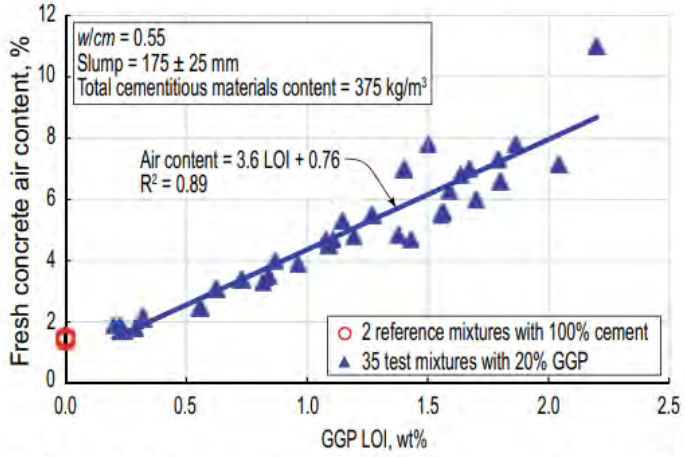

Fig. 2: Fresh air content versus LOI of GGP. The pozzolan comprised 20% of the total cementitious material in the 35 test mixtures *(figure courtesy of Arezki Tagnit-Hamou)* **(Note: 1 mm = 0.04 in.; 1 kg/m³ = 1.7 lb/yd³)**

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ASTM C1866 Physical Requirements for Ground Glass Pozzolans

TABLE 3 Physical Requirements

	Classification	
	Type GS	Type GE
Fineness		
Amount retained when wet-sieved on 45 µm (No. 325 sieve), max %	5.0	5.0
Strength activity index		
With portland cement, at 7 days, min % of control	75[A]	75[A]
With portland cement, at 28 days, min % of control	85[A]	85[A]
Water requirement, max % of control	Report Only	Report Only
Relative Density	Report Only	Report Only

[A] Meeting both the 7-day and 28-day strength activity index is required for specification compliance.

NOTE 4—Relative density values for specific Type GS and GE pozzolans have been reported by suppliers to be 2.51 and 2.55, respectively.

Typically, GGPs are ground to achieve a specific surface area of approximately 1000 to 2000 m²/kg with an average particle size less than a few microns.

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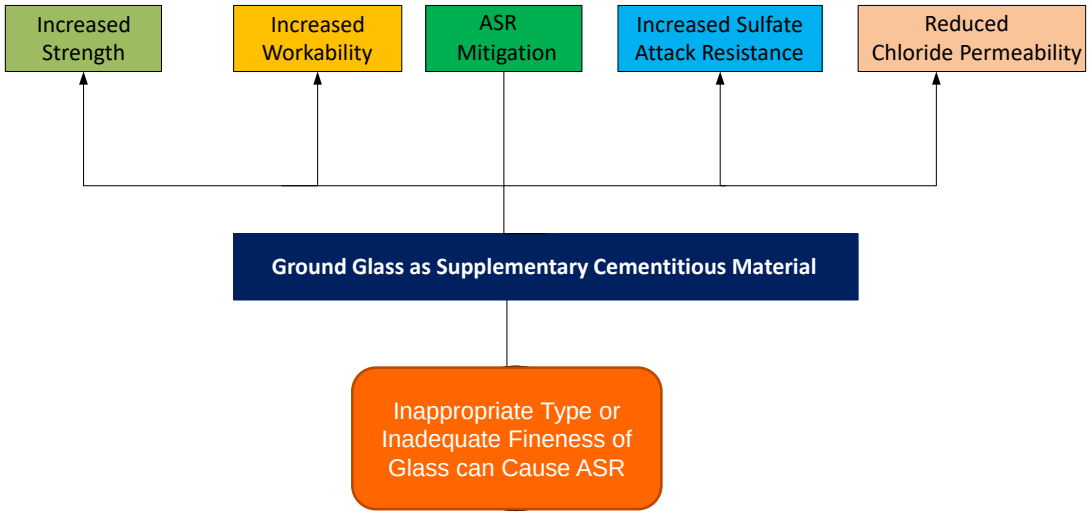
Impact of GGPs on Properties of Concrete Mixtures



