






Outline

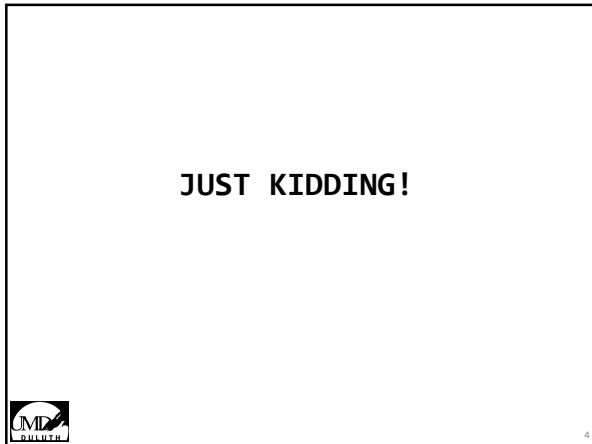
- Why alternative cements?
- Geopolymer cement
 - Geopolymerization
 - Materials
- My research
 - Waste glass
 - Glass-based geopolymers
- Geopolymer Research at UMD
- The future

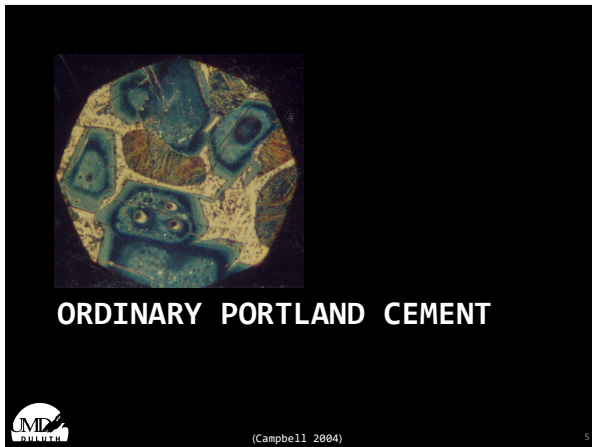


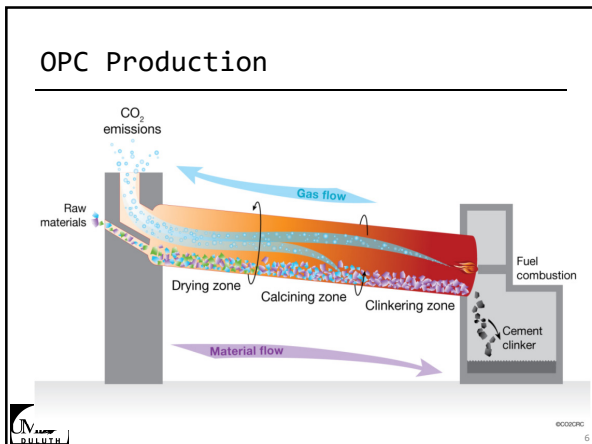
HOW DO I KNOW IF IT'S FRESH... AND NOT BEEN SITTING AROUND IN YOUR TRUCK...?

WHAT IS CONCRETE?

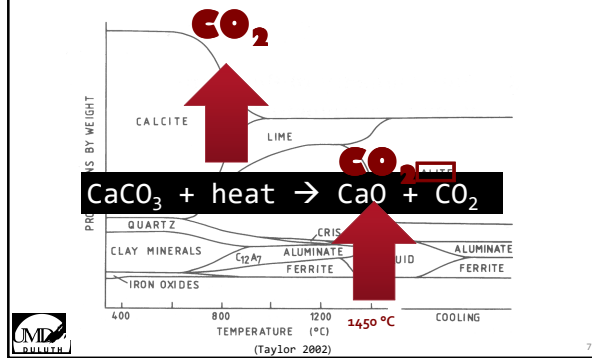








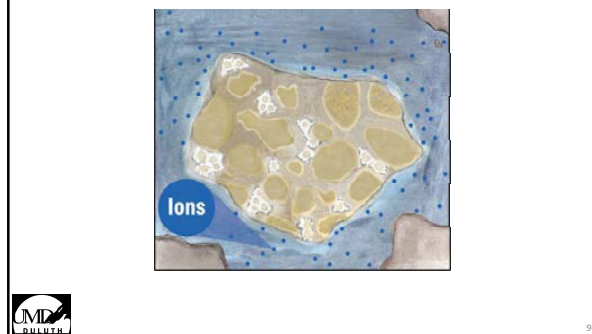
In the Kiln



OPC Hydration



OPC Hydration

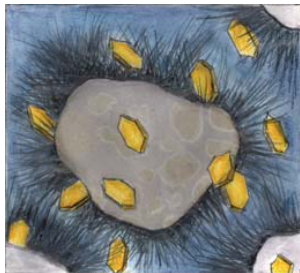


OPC Hydration



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OPC Hydration



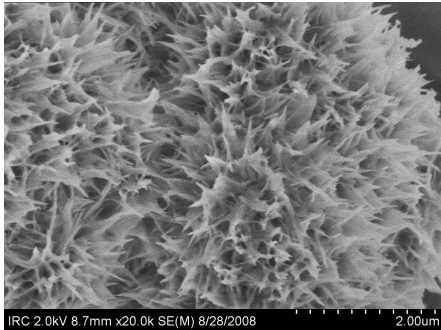
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OPC Hydration



