What is a GeoPolymer?

- Not a Plastic
  - Not HDPE/PVC/Epoxy

- Looks and feels like cement
  - Workability
  - Material Properties
  - Service Life

- Chemical structure like natural stone
  - Monolithic
  - Durable
  - Corrosion Resistant
Geopolymers or alkali cements consist predominantly alumino-silicates or polymer Si-O-Al bonds and are similar in chemical make-up to natural Zeolites. Traditional starting materials for geopolymers cements are fumed silica, fly ash & metal slag.

- Geopolymers can be produced from commercially available industrial waste streams, creating a highly environmentally friendly product.

- The chemical reactions of geopolymer create only a fraction of the CO$_2$ emissions of standard cementitious materials.

- Geopolymers have excellent chemical and thermal resistance and can essentially be considered engineered stone.

Source - J. Davidovits - Geopolymer Chemistry and Applications, 3rd ed.
Geopolymer material solutions offer significant chemical, physical, environmental, and economic advantages over traditional materials.

<table>
<thead>
<tr>
<th></th>
<th>Portland Cement</th>
<th>GeoSpray™</th>
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</thead>
<tbody>
<tr>
<td>Specific Strength</td>
<td>Variable</td>
<td>Excellent</td>
</tr>
<tr>
<td>Early Strength</td>
<td>Variable</td>
<td>Excellent</td>
</tr>
<tr>
<td>Acid Resistance</td>
<td>Poor</td>
<td>Very Good</td>
</tr>
<tr>
<td>Self-Adhesion</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>% Recycled Content</td>
<td>&lt;10%</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Single Pass Thickness</td>
<td>X</td>
<td>2X-3X</td>
</tr>
<tr>
<td>Total Installed Cost</td>
<td>$$</td>
<td>$</td>
</tr>
</tbody>
</table>
Geopolymer Liner
ODOT I-75

Project Details?
Queen’s University Testing
GeoSpray™ geopolymer liner applied to CMP

Testing Completed November, 2013
Assembled and instrumented culverts prior to burial and testing
Queens’ Testing
Buried and Tested

Time lapsed view of culvert burial to 1200 mm depth
50.8 mm (~2 inch) liner thickness (Actual 1.7 inch):

Initial signs of damage to the culvert under load were first observed at 650 kN (146,000 lbs-force) or 18% higher than the fully factored design load of 552 kN (~124,000 lbs-force).

76.2 mm (~3 inch) liner thickness (Actual 2.6 inch):

Initial signs of damage to the culvert under load were first observed at 800 kN (~180,000 lbs-force) or 45% higher than the fully factored design load of 552 kN (~124,000 lbs-force).

Engineering Models
19. Thin tube under uniform lateral external pressure (radius of tube = r)

\[ q' = 0.807 \frac{E t^2}{l^r} \sqrt{\left( \frac{1}{1 - v^2} \right)^3 \frac{t^2}{l^2}} \]

\( \frac{r}{l} > 10 \)

\[
t = 2.5 \sqrt{\left( \frac{q_t L r^{1.5} (1 - \mu^2)^{0.75} N}{0.807 E_L C} \right)}
\]

Where:
- \( t \) = thickness
- \( q_t \) = Design Load (Live and Dead Loads)
- \( L \) = Length held at constant radius (24 ft for standard road conditions)
- \( \mu \) = The Poisson ratio of GeoSpray
- \( E_L \) = Long term elastic modulus of GeoSpray
- \( N \) = Safety Factor
- \( C \) = Ovality Reduction Factor

Source: Roark’s Equations, Table 15.2 case 19b
Using the fact that $S_F = Mc/l$; where $l = t^3/12$ and $c = t/2$

$$t = \sqrt{\left(\frac{0.0372Pr^2 N}{S_F} \right) \frac{1}{C}}$$

Engineering Models
Design Thickness - Crack Propagation

\[ w = c \left[ \frac{M}{IE} \right] \]

Where \( w \) - is crack width and \( c = t/2 \)

\[ \Pr^2 (2/3 + 3\pi/8)/\pi = 0.5872Pr^2 \]

\[ t = \sqrt{\frac{7.0464 \times P \times r^2}{wE} \frac{N}{C}} \]

Where \( w \) - is crack width and \( c = t/2 \)

\( w \) is typically set to 0.01. Some have suggested 0.0625 for storm pipes.

