Alternative Sustainable Materials for Use in Portland Cement Concrete

Jerry Paris, M.E., E.I.

Christopher Ferraro, Ph.D.

Justin Roessler, E.I.

Timothy Townsend, Ph.D., P.E.

Florida Department of Transportation
Concrete Coalition of Florida Meeting
February 26, 2014

UF UNIVERSITY of FLORIDA

Motivation for Research

- Sustainability / Renewables
- Supply Shortages
  - The transition from coal to natural gas
- CO_2 Production

Currently Allowable Byproducts for Use in Portland Cement Concrete (FDOT 346.2)

- Granulated Blast Furnace Slag
- Class F Fly Ash (coal)
- Class C Fly Ash (coal)
  - Case Specific Beneficial Use Determination vs. Standing Beneficial Use Determination
- Microsilica (Silica Fume)

UF

Proposed Alternative Sustainable Materials for Use in Portland Cement Concrete

- Class C Fly Ash
- Rice Husk Ash
- Sugar Cane Bagasse Ash
- Waste Energy Ash (agg. replacement)
- Waste Glass Powder
- Waste Wood Fly Ash
- Equilibrium Catalyst?

Possible Alternative Solutions

Material	Production	Consumption	Surplus
GBFS[1,4]	541,000 tons	541,000 tons	-
Coal Fly Ash[1,2]	52.1M tons	23.2M tons	28.9M tons
Recycled Glass[3]	731,000 tons	131,000 tons	600,000 tons
WTE Fly Ash[3]	900,000 tons	0	900,000 tons
Rice Husk Ash[1,5]	2.8M tons	0	2.8M tons
Sugarcane Ash[3,5]	0.5-2.4M tons	0	0.5-2.4 tons
E-Cat[6]	400,000 tons	-	-
Waste Wood[1,7]	16.4M tons	1.6M tons	14.8M tons

- How big of a difference can this make in Florida's cement needs?
  In 2012, Florida consumed 3.9M tons of cement.

[1] In the U.S.
[2] No distinction between class F and C ash.
[3] In Florida.
[4] Blended into cement.
[5] Estimated potential based on agricultural production.
[6] Worldwide production
[7] Unburned wood

Project Goals

- Evaluate alternatives from different aspects:
  - Reactivity
  - Strength & Durability characteristics
  - Optimum replacement percentage
  - Cost

Waste-to-Energy Ash

Defined as the ash produced from the combustion of Municipal Solid Waste (MSW)

- Florida currently has 12 operating Waste-to-Energy Facilities (WTE) the most of any state
- 4.5 Million Tons of MSW combusted in Florida in 2012
  - Producing approximately 900,000 tons of MSW ash
- Combustion in a waste to energy facility produces two separate residuals
  - Fly Ash
    - Approximately 20% of ash product by volume
    - Typically contains higher levels of potentially harmful constituents
  - Bottom ash
    - Approximately 80% of ash product by volume
    - More chemically inert fraction

UF

Ash Management Practices

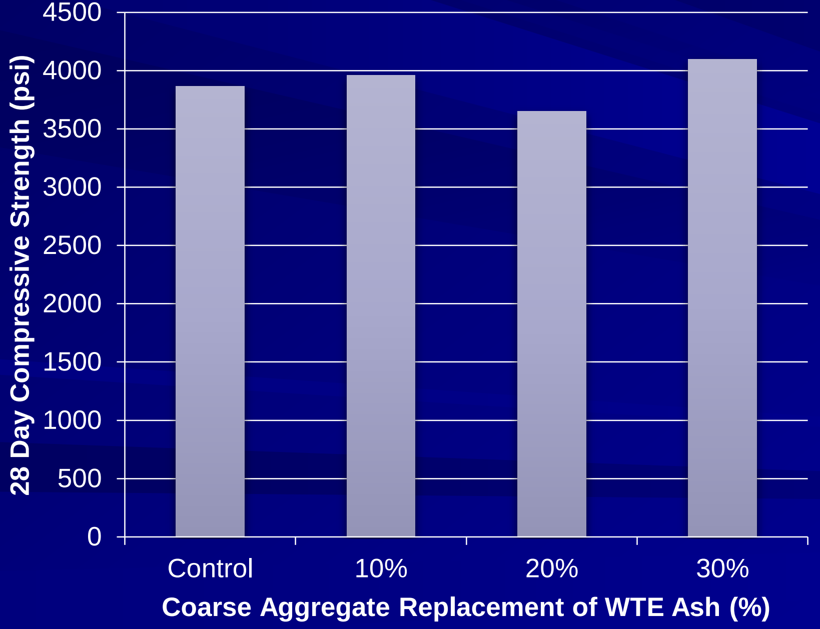
- New ash processing strategies have allowed for the ability to dispose of fly ash and bottom ash separately
- Ash in Florida primarily disposed in monofills
  - Landfills composed of only ash
- Financial incentive to process ash for metals recovery
  - Potential for mining of existing monofills
  - Large stockpile of material
- Bottom ash may be further split to improve metals recovery process
- This has created the opportunity to utilize bottom ash as an aggregate in construction applications