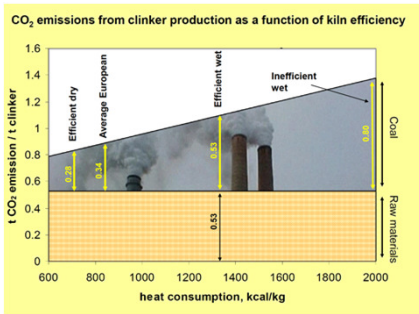
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OPC Hydration



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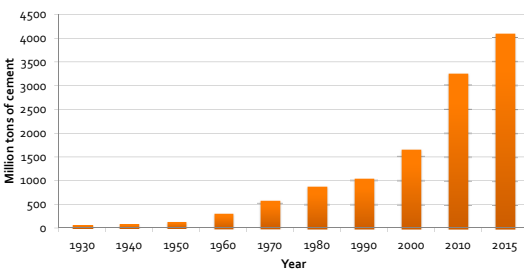
Emissions



(Herfort 2012)

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Cement Production Historically



(USGS 2016)

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Portland cement production is said to be responsible for 5-8% of global anthropogenic CO₂




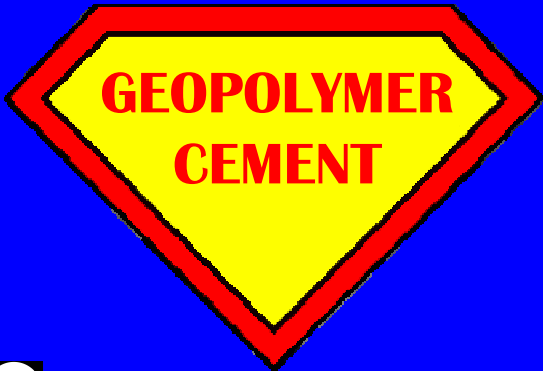
(Scrivener 2008) 16

Attempts to Improve Sustainability

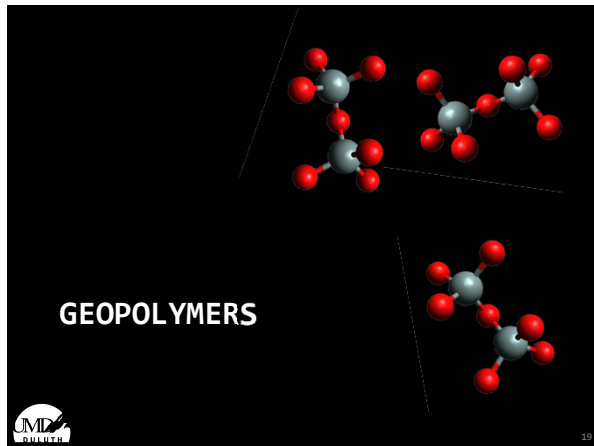
- Improved cement plant efficiency
 - 33% since 1970
- Supplementary cementitious materials (SCMs)
 - Fly ash (FA)
 - Ground granulated blast furnace slag (GGBFS)
 - Silica fume (SF)
- Alternative cements
 - Calcium aluminate cements
 - Magnesium-based cements



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What is a geopolymer?

A **binder** ...

- that results from the **alkali activation** of an **aluminosilicate source**,
- can have a significantly **smaller carbon footprint** than OPC,
- and has demonstrated similar or **increased performance** in terms of mechanical and durability properties as compared to OPC.

(Davidovits 2008)

Great Pyramid of Giza

Some believe blocks in the Great Pyramid of Giza were cast from an ancient geopolymer formula

(Davidovits 2008)

Geopolymer Cement Development

1930s - 60s




- Alkali activation of high-Ca slags
- Glukhovskiy's soil cements


1970s - 80s

- Alkali activation of kaolinite clay
- Davidovits' "geopolymers"

1990s to present

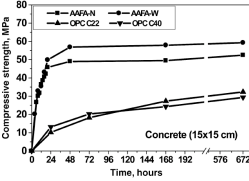
- Alkali activation of fly ash and metakaolin
- Increased research due to "sustainability" push
- Available commercially - Zeobond, Ceratech, Wagners, etc.



