



# Fundamentals of Spray-Applied Geopolymer Linings



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In the **2017 Infrastructure Report Card**, the American Society of Civil Engineers (ASCE) issued a grade of **D+** for the condition of the country's wastewater systems. ASCE classifies wastewater to include sewage treatment plants, sanitary sewer pipelines and collection systems, stormwater management and combined sewer overflows (CSOs). The aged and decaying state of wastewater systems is not only unique to the United States but is also a global concern. While many local and federal agencies around the world have begun to develop asset management plans for their wastewater systems, and thousands of pipeline rehabilitations are conducted annually, one area of key concern is large-diameter wastewater pipelines. Typical dig-and-replace technologies are often not practical because, in most urban areas, these degrading pipes are located directly under critical infrastructure such as major roadways or other assets. As the diameter of these pipes becomes larger (more than 36 inches), the cost of many traditional trenchless technologies like cured-in-place pipe (CIPP) becomes exponentially more expensive and often requires significant excavation around access points that present additional issues related to community disturbance, traffic control, noise and general disruption. Other techniques like slip-lining would require an even greater excavation diameter for an access hole to install new liners. Additionally, other issues related to either the shape (round, arched, elliptical) or the layout (straight, curved, bends of various radii) can make these repair technologies impractical.

During the last decade, additional trenchless technologies have been developed to help fill the need for larger diameter pipe repairs at effective costs — all with little or no excavation requirements and minimal community disruptions. One such technological advance is the use of centrifugally cast geopolymer mortars to create a new pipe inside of the existing pipe. This technique allows for a cementitious pipe to be created within the existing structure, using the pipe as a form, and can be designed so that a new and fully structural pipe is created. The flexibility of the technique allows for pipes of all shapes and layouts to be repaired either using automated mechanical casting or manually controlled material placement. The necessary equipment can easily fit down standard manholes and all excavation can typically be avoided if there are access points located at least every 800 linear feet.



**2017**  
**INFRASTRUCTURE**  
**REPORT CARD**





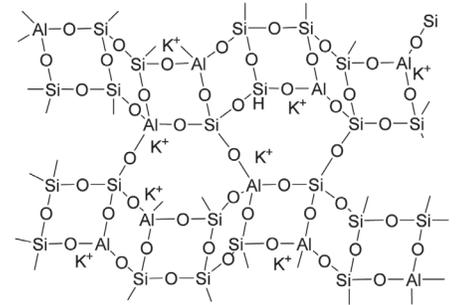
## History of Geopolymers

Geopolymer is a term originally coined by French researcher Joseph Davidovits to describe a class of “cement” formed from aluminosilicates. While ordinary portland cement (OPC) — the most common type of cement used in building and construction — relies on the absorption of water to create its strength, geopolymers cure by forming much stronger covalent bonds between the molecules in the presence of a basic or alkaline environment. Geopolymers are commonly referred to in the industry as “alkali-activated cement” or “inorganic polymer concrete.” Geopolymers provide comparable or better performance to OPC in terms of physical properties, such as compressive or tensile strengths, but with the added advantages of significantly reduced greenhouse emissions, increased fire and chemical resistance and reduced water utilization. The use of geopolymers in modern industrial applications has become increasingly popular based on their intrinsic environmental and performance benefits.

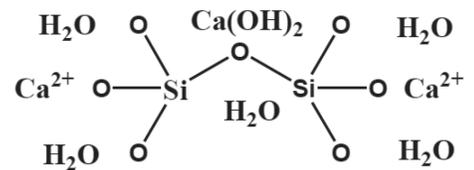
The structure of a geopolymer is a cross-linked inorganic polymer network consisting of covalent bonds between aluminum, silicon and oxygen molecules that form an aluminosilicate backbone with associated metal ions. The materials that react to form the geopolymer are also commonly referred to as pozzolanic materials. In contrast, OPC is a hydrated complex of small molecules that are not covalently bonded but associated and held by the hydrogen bonding power of the water molecule. This is done with no long chain covalently bonded backbone or network structure.