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Pozzolanic Reactivity and Water-Demand of GGP

Pozzolan	Potential cement replacement, %*	Reactivity	Water demand
Container glass	10 to 40	Moderate to high	Reduction
E-glass	10 to 30		
Plate glass	10 to 40		
Class F fly ash	10 to 30	Low	Reduction
Class C fly ash	10 to 40	Moderate to high	Reduction
Natural pozzolan†	10 to 20	Low to moderate	Moderate to large increase
Slag cement	25 to 50	Moderate	Neutral
Silica fume	5 to 8	High	Large increase
Metakaolin	5 to 15	High	Large increase

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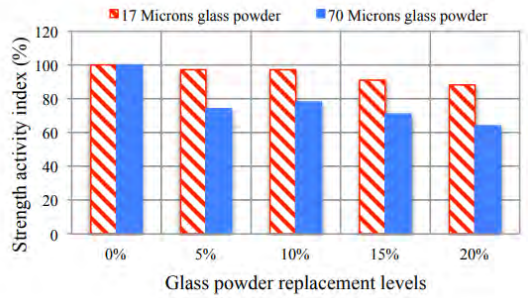
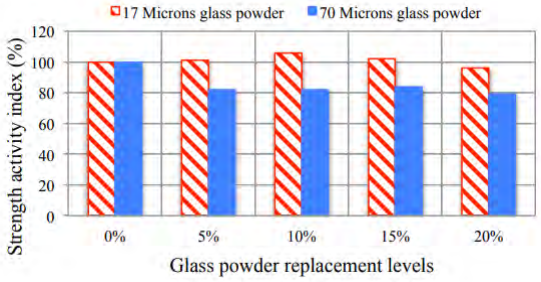
Strength-Activity Index of Soda Lime Glass Powder

28-Day Strength Activity Index (Soda Lime Glass)



56-Day Strength Activity Index (Soda Lime Glass)



Afshinnia, 2015, Clemson University

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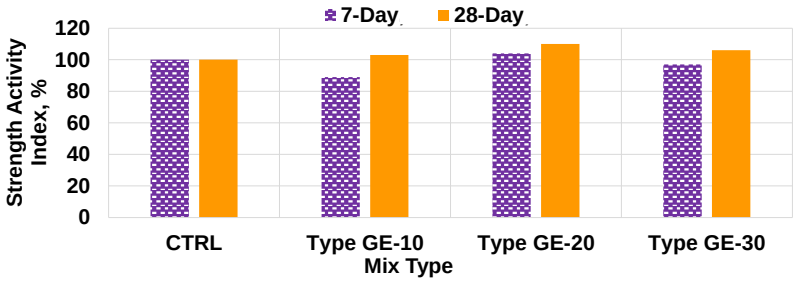
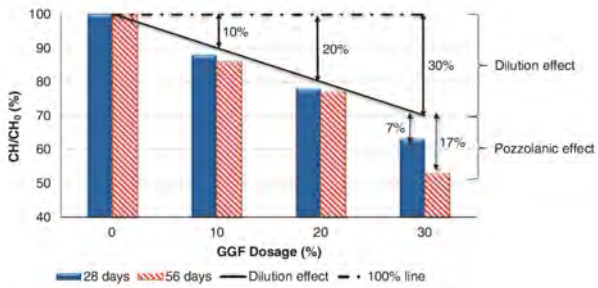
Strength Activity Index of Type GE Glass Pozzolan