Ash Management Practices

- Rule Change to Florida Administrative Code
- (F.A.C.) 62-701
- Allows for the WTE ash as beneficial use for base and concrete materials

Preliminary Results

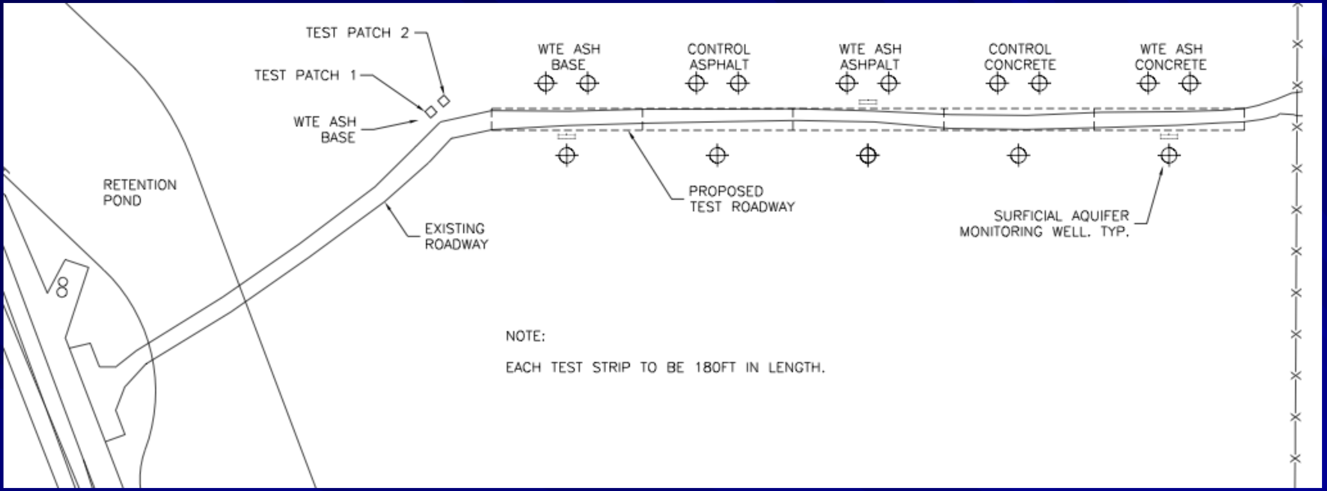
Compressive Strength Testing



Construction of Pavement

- Covanta Facility and Pasco County:
  - WTE for use as base material
    - Coarse and fine fraction
  - WTE for use in asphalt
    - Coarse only
  - WTE for use in PCC
    - Coarse only

Project Site



Thank you

Portland Cement

PC Major Chemical Components

CaO (Lime, C):	60-67%
SiO_2 (Silicate, S):	17-25%
Al_2O_3 (Alumina, A):	3-8%
Fe_2O_3 (Ferrite, F):	0.5-6%

C_3S	C_2S	C_3A	C_4AF
50-70%	10-30%	3-13%	5-15%

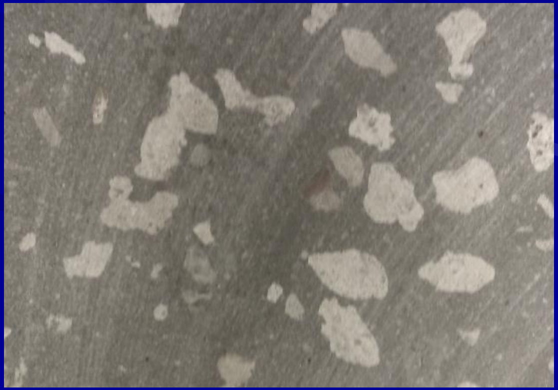
$$2Ca_3SiO_5 + 6(H_2O) \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2$$