While there is no perfect test for determining that a geopolymer structure has formed, there is a simple rule of thumb that will ensure the material is not just a standard OPC. The complete mixture should contain at least 70 percent pozzolanic material. At this level of pozzolanic content, a standard OPC material would not adequately build strength. Typical pozzolanic molecules present are metal oxides such as  $Al_2O_3$ ,  $SiO_2$ ,  $MgO$  and  $Fe_2O_3$ , among others.

*In 2011, Milliken Infrastructure Solutions, LLC (MIS) developed and introduced the first geopolymer mortar material specifically designed for trenchless wastewater rehabilitation: **GeoSpray**<sup>®</sup> geopolymer mortar. The development of geopolymers for large-scale industry-applicable systems required the creation of a “just add water” mixture that avoided the necessity of alkaline solutions used to create the proper reaction conditions. To date, more than 40 million pounds of **GeoSpray** mortar have been applied successfully around the world on more than 200 unique projects — totaling well over 100,000 linear feet of large-diameter pipelines.*



*Geopolymer structure of bonded network*



*Ordinary portland cement (OPC) chemistry with associated water molecules*



*GeoSpray geopolymer mortar was the first geopolymer mortar material designed for trenchless wastewater rehabilitation.*



## Benefits of Geopolymers

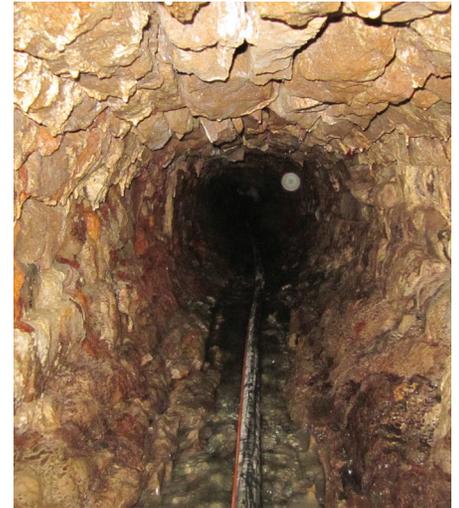
Geopolymer mortars provide some unique advantages when compared to OPC mortars or other trenchless technologies such as CIPP or slip-lining.

### Flexural Strength

Geopolymers and other cementitious materials, such as OPC, are typically considered rigid liners when compared to CIPP or slip-lining, which are classified as flexible liners. These liners will be designed differently based on their failure modes. The failure mode of flexible liners is often buckling, while rigid liners like reinforced concrete pipes (RCPs) would fail by longitudinal cracking. The key design parameter of a rigid geopolymer lining would be flexural strength.

The covalently bonded network of a geopolymer helps the materials develop higher flexural strength values as compared to OPC materials. In addition, inorganic fibers can often be incorporated in the geopolymer formulation. These fibers react into the system and become part of the polymer backbone, providing further benefit to an enhanced flexural strength. A properly formulated and cured geopolymer material can have between 25-50 percent higher flexural strength compared to standard OPC formulations.

For cementitious materials, there are several standard test methods for flexural strength, so it is important that design engineers use the most conservative methods when providing design values. Methods that apply third-point loading, such as ASTM C-78, give more conservative values and should be preferred as compared to center point loading methods, such as ASTM C-293 or ASTM C-348.



*Brick sewer before geopolymer mortar application.*



*Rehabilitated sewer using GeoSpray mortar.*



## Self-Bonding & Cold Joints

One of the major drawbacks of standard OPC materials is the common formation of cold joints. Cold joints are undesired discontinuities between two layers of concrete that typically occur due to the inability of a freshly poured layer of wet cement to intermingle and bind with an already hardened layer. Geopolymer chemistry helps avoid this issue. The condensation reaction that forms the geopolymer backbone is really a living chemistry, and new layers of material will directly react with the existing pour materials no matter the amount of time between applications. Due to practical job site constraints, most geopolymer and OPC pipe linings are placed in multiple lifts. However, the unique chemical nature of GeoSpray geopolymer mortar helps ensure that those layers are intimately and chemically bonded, so they do not become the weak point of the structure as they do with OPC.

