American Concrete Institute
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Concrete with Recycled Materials

ACI Fall 2013 Convention
October 20 - 24, Phoenix, AZ

Mr. Jared Wright is a PhD Candidate in the Department of Civil and Environmental Engineering at The Pennsylvania State University. Mr. Wright's research focuses on the mechanical properties of concrete using recycled materials and the characterization and subsequent mitigation of ASR. Mr. Chris Cartwright is a Master's student at Penn State in the Department of Civil and Environmental Engineering.

Civil and Environmental Engineering
The Pennsylvania State University

ACI Committee 555: Concrete with Recycled Materials

Proportioning and Performance Evaluation of Concrete with Recycled Glass Fine Aggregate

Jared Wright, Chris Cartwright, Farshad Rajabipour

ACI Fall Convention 2013
Phoenix, Arizona
10/21/2013

Research Motivation

20%

80%

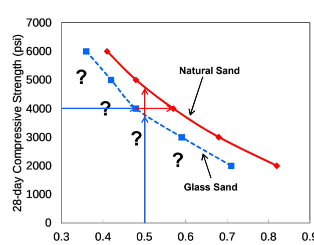
600,000 tons/year

Storage?

Stockpile of recycled glass cullet, West Virginia, USA

Objectives

- Develop Specifications for proper use of glass in concrete (Glasscrete)
- Compare Fresh and Hardened Properties of Natural Sand Concrete to Glasscrete
  - Similar w/cm
  - Similar Design f'c



Courtesy of ACI 211.1

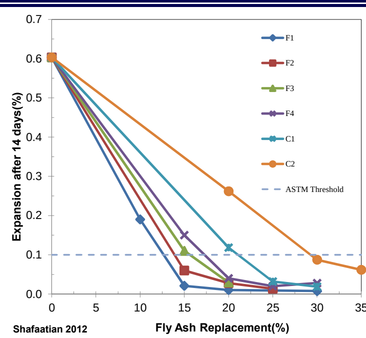
Nomenclature

Acronym	Design 28-day f'c (ksi)	w/cm	Slump	Fine Aggregate	Application
N5,5.0"	5	0.46	5.0"	Natural Sand	Building Frames and Bridge Decks
G5,5.0"	5	0.42	5.0"	Glass Sand	Building Frames and Bridge Decks
N4,1.5"	4	0.57	1.5"	Natural Sand	Pavement and Slip-Form Applications
G4,1.5"	4	0.48	1.5"	Glass Sand	Pavement and Slip-Form Applications
N4,5.0"	4	0.57	5.0"	Natural Sand	Building Frames and Bridge Decks
G4,5.0"	4	0.48	5.0"	Glass Sand	Building Frames and Bridge Decks
N0.48,5.0"	?	0.48	5.0"	Natural Sand	Building Frames and Bridge Decks

Concrete Constituents

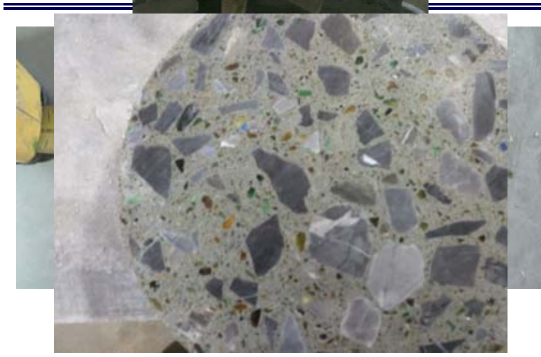
- Coarse Aggregate
  - ASTM C 33 #57 crushed limestone
- Natural Sand Fine Aggregate
  - ASTM C 33 Type A river sand
- Glass Sand Fine Aggregate
  - Soda-Lime Glass
- Cement
  - Type I
- Mineral Admixture
  - 20% F Fly Ash for all mixtures
    - For **mitigation of ASR**
- Chemical Admixtures
  - Super-plasticizer
  - Air Entrainer

Fly ash results for ASTM C 1567



- **100% Glass Sand**

Glasscrete Production



Experiments

- ASTM C 143: Slump
- ASTM C 231: Plastic Air Content (Pressure Method)
- ASTM C 39: Compressive Strength
- ASTM C 469: Elastic Modulus
- ASTM C 157: Drying Shrinkage
- ASTM C 944: Abrasion Resistance of Concrete
- ASTM C 1202: Rapid Chloride Penetration Test (RCPT)
- ASTM C 1585: Sorptivity of Concrete