Dezfouli-Rashidian and Rangaraju, 2018

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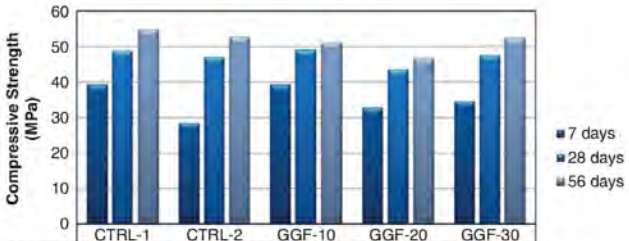
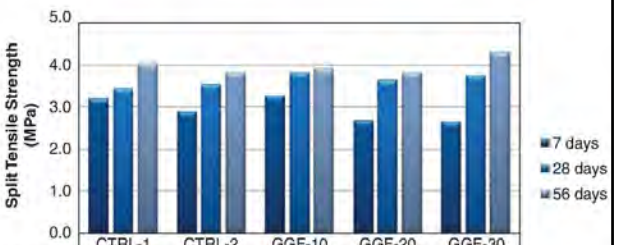
Mechanical Properties of Concrete with Type GE Pozzolan

Compressive Strength



	CTRL-1	CTRL-2	GGF-10	GGF-20	GGF-30
7 days	39	29	39	31	35
28 days	49	47	49	44	48
56 days	55	53	51	47	53

Split Tensile Strength



	CTRL-1	CTRL-2	GGF-10	GGF-20	GGF-30
7 days	3.2	2.9	3.3	2.7	2.7
28 days	3.4	3.5	3.8	3.7	3.8
56 days	4.0	3.8	3.9	3.8	4.3

Dezfouli-Rashidian and Rangaraju, 2018

17

ASR Mitigation Potential of Type GE in ASTM C1293

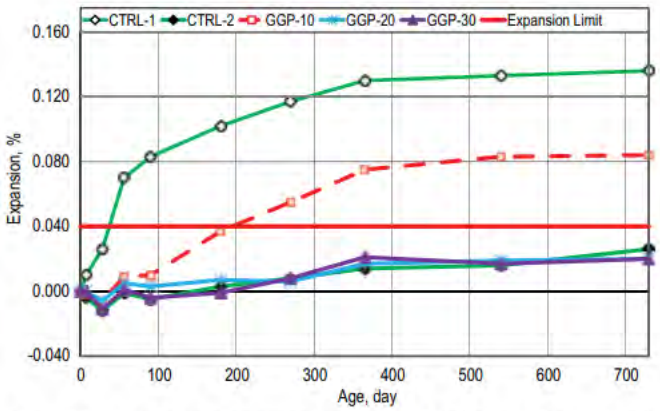


Fig. 5: Concrete prism expansion per ASTM C1293 for mixtures with 10, 20, and 30% of Type GE GGP cement replacement.[35] Mixtures CTRL-1 and CTRL-2 comprised OPC and OPC with 25% replacement with fly ash, respectively (GGP properties: LOI = 1 wt.%; avg. diameter = 4 microns; SG = 2.60; Blaine fineness = 1020 m²/kg)

Rashidian-Dezfouli and Rangaraju, 2018

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ASR Mitigation Potential of Type GE in ASTM C1567

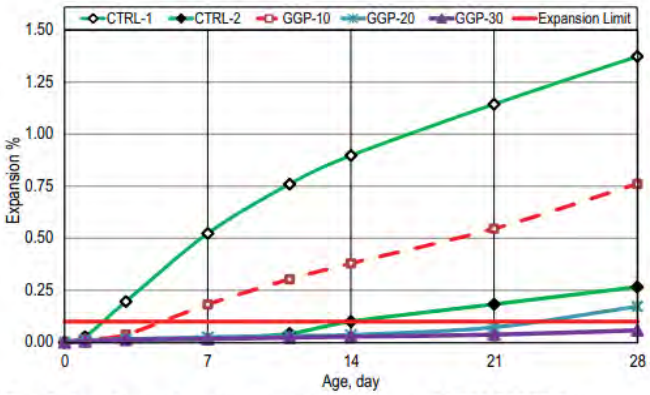

Fig. 4: Accelerated mortar bar expansion per ASTM C1567 for mixtures with 10, 20, and 30% of ground-glass fiber (Type GE GGP) as cement replacement.[34] Mixtures CTRL-1 and CTRL-2 comprised OPC and OPC with 25% replacement with fly ash, respectively (GGP properties: LOI = 1 wt.%; avg. diameter = 4 microns; SG = 2.60; Blaine fineness = 1020 m²/kg)