## Chemical Resistance

In sanitary sewage environments, cementitious materials are susceptible to a degradation process known as microbial-induced corrosion (MIC), which might be referred to as  $H_2S$  corrosion. This is the typical cause for long-term failure of most existing large-diameter concrete sewer pipes. The  $H_2S$  gas emitted from the sewer effluent is digested by microbes to create sulfuric acid, which attacks unreacted calcium hydroxide in the cementitious material. OPC grouts contain between 2-5 percent of free calcium hydroxide, a byproduct of the manufacturing process, which remains unreacted after the concrete is cured. Geopolymers typically contain significantly less than 1 percent of the free calcium hydroxide, which makes them more chemically resistant to the corrosion process than OPC materials.



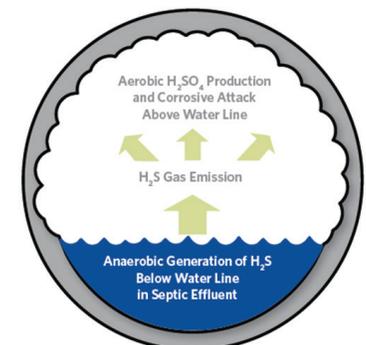
*GeoSpray geopolymer slant shear cylinders tested in compression don't have cold joints.*



*Cylinders of common pipe rehab OPC product shear on the cold joint in all cases tested.*



*OPC loses 50% of its mass when exposed to 7% sulfuric acid; geopolymer mortar is an order of magnitude better in performance.*



*Mechanism of microbial-induced corrosion (MIC).*



## Environmentally Friendly

Geopolymers have a variety of environmental advantages compared to a wide range of pipe rehabilitation technologies.

### Geopolymer advantages include:

- Styrene-free
- Greater than 75 percent reduction in greenhouse gas emissions from raw material production
- A significant percentage of post-industrial waste streams

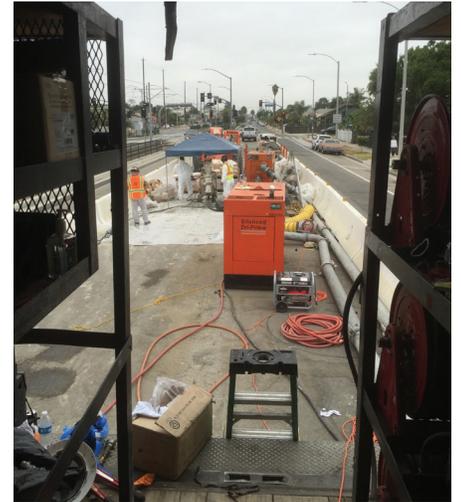
### Additional trenchless advantages include:

- Minimal community disruption
- Little to no site excavation
- Greater than 50 percent reduction of greenhouse gas emissions from the installation process

## Reliable

MIS's **GeoSpray** geopolymer mortar has been tested, investigated or certified by a variety of independent consultants and governing bodies including:

- US Environmental Protection Agency (US EPA)
- Water Research Center (WRc) – WRc Approval
- Water Regulations Advisory Scheme (WRAS) – WRAS Approved
- Australian Water Quality Centre – AS/NXS 4020: 2005 Drinking Water Contact
- Certified NSF/ANSI 61 Section 5 & NSF/ANSI 372 Drinking Water Certifications for pipes greater than 6" diameter or tanks greater than 300 gallons
- More than 20 explicitly approved product listings (APL) for Departments of Transportation (DOTs) and local municipalities