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Free\ Lime$$

$$C - S - H\ and\ Free\ Lime$$

$$2Ca_2SiO_4 + 4(H_2O) \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + Ca(OH)_2$$

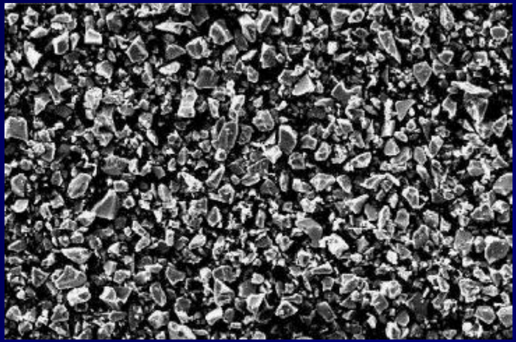
$$2C_2S + 4H \rightarrow C_3S_2H_3 + Free\ Lime$$

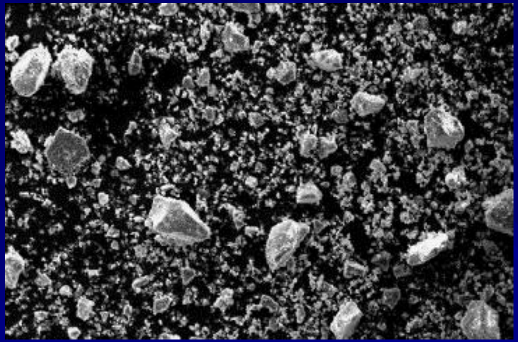


Granulated Blast Furnace Slag

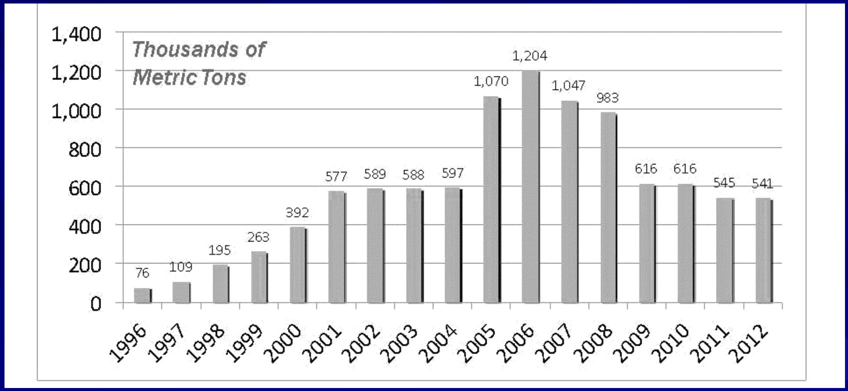
- Standard Specification for Slag Cement (ASTM C989)
- Product of steel smelting industry
- Replaces Portland cement (20-70%)
- Allowable per FDOT 346 and ASTM C989
  - Structural
  - Pavement
  - Mass (Dams, Large Foundations, etc)

Granulated Blast Furnace Slag





100 µm



U.S. Production of Slag Cement
Source: Slag Cement Assoc. (SCA)

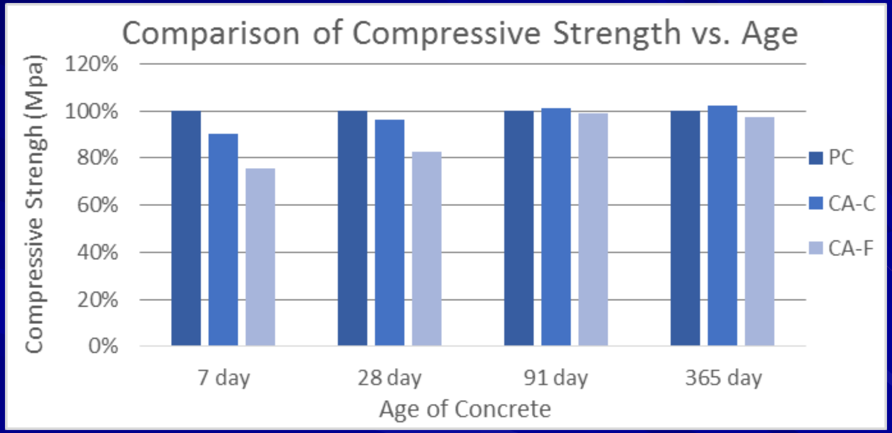
GBFS Major Chemical Components

C:	30-42%	(PC: 60-67%)
S:	35-40%	(PC: 17-25%)
A:	10-15%	(PC: 3-8%)
F:	0.3-2.5%	(PC: 0.5-6%)