Rashidian-Dezfouli and Rangaraju, P.R., 2018

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ASR Mitigation Potential of Type GS in ASTM C1293

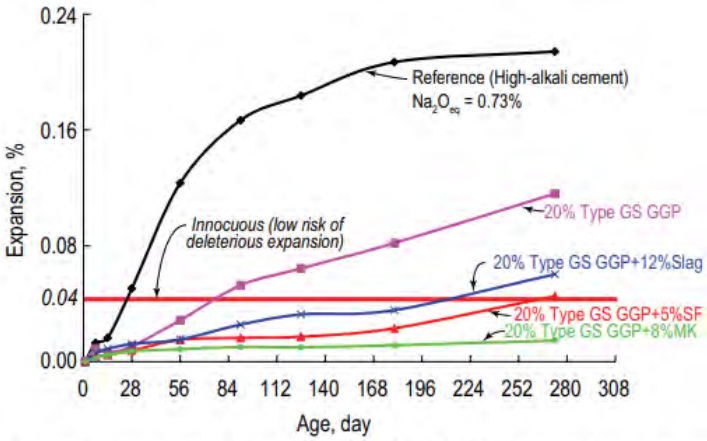

Fig. 6: Concrete prism expansion per ASTM C1293 for mixtures with Spratt aggregate, high-alkali cement, and cement replacement with Type GS GGP, silica fume (SF), and metakaolin (MK) *(figure courtesy of Arezki Tagnit-Hamou)*

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Comparison of ASR Mitigation of Type GE, GS and Class F Fly Ash in ASTM C1293 Test

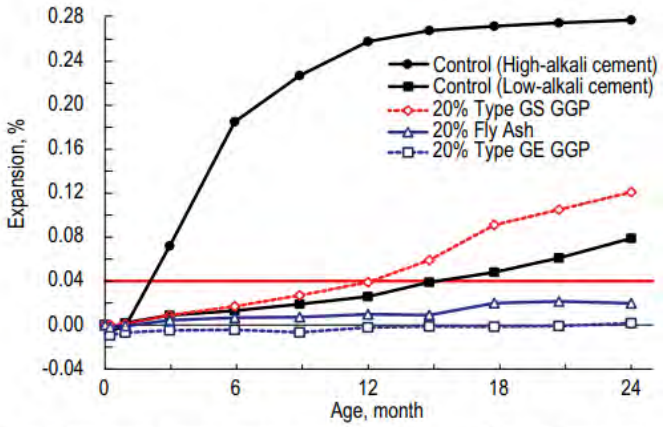

Fig. 7: Concrete prism expansion per ASTM C1293 for mixtures with Spratt aggregate, high- or low-alkali cement, and cement replacement with Type GS GGP, Type GE GGP, or fly ash *(figure courtesy of Michael D.A. Thomas)*