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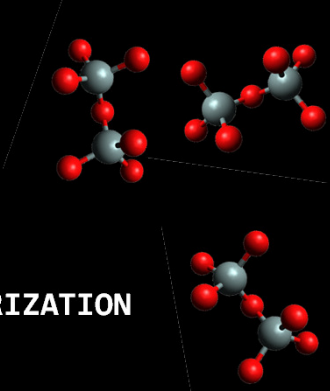
Benefits of GPC

- Lower carbon footprint than OPC
 - Does not require the calcination of limestone
 - Reduced or zero fuel combustion necessary
 - High volume usage of industrial byproducts
- Mechanical properties
 - High-early strength
 - High-ultimate strength
 - Stronger interfacial transition zone (ITZ)




Concrete (15x15 cm)


(Fernandez-Jimenez, Palomo et al. 2006)
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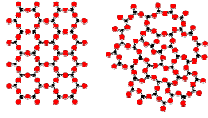


GEPOLYMERIZATION

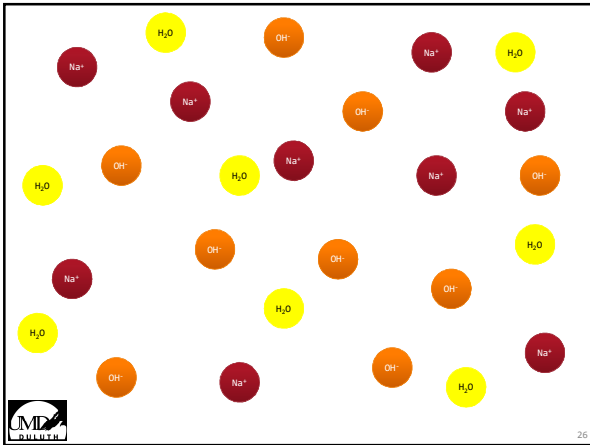

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Materials

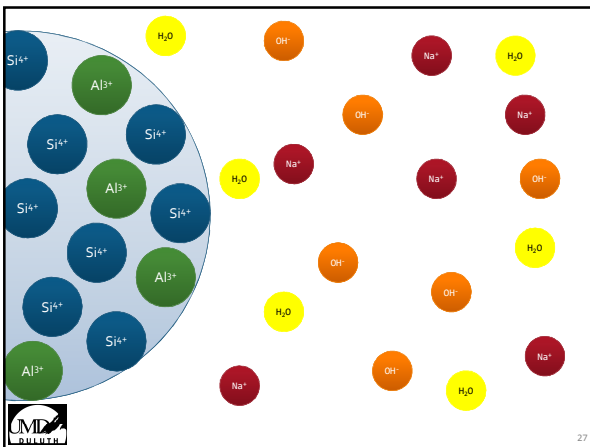
- Aluminosilicate source
 - Reactive Si and Al
 - Amorphous structure
 - Physically and compositionally homogeneous
 - Hard
- Alkali activating solution
 - Alkali hydroxide (NaOH, KOH, etc.)
 - Alkali silicate (sodium silicate, etc.)



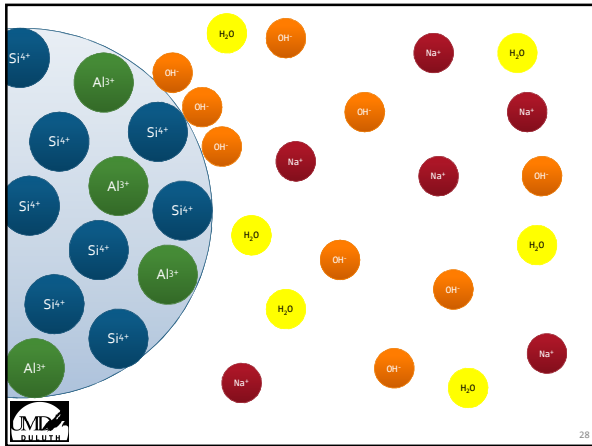
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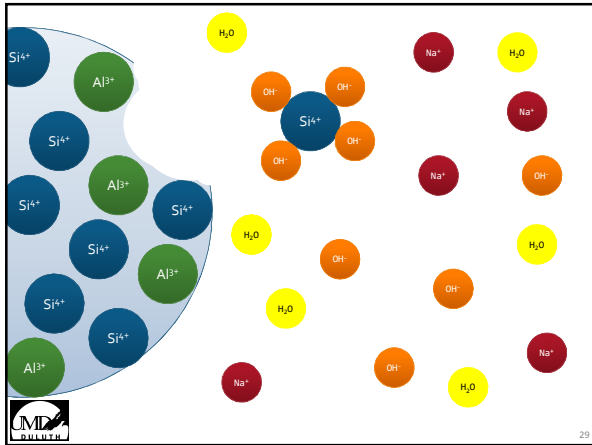