UF

Class F Coal Fly Ash

- Low Calcium Fly Ash (ASTM C618)
- Product of coal burning
- Replaces Portland cement (15-50%)
- Allowable per FDOT 346
  - Structural
  - Pavement
  - Mass Concrete



Source: Carette and Malhorta: Characterization of Canadian Fly Ashes and their Performance in Concrete

CA-F Major Chemical Components

C:	0.7-7.5%	(PC: 60-67%)
S:	45-64.4%	(PC: 17-25%)
A:	19.6-30.1%	(PC: 3-8%)
F:	3.8-23.9%	(PC: 0.5-6%)

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Free\ lime$$

$$Free\ lime = \mathrm{Ca(OH_2)}$$

$$Ca(OH)_2 + H_4SiO_4 \rightarrow CaSiO_4H_2 \cdot 2H_2O$$

Class C Coal Fly Ash

- Standard Specification for Coal Fly Ash (ASTM C618)
- Product of coal burning
- Replaces Portland cement (15-50%)
- Allowable per FDOT 346 and ASTM C618
  - Structural
  - Pavement

CA-C Major Chemical Components

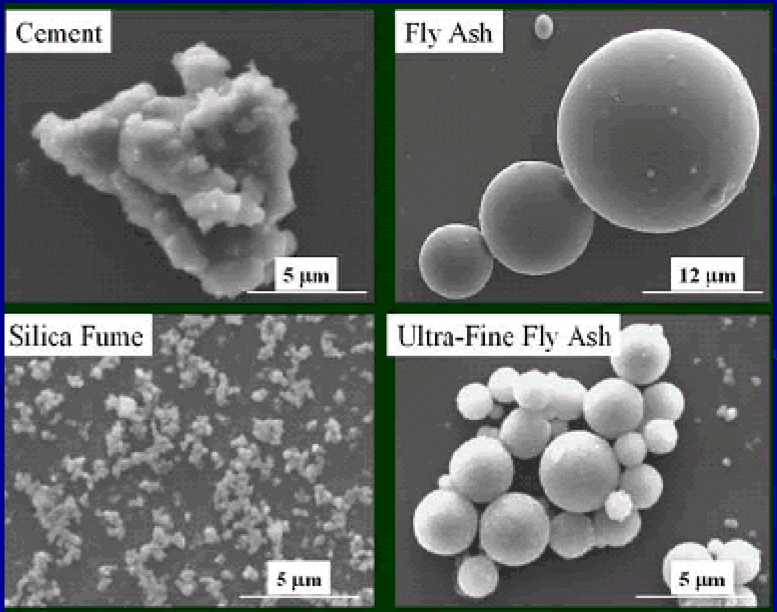
C:	11.6-29.0%	(PC: 60-67%)
S:	23.1-50.5%	(PC: 17-25%)
A:	13.3-21.3%	(PC: 3-8%)
F:	3.7-22.5%	(PC: 0.5-6%)

- Problems with using CA-C?

UF

Microsilica (Silica Fume)

- Standard Specification for Silica Fume Used in Cementitious Mixtures (ASTM C1240)
- Product of silica and ferrosilicon industry
- Replaces Portland cement (up to 9%)
- Allowable per FDOT 929 and ASTM C1240
  - Structural
  - Pavement