Glasscrete requires less plasticizer to reach target slump

	N5,5.0"	G5,5.0"	N4,5.0"	G4,5.0"	N0.48,5.0"
Design Fresh Air Content	3.0%				
Design 28-day f'c (ksi)	5		4		?
Design Slump (in.)	5.0				
w/cm	0.46	0.42	0.57	0.48	0.48
Plasticizer (fl. oz./yd^3)	**190**	**136**	**190**	**115**	**187**
Measured Slump (in.)	4.5-5.5				
Measure Fresh Air Content (%)	2.0-4.0				

Glasscrete requires less plasticizer to reach target slump

	N5,5.0"	G5,5.0"	N4,5.0"	G4,5.0"	N0.48,5.0"
Design Fresh Air Content	3.0%				
Design 28-day f'c (ksi)	5		4		?
Design Slump (in.)	5.0				
w/cm	0.46	0.42	0.57	0.48	0.48
Plasticizer (fl. oz./yd^3)	**190**	**136**	**190**	**115**	**187**
Measured Slump (in.)	4.5-5.5				
Measure Fresh Air Content (%)	2.0-4.0				

Glasscrete requires a lower w/cm to achieve similar f'c

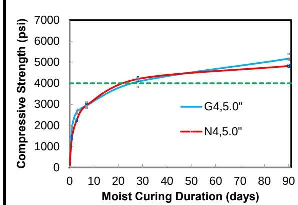
	N5,5.0"	G5,5.0"	N4,5.0"	G4,5.0"	N0.48,5.0"
Design 28-day f'c (psi)	5000		4000		?
Design Slump (in.)	5.0				
Design Fresh Air Content	3.0%				
w/cm	**0.46**	**0.42**	**0.57**	**0.48**	**0.48**
Measure f'c @ 28-days (psi)	**5420**	**5060**	**4200**	**4070**	**4750**

f'c (G) < f'c (N) @ same w/cm

	N5,5.0"	G5,5.0"	N4,5.0"	G4,5.0"	N0.48,5.0"
Design 28-day f'c (psi)	5000		4000		?
Design Slump (in.)	5.0				
Design Fresh Air Content	3.0%				
w/cm	**0.46**	**0.42**	**0.57**	**0.48**	**0.48**
Measure f'c @ 28-days (psi)	**5420**	**5060**	**4200**	**4070**	**4750**

f'c development over time

Similar design 28-day f'c of 4000psi

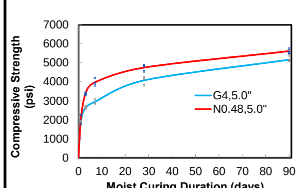


	N4,5.0"Strength (psi)	G4,5.0"Strength (psi)
	0.57	*0.48*
1 day	1420	1900
3 days	2250	2640
7 days	2950	2950
28 days	4200	4070
90 days	4820	5160

- **Glasscrete gains strength quicker (due to lower w/cm)**
- **At later ages natural sand concrete may reach and even exceed glasscrete's f'c**

f'c development over time

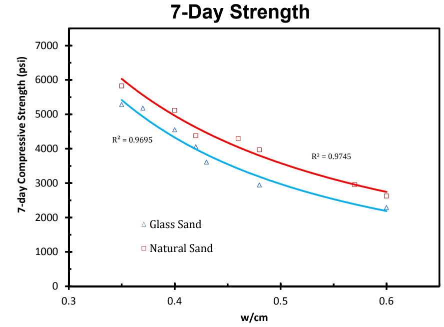
Same w/cm of 0.48



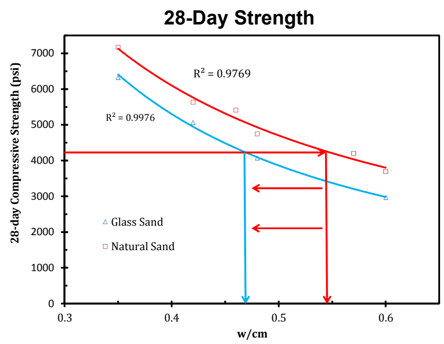
	N048,5.0" Strength (psi)	G4,5.0"Strength (psi)
	0.48	*0.48*
1 day	2010	1900
3 days	3380	2640
7 days	3970	2950
28 days	4750	4070
90 days	5610	5160

- **Early ages have similar strengths**
- **Natural sand concrete has greater strength at later ages**

Glasscrete needs a lower w/cm!



Glasscrete needs a lower w/cm!