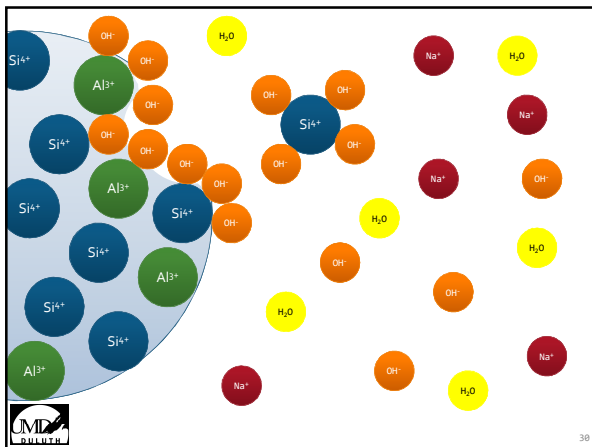
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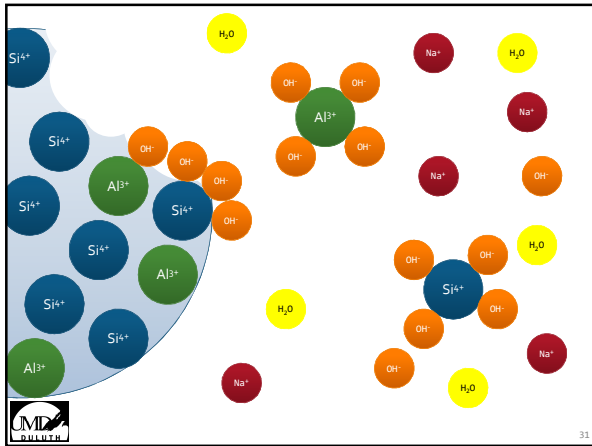


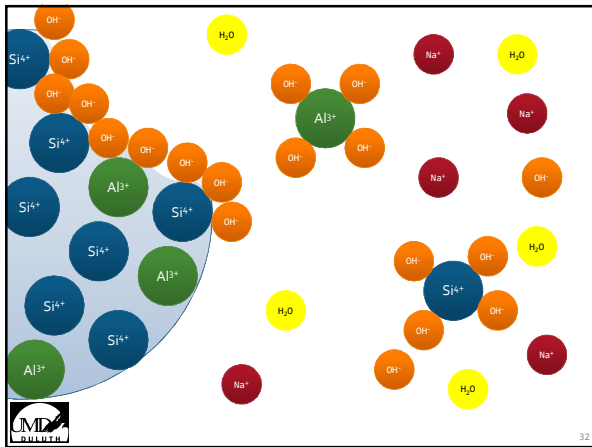
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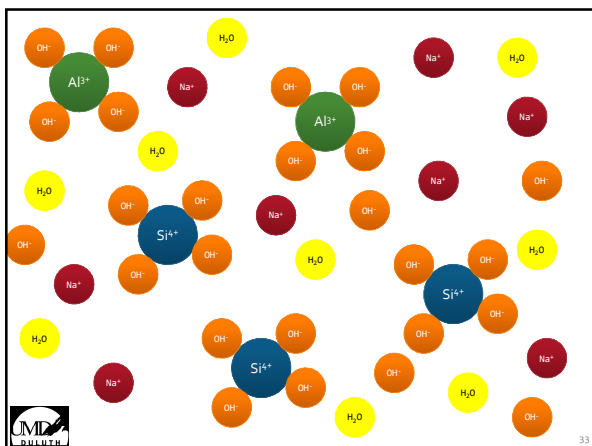