Where $B$ & $\lambda_0$ are regression constants and $d_a$ is the size of the largest aggregate.
La Tech University (TTC) Joint Testing
Geopolymer liners applied to RCP, CMP & Cardboard

Testing Completed November, 2014
La Tech Testing
June 5th 2014
Not too sure whose bright idea it was to let me use the 16” saw?
La Tech Testing
June 22, 2014
Designation: C497 – 13

Standard Test Methods for
Concrete Pipe, Manhole Sections, or Tile¹

This standard is issued under the fixed designation C497; 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.
La Tech Testing
June 15, 2014
La Tech Testing
48” ID RCP - 2.66” Geopolymer Liner
The Land of Destruction
The “first” crack

D-Load Testing of New 24” ID RCP Control Pipe

Load (lbs) vs. Extension (in)
What happens next.

D-Load Testing of New 24” ID RCP Control Pipe

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La Tech Testing
D-Loading of RCP Pipe

What that looks like.
La Tech Testing
New vs Rehabilitated Pipe

D-Load Testing of Rehabilitated 36" ID Pipes
2" GeoPolymer Liner Thickness

- Rehabilitated RCP
- New RCP

Shift in Deflection at D-Load
La Tech Testing
Comparing RCP, CMP & Cardboard

D-Load Testing of Rehabilitated 36” ID Pipes
2” GeoPolymer Liner Thickness

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Comparison of Model Thickness Predictions to Test Data for Rehabilitated 48" ID RCP Pipes - Using Safety Factor of 2.

- Test Data RCP
- Poly. (Roarks)
- Poly. (Crack 0.01)
- Poly. (Crack 0.0625)
- Poly. (Distributed Beam)
- Poly. (Bazant-Cao)
Comparison of Model Thickness Predictions to Test Data for Rehabilitated 36” ID RCP Pipes - Using Safety Factor of 2.

- Test Data RCP
- Poly. (Roark’s)
- Poly. (Crack 0.01)
- Poly. (Crack 0.0625)
- Poly. (Distributed Beam)
- Poly. (Bazant-Cao)
Comparison of Model Thickness Predictions to Test Data for Rehabilitated 24" ID RCP Pipes - Using Safety Factor of 2.
Design Thickness of Buried Pipes
Assumes ground water is at surface - LFRD Loadings - Distributed Load Arch Model

Design Thickness (in) vs Depth of Bury (ft)
The actual design load was 124,000 lbs. But the applied load in a 1.2 m (~48 inch) pipe with 1.2 m (~48 inch) of cover was 146,000 lbs.

That results in a design pressure of \( \sim 35.6 \) psi

The actual installed thickness was \( \sim 1.65'' \)

The distributed load arch model suggest \( \sim 1.38'' \)

The crack propagation model suggests \( \sim 1.20'' \)

The Bazant & Cao Model suggest \( \sim 1.35'' \)

All 3 of these models are within the likely experimental error of the actual measurements.
• Testing of Geopolymer liners in RCP, CMP and Cardboard have been conducted.

• The data for RCP pipes suggest that several models are relevant to the design of such pipe systems.

• Repaired Pipes have significantly more deflection prior to cracking making them more semi-rigid than rigid.

• The models correlate both with the data generated by Milliken & La Tech, but also with that of CMP work by Queens’.

Additional work on the analysis of the CMP data and the likely effects of soils and soil structures on the designs is continuing.
Questions