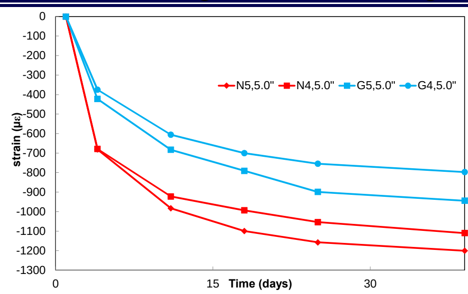


E(G) > E(N)

	N4,5.0"	G4,5.0"	N0.48,5.0"
w/cm	0.57	0.48	0.48
MOE (E06 psi)	3.46	4.06	3.81

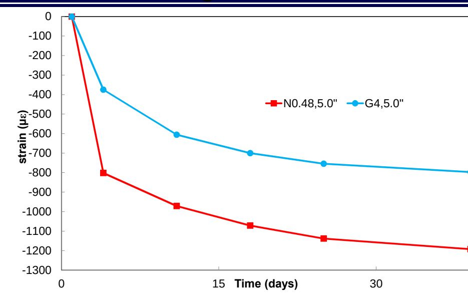
- Glasscrete's have a higher elastic modulus @ similar strengths and same w/cm

Glasscrete has a reduced drying shrinkage @ similar strength



- Glasscrete's have a lower drying shrinkage @ similar strengths

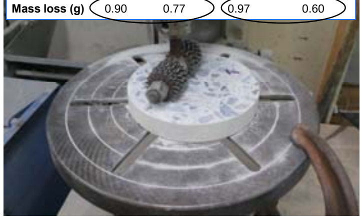
Glasscrete has a reduced drying shrinkage @ same w/cm



- Glasscrete's have a lower drying shrinkage @ same w/cm

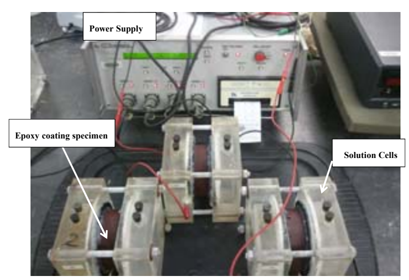
Glasscrete less abrasion resistant @ same w/cm

	N5,5.0"	G5,5.0"	G4,5.0"	N0.48,5.0"
w/cm	0.46	0.42	0.48	0.48
Mass loss (g)	0.90	0.77	0.97	0.60



Glasscrete typically more abrasion resistant at same strength
Glasscrete less abrasion resistant at same w/cm

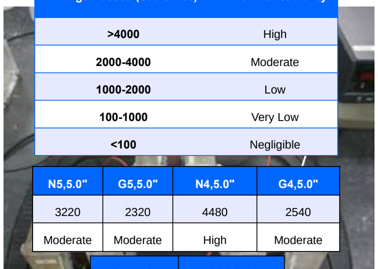
ASTM C 1202: RCPT



3.0% $NaCl$

0.3N $NaOH$

Glasscrete more ion resistant



Charge Passed (coulombs)	Cl ion Penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

3.0% $NaCl$

0.3N $NaOH$

N5,5.0"	G5,5.0"	N4,5.0"	G4,5.0"
3220	2320	4480	2540
Moderate	Moderate	High	Moderate

G4,5.0"	N0.48,5.0"
2540	3080
Moderate	Moderate

Glasscrete is still more resistant to ion penetration at same w/cm

Prepared by: JR Wright — Slide: 25/25

Glasscrete has a reduced water sorptivity

	N5,5.0"	G5,5.0"	N4,5.0"	G4,5.0"	N0.48,5.0"
w/cm	0.46	0.42	0.57	0.48	0.48
Paste Content	0.34	0.35	0.31	0.32	0.32
Initial Sorptivity (E-04)	13.3	6.74	37.4	10.0	15.8
Final Sorptivity (E-04)	11.7	5.46	26.8	6.41	13.8

Glasscrete absorbs less water

Prepared by: JR Wright — Slide: 26/25

Conclusions of glass sand's effect on concrete…

Property Comparison	@ Similar f'c	@ Same w/c
Plasticizer to reach similar slump	⇩⇩	⇩⇩
Abrasion resistance	⇧⇧	⇩⇩
Ion penetrability	⇩⇩	⇩⇩
Drying Shrinkage	⇩⇩	⇩⇩
Elastic Modulus	⇧⇧	⇧⇧
Water Sorptivity	⇩⇩	⇩⇩

THANK YOU

U.S. Department of Transportation
Federal Highway Administration

Prepared by: JR Wright — Slide: 27/25