Silica Fume Chemical Components

C:	0.3-0.5%
S:	92-96%
A:	0.2-0.9%
F:	0.4-2.0%

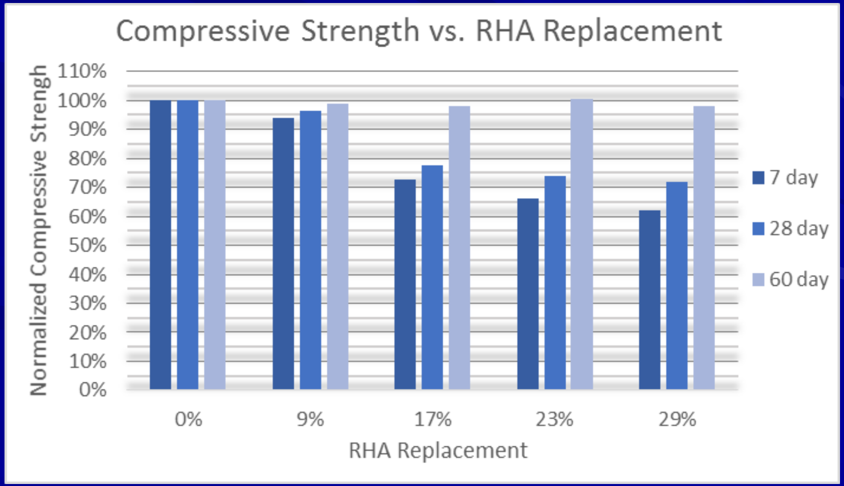
UF

Rice Husk Ash

- Classified as a Class N Natural Pozzolan (ASTM C618)
- Product of burning rice husks for waste energy
- Replaces Portland cement (10-30%)
- Will be investigated for Florida as rice is a cover crop for sugar cane farmers. Arkansas and Louisiana are top US producers (6.08M tons of rice, 430K ton ash potential)
- Utilized in Asian countries due to large supply

RHA Major Chemical Components

C:	0.5-1.4%
S:	86.0-91.8%
A:	0.1-1.2%
F:	0.1-1.9%



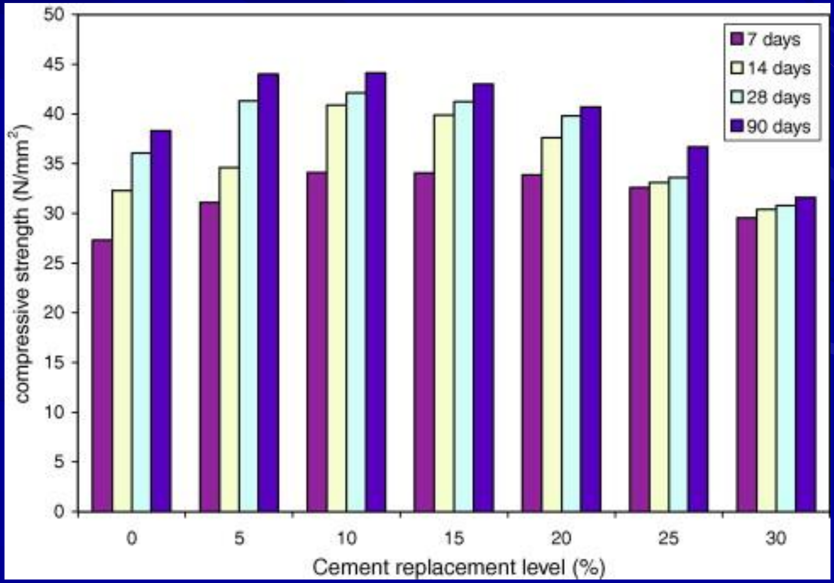
Source: Rahman: Use of Rice Husk Ash in Sandcrete Blocks for Masonry Units

Sugar Cane Bagasse Ash

- Classified as a Class N Natural Pozzolan (ASTM C618)
- Product of burning sugar cane bagasse for waste energy
- Replaces Portland cement
- Will be investigated for Florida as sugar cane is a major cash crop for local farmers.
- Utilized in Brazil and Thailand due to abundant supply

SCBA Major Chemical Components

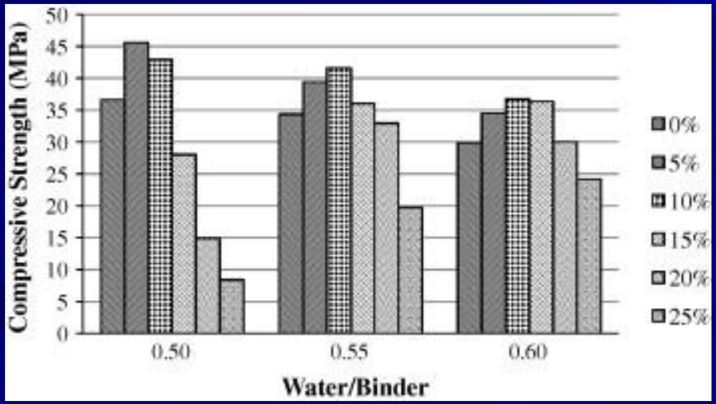
C:	0.1-5.0%
S:	78.0-96.2%
A:	0.2-8.9%
F:	1.9-8.8%