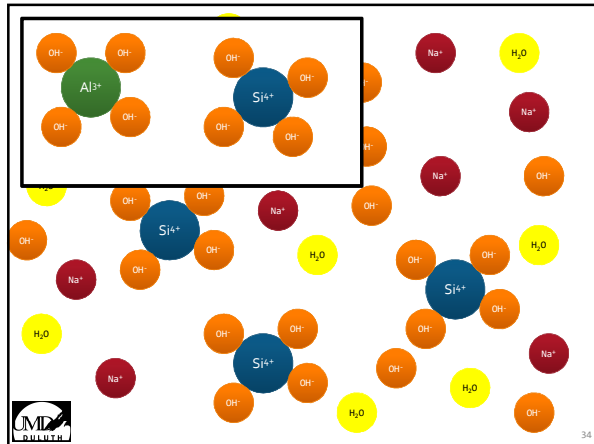


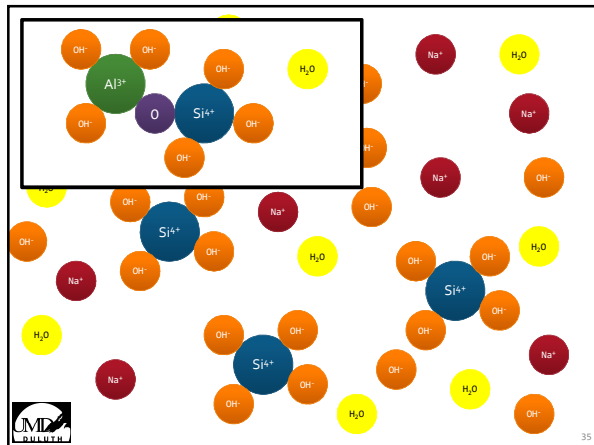


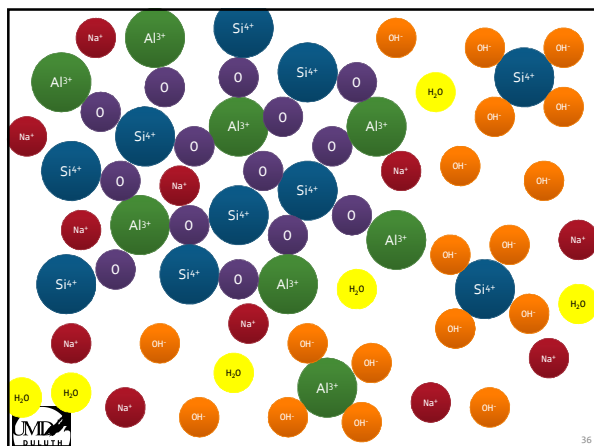




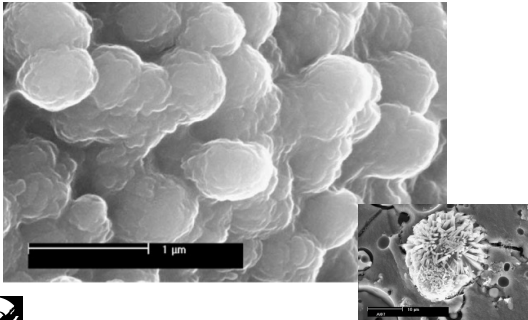








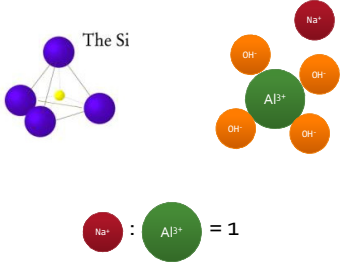
Basic GPC Microstructure



(Stevenson and Sagoe-Crentsil 2005)

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What about the Na⁺?



The Si

Na⁺ : Al³⁺ = 1

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OPC vs GPC

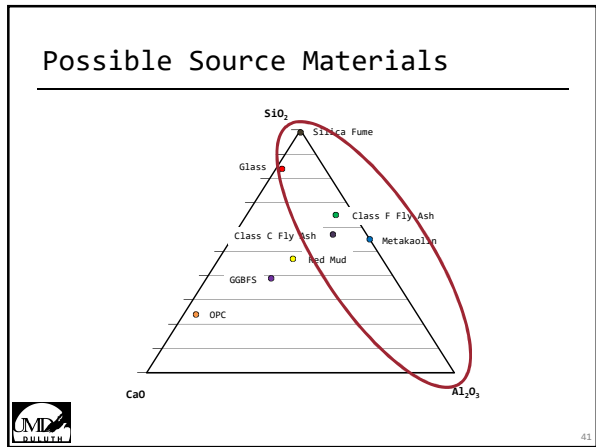
	Portland Cement Concrete	Geopolymer Concrete
Raw Materials	limestone, clay, gypsum	fly ash, glass, metakaolin
Calcination?	yes	no
Primary Elements	Ca, Si	Si, Al, Na
Activator	water	alkali solution
Desired Phase	C-S-H	N-A-S-H
Curing	moist ambient cure	moist heat cure

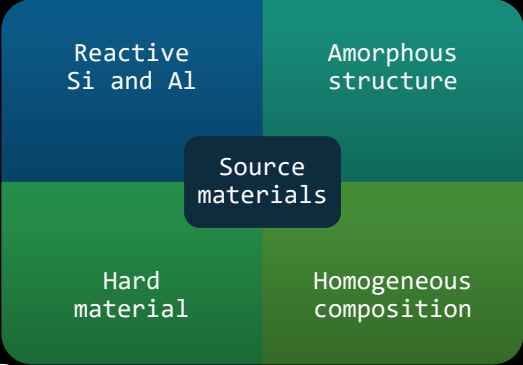
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SOURCE MATERIALS