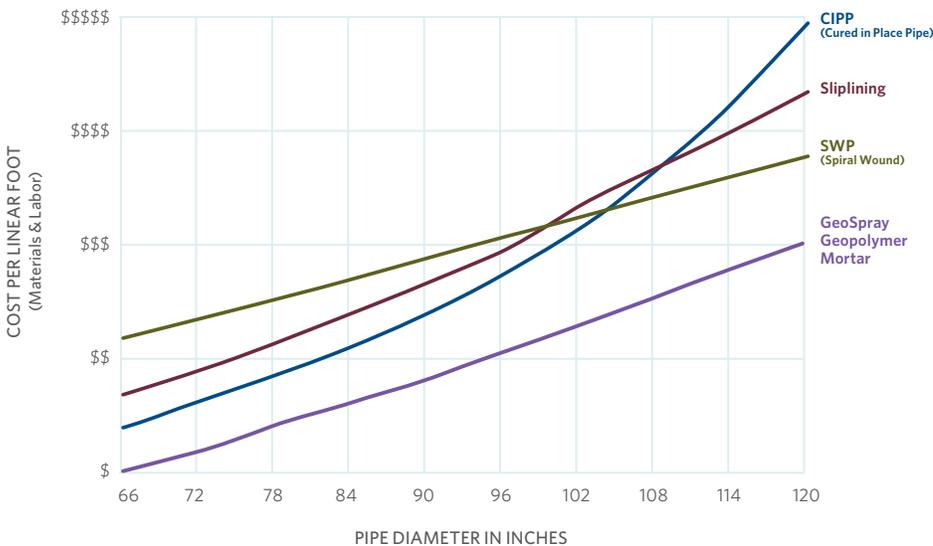
Example geopolymer installation project site.  
View from truck.





## Cost

It has been well-established that the cost of trenchless technologies (where a pipe can be repaired instead of replaced) is significantly lower than dig and replace options in most urban environments. Estimates suggest that trenchless technologies of any kind have between a 50-70 percent advantage over the cost of open-trench solutions. Among trenchless technologies, spray-applied geopolymer linings are often the most cost-effective method for wastewater pipes with greater than a 48" diameter. Geopolymers may also offer an advantage in smaller diameters based on specific site details. As the pipe diameter increases, the cost of repairs dramatically increases due to the cost of materials and labor required to clean, prepare and repair the pipe. Spray-applied geopolymer linings can often be between 20-50 percent less expensive in comparison to CIPP, the market's leading solution for pipes larger than 60".





## Geopolymer Lining Applications

To date, spray-applied geopolymer linings have been used in a myriad of applications, including:

- **Host Pipe Sizes:** 24" diameter to greater than 18' diameter
- **Host Pipe Materials:** Brick, Stacked Stone, Reinforced Concrete (RCP), Unreinforced Concrete, Corrugated Metal (CMP), HDPE, Steel, and Aluminum Plate
- **Host Pipe Shape:** Boxes, Arches, Egg-Shaped, Elliptical, Round
- **Host Pipe Applications:** Sanitary, Storm, Culverts, Manholes, Drinking Water, Industrial, Gravity, Force Main
- **Host Pipe Features:** Size changes, non-round, bends or curves any angle, missing inverts, less than 10 percent deflected

### Geopolymer Application Process:

Prior to the spray application of a geopolymer lining, the host pipe is cleaned in place, typically with high-pressure water-blasting of 3,500 psi or more. To ensure adhesion of the geopolymer to the damaged substrate, it is sometimes necessary to perform an additional cleaning with an environmentally friendly detergent to remove excess oil and grease from the existing pipe walls. If there are large leaking holes, the pipe can be plugged with a thin application of a plugging compound, hydraulic cement or chemical grout. Active water flow should be stopped.

The geopolymer mortar is usually centrifugally cast from atop a sled, which is slowly removed from the pipe to provide a uniform application. Typical application thicknesses range between 1-3" (25-75 mm), depending on the type of pipe, local soil and water conditions, current condition of the existing pipe and the design life requirements of the pipe in question. Hand-spray application for difficult-to-reach areas, host pipes greater than 10' in diameter and non-round shapes are common circumstances as well.