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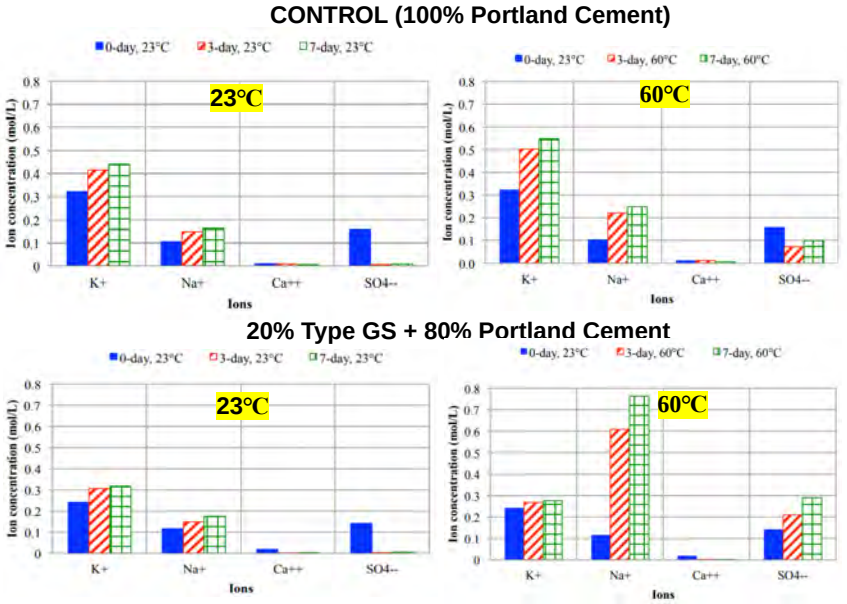
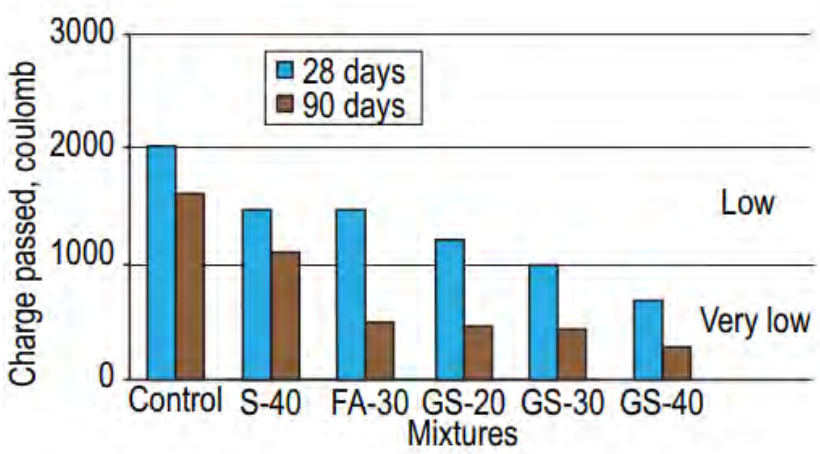
Evolution of Pore Solution Composition in Mixtures with Type GS GGP



Afshinnia, 2015, Clemson University

22

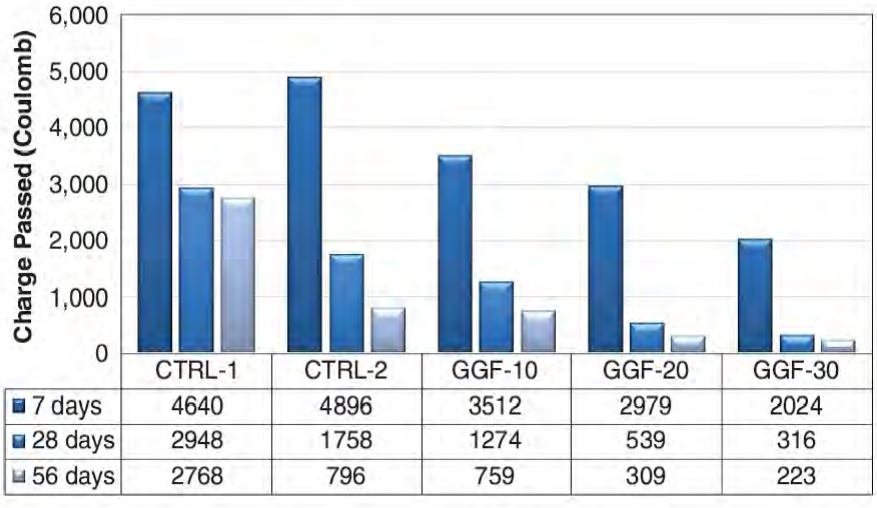
Influence of Type GS on Rapid Chloride Ion Permeability (ASTM C1202)