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Reactive Si and Al

Amorphous structure

Source materials

Hard material

Homogeneous composition



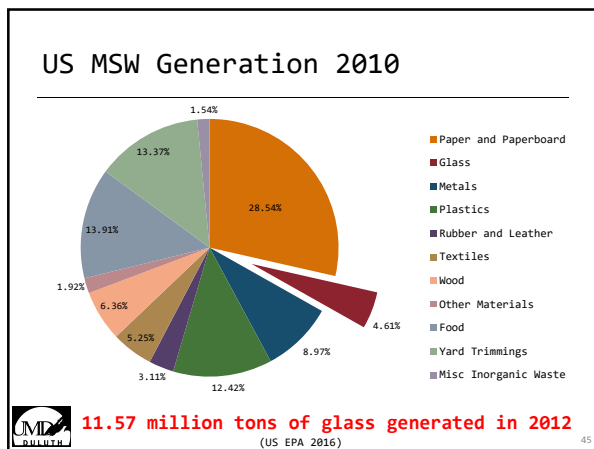
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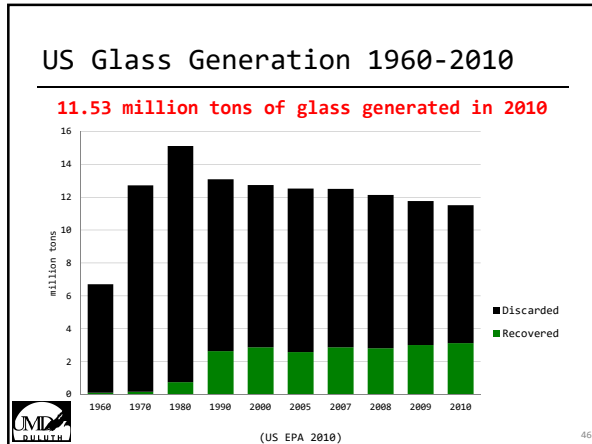


Packaging Glass

Oxide	Weight %
SiO ₂	72
Na ₂ O	13
CaO	12
Al ₂ O ₃	2
Minors	1

(Glass Packaging Institute 2012)





“Glass is 100% recyclable and can be recycled endlessly with no loss in quality or purity.”

(Glass Packaging Institute 2012)

Glass Recycling Hurdles

- Materials processing costs
 - Color Separation
 - Flint (clear)
 - Emerald (green)
 - Amber (brown)
 - Contaminants
 - Ceramics, pottery, clay pots
 - Mirrors, windshields, windows
 - Pyrex, dishes, glasses
 - Light bulbs
 - Stones and dirt
 - Metal or plastic caps
- Transportation costs

(Glass Packaging Institute 2012)





Waste Management - Houghton, MI





GLASS-BASED GEOPOLYMER MORTARS

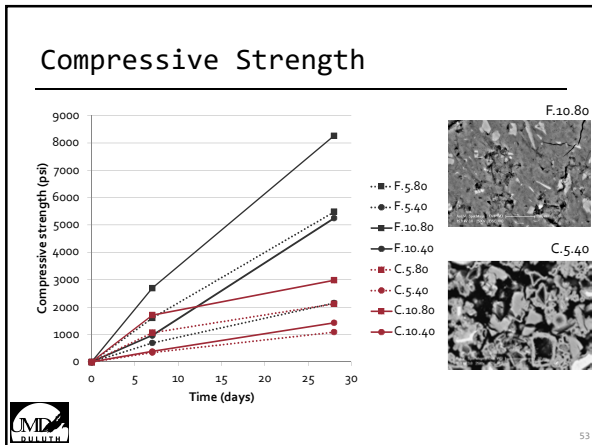


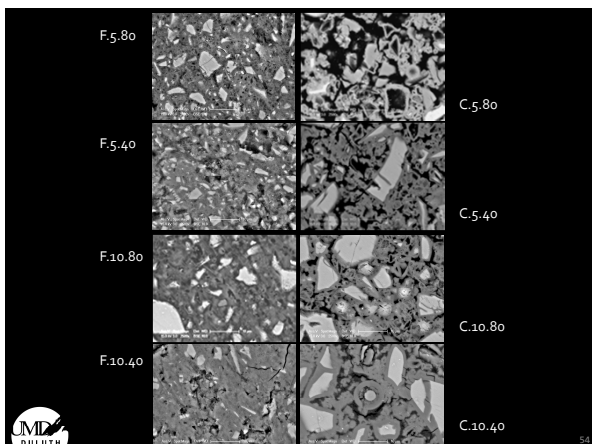
Preliminary Glass Mixtures

- Variables
 - Glass particle size
 - Fine
 - Coarse
 - NaOH concentration
 - 5M NaOH
 - 10M NaOH
 - Curing temperature
 - 40°C
 - 80°C

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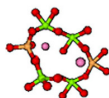




Typical Stoichiometry

	Fly Ash	Metakaolin	Soda-lime Glass
SiO ₂	39	53	72
Al ₂ O ₃	20	43	2
CaO	14	<1	12
Na ₂ O	6	0	13

- Fly ash or metakaolin geopolymer
 - Si/Al = 2-5
 - Na/Al = 1



- Soda-lime glass geopolymer
 - Si/Al = 50
 - Na/Al = 20



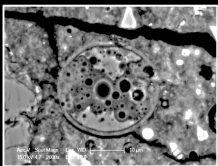
(Shi, Fernandez Jimenez, et al. 2011)