Source: Ganesan et al.: Evaluation of Bagasse Ash as Supplementary Cementitious Material

Equilibrium Catalyst

- Equilibrium Catalyst is an aluminosilicate byproduct of petroleum industry
- Currently being added to cements in Texas as a "non-reactive" filler.
- Chemical composition varies with producer and manufacturer.



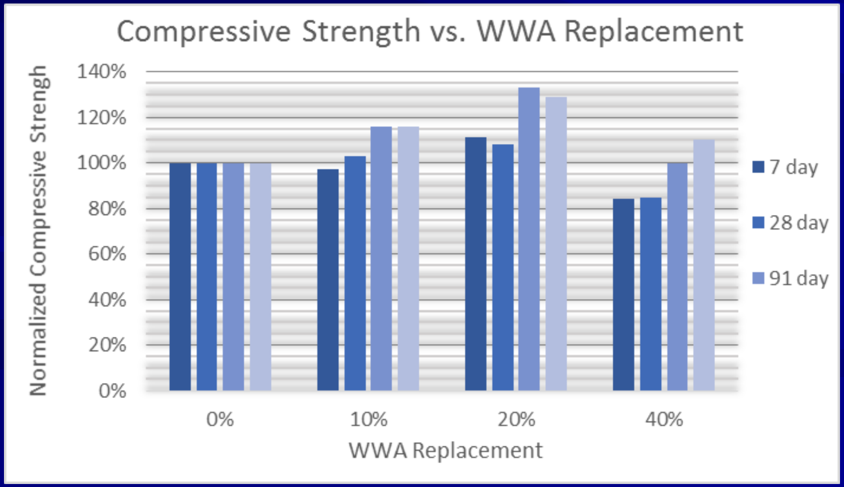
Source: Khalifa et al.:Potential Use of FCC Spent Catalyst As Partial Replacement of Cement or Sand in Cement Mortars

Recycled Glass Powder

- Relatively new industry
- MSW glass is collected and separated, then crushed into several sizes (cullet, sand, powder, etc)
- Can be amended with different chemical additions
    - Chemical composition varies with product and manufacturer.

Waste Wood Ash

- Byproduct of biomass energy combustion facilities
- Will burn “yard clippings” as well as construction materials
- Incredibly varied fuel source
  - By product is affected by originating fuel source



Source: Cheah and Ramli: The Implementation of Wood Waste Ash As A Partial Cement Replacement Material in the Production of Structural Grade Concrete and Mortar: An Overview

Plastic Properties of Different SCM Additions

Effect Due To Addition of SCM:	GBFS	CA-C	CA-F	Silica Fume	RHA	SCBA	E-Cat	Ground Glass	Wood Ash
Workability	↑	↑	↑	↓	↓	↓		↓	↓
Heat of Hydration	↓	↓	↓	↑		↓			
Setting Time	↑	Dependent on Replacement %	↑	↑	↑ Initial ↓ Final		↓		↓
Bleeding and Segregation	↑	↓	↓		↓		↓		

Hardened Properties of Different SCM Additions

Effect Due To Addition of SCM:	GBFS	CA-C	CA-F	Silica Fume	RHA	SCBA	E-Cat	Ground Glass	Wood Ash
Compressive Strength	↑ In late strength	↑	↓ Initial ↑ Final	↑	↑	↑		↓	Dependent on Replacement %
Tensile Strength	↑	↑	↑	↓	↑	↑		↑	↓
Flexural Strength	↑	↑	↑	↑	↓			↑	↓
Durability	↑	↑	↑	↑					
Permeability	↓	↓	↓	↓	↓	↓			↓
Resistance to ASR	↑	↓	↑	↑	↑	↑			
Freeze/Thaw Resistance	↓	↑	↑	↑	↑				No Sig. Change
Resistance to Sulfate/Chloride Attack	↑	↑	↑	↑	↑	↑		↑	
Resistance to Corrosion	↑	↑	↑	↑					↑