Krstic and Davalos, 2018

23

Influence of Type GE on Rapid Chloride Ion Permeability (ASTM C1202)



	CTRL-1	CTRL-2	GGF-10	GGF-20	GGF-30
7 days	4640	4896	3512	2979	2024
28 days	2948	1758	1274	539	316
56 days	2768	796	759	309	223

Rashidian-Dezfouli and Rangaraju, P.R., 2018

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Effect of GGPs on Resistance to Sulfate Attack

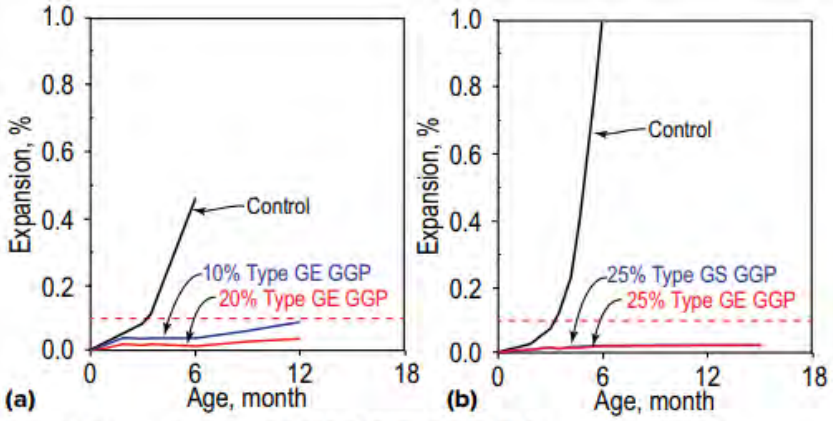

Fig. 8: Expansion per ASTM C1012/C1012M for concrete mixtures with a high-C3A portland cement: (a) 10 and 20% E-glass (Type GE); and (b) 25% Type GS and GE pozzolan *(figure courtesy of Michael D.A. Thomas)*

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Conclusions

- Performance of ground-glass pozzolans is dependent on meeting ASTM C1866 requirements, particularly in terms of chemical composition, LOI limit and Max. percent retained on No. 325 sieve (45 micron-sieve).
- Type GS and Type GE ground-glass pozzolans are effective SCMs and provide comparable performance to traditional Class F and C fly ashes in concrete, in terms of fresh properties and mechanical properties, at equivalent dosage levels.
- Type GE and GS can be effectively used as SCMs to provide sufficient durability in terms of resistance of concrete against sulfate attack and chloride ingress.
- Type GE pozzolan is superior in mitigating ASR in concrete containing reactive aggregates, compared to Type GS pozzolan. Type GS pozzolan can be used exclusively if no reactive aggregates are present, or Type GS in combination with other pozzolans can be used, provided ASR mitigation effectiveness is established. ASTM C1293 method is the appropriate test method to evaluate Type GS pozzolan.
- **Type GS and Type GE ground-glass pozzolans are effective pozzolans to meet the growing demand for SCMs in areas where they are readily available.**

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Relevant Standard Specifications for GGPs

ASTM C1866/C1866M - 20

Designation: C1866/C1866M – 20

Standard Specification for
Ground-Glass Pozzolan for Use in Concrete[1]

ASTM C1697-21

Designation: C1697 – 21

Standard Specification for
Blended Supplementary Cementitious Materials[1]

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Acknowledgements

ASTM C09.24 Subcommittee Members

- Amanda Kamisky, Building Products Ecosystem, LLC
- Dr. Marija Krstic, City College of New York
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- Boyd Clark, Construction Technology Laboratories
- **Louis Grasso, Urban Mining Northeast**
- **Dale Hauke, Urban Mining Northeast**
- **Joe Keating, Vitro Minerals, LLC (Potter Industries)**
- **Others**

- **Dr. Kaveh Afshinnia, Clemson University**
- **Dr. Hassan Dezfouli-Rashidian, Clemson University**

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