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C₅S₈ Na/Al = 7.8



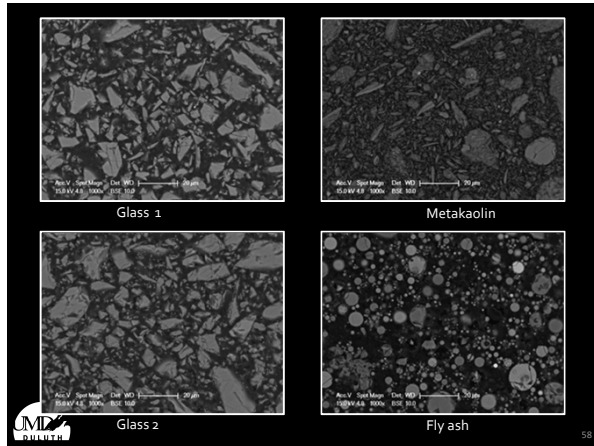
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STOICHIOMETRIC MIX DESIGN

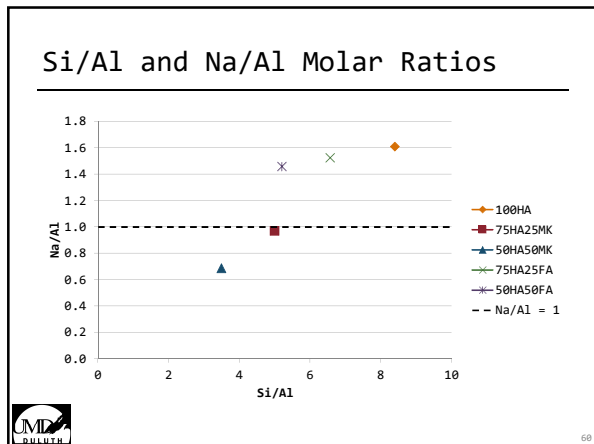


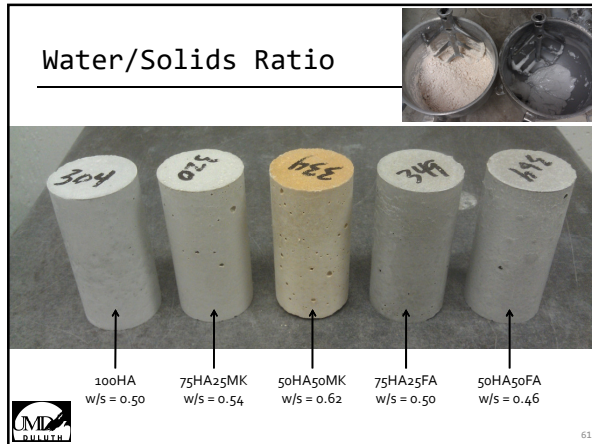
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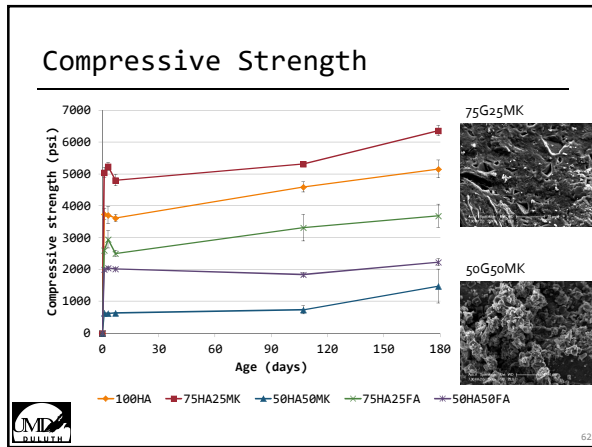


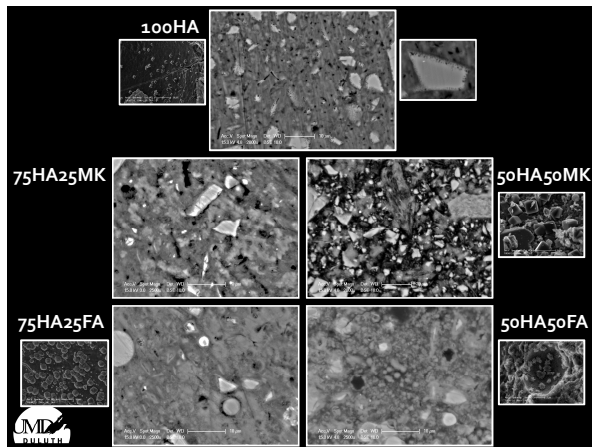
Experimental Testing

- Compressive strength
- Microstructure
 - Fracture surfaces (SE ESEM)
 - Polished sections (BSE ESEM)
- Composition
 - EDS
 - Compare actual to bulk
- Degree of reaction
- XRD
- Calorimetry