### Quality Control:

Geopolymer mortar applications typically have three levels of quality control:

- Internal manufacturing test of raw material quality and final physical property testing
- Field verification of compressive strength by certified third-party independent test labs
- Installer lead verification of application thickness



*CMP culvert*



*Brick culvert*



*Concrete culvert*



*Manhole*



## Engineering Methodology

Multiple third-party external firms, universities and research centers have tested and evaluated field-applied geopolymer liners. More than 60 lined pipe samples have been tested to failure to determine an appropriate engineering design methodology for the proper structural thickness and design life. These studies have been through a rigorous peer-reviewed process. All standalone structure applications using **GeoSpray** geopolymer mortars are designed using this conservative approach.

## Conclusion

Spray-applied geopolymer mortar linings are quickly becoming the preferred structural rehabilitation technology for large-diameter pipeline repairs. With a significant advantage over traditional OPC materials and other trenchless methods, geopolymer repairs might just be the ideal solution for your wastewater rehabilitation needs.

If you are not sure or need more information to determine if spray-applied geopolymer mortar linings are the right choice for your project, Milliken Infrastructure Solutions engineers are available to answer any questions and concerns. Contact us via our website, [infrastructure.milliken.com](http://infrastructure.milliken.com), or by calling 855-655-6750.

**North American Society for Trenchless Technology (NASTT)**  
NASTT's 2017 No-Dig Show  
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**TMD-73-04**  
**Laboratory Testing and Analysis of Geopolymer Pipe-Lining Technology for Rehabilitation of Sewer & Storm Water Conduits, Part I - GMP Culvert Analysis**

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Tashaisha, PhD, P.E., Trenchless Technology Center, Louisiana Tech University, Ruston, LA

**1. ABSTRACT**  
According to ASCE, capital investment needs for the nation's wastewater and storm water systems are estimated to reach \$200 billion over the next twenty years. Specifically, there is growing recognition that many of the hundreds of thousands of corrugated metal culverts that the country owns have serious rehabilitation and safety issues that are approaching the end of their useful service life over the 20-year design service life of the culverts. The need to address this problem is a top priority for many states and local governments. This paper reviews a geopolymer mortar system that has been used in the U.S. since 2011 for the successful rehabilitation of thousands of deteriorated and structurally deficient culverts that suffer from deterioration. The paper reviews a geopolymer mortar system that has been used in the U.S. since 2011 for the successful rehabilitation of thousands of deteriorated and structurally deficient culverts that suffer from deterioration. The paper reviews a geopolymer mortar system that has been used in the U.S. since 2011 for the successful rehabilitation of thousands of deteriorated and structurally deficient culverts that suffer from deterioration.

**2. INTRODUCTION**  
As the need for investment in the repair and rehabilitation of sewer and storm water systems continues to increase around the world, engineers and asset owners are searching for cost-effective technologies for structural rehabilitation. This is particularly true in the case of large diameter pipe systems, as the selection of rehabilitation methods for these structures is limited and the cost per linear foot tends to be substantial. One such technology that offers promise is the use of concrete-based design methodology. This also includes the use of geopolymer mortar systems. The paper reviews a geopolymer mortar system that has been used in the U.S. since 2011 for the successful rehabilitation of thousands of deteriorated and structurally deficient culverts that suffer from deterioration. The paper reviews a geopolymer mortar system that has been used in the U.S. since 2011 for the successful rehabilitation of thousands of deteriorated and structurally deficient culverts that suffer from deterioration.

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Milliken Infrastructure Solutions, LLC has developed a geopolymer mortar mortar - called GeoSpray - as a trenchless technology equipped with Post-tensioned steel reinforcement meshing. (a) enhanced chemical resistance, (b) enhanced

**Performance of deteriorated corrugated steel culverts rehabilitated with sprayed-on geopolymer mortar linings subjected to surface loads**

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