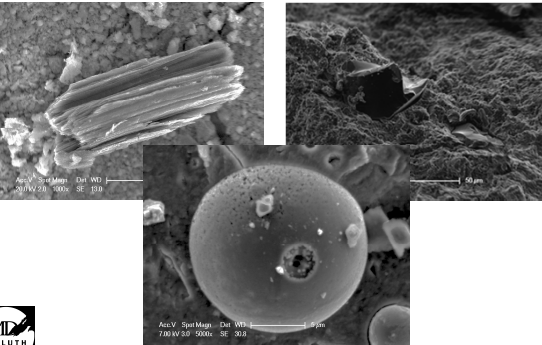








Unreacted Particles



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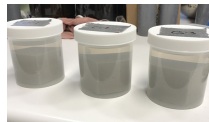
CURRENT RESEARCH



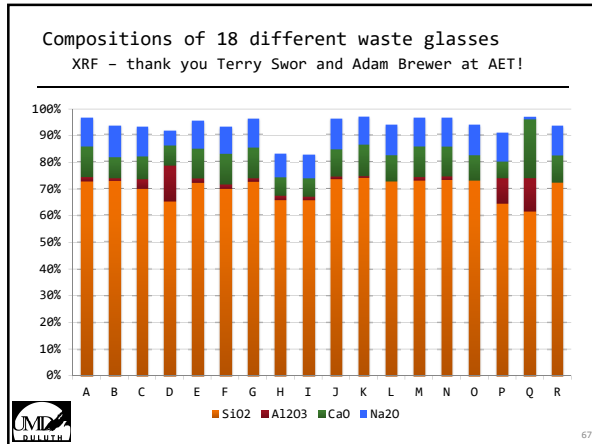
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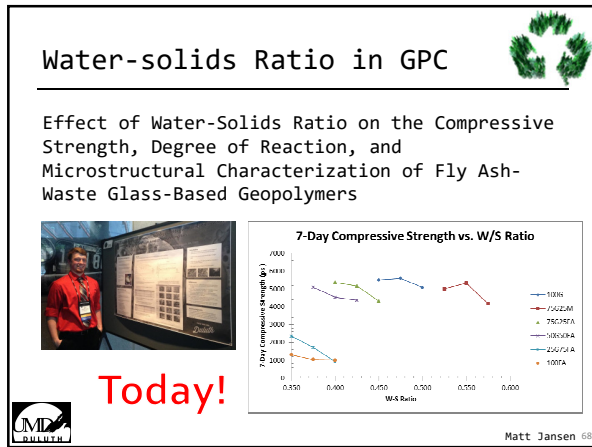
Variation in Glass Composition

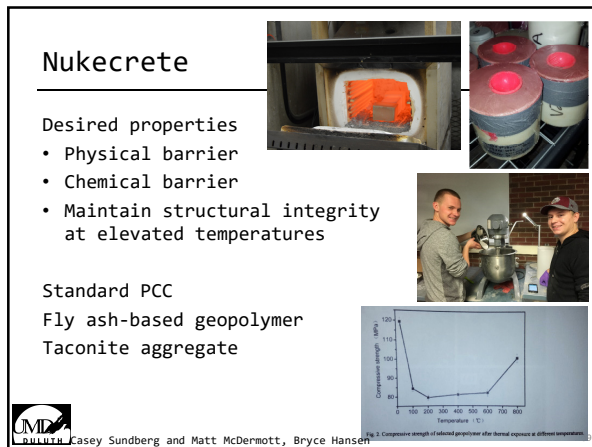
- Effect of the activator
- Compressive strength
- Water stability
- Leaching of alkalis
- Stoichiometric design
- Microstructural analysis



Scot Larson, Corey Schlosser







Sustainable Sidewalks

- UMD Campus
- 16 different mixtures
 - Varying amounts of fly ash and silica fume
- Geopolymers coming soon
- Thanks to Arrowhead Concrete



Rob Larson, Scot Larson, Corey Schlosser, Ryan Dagger

Alternative Cements at ACI

- Innovation Task Group (ITG-10) - Alternative Cements
 - Chair: Larry Sutter
 - Secretary: Mary Christiansen
- Submitted draft of Report on Alternative Cements to TAC in Fall 2016
- Likely to become a full committee



American Concrete Institute
Always advancing



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Hurdles

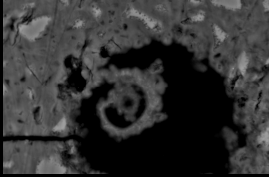
- Industry acceptance and education
- Codes and specifications are written primarily for portland cement concrete
- Testing procedures
- Long-term durability testing needed
- Heat cure
- Firmer understanding of geopolymerization



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THANK YOU.

Mary Christiansen
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