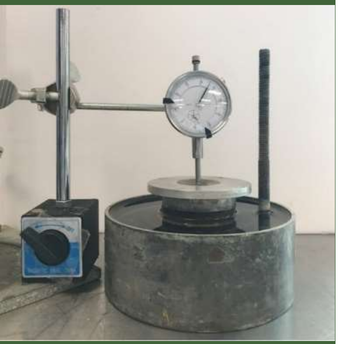
Eco-friendly Stabilization of Sulfate-rich Expansive Soils Using Geopolymers for Transportation Infrastructure

Assessing the viability of utilizing metakaolin-based geopolymer for stabizling sulfate-rich expansive soils



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Traditional calcium-based stabilizers are ineffective for stabilizing sulfate-rich soils due to the formation of expansive minerals like ettringite and thaumasite. This study's primary objective is to evaluate the feasibility of utilizing geopolymers for stabilizing sulfate-rich expansive soils. Expansive soils with low, moderate, and high-sulfate levels were treated with lime and metakaolin-based geopolymer. The effect of geopolymer dosage and curing period was studied using an array of engineering tests, including free swell strain, linear shrinkage strain, and unconfined compressive strength. Mineralogical and microstructural analyses were performed to corroborate the observed engineering properties. The test results indicate that geopolymer treatment can mitigate ettringite-induced heaving and be used as a sustainable sulfate-rich expansive soil stabilizer.

Background

Stabilization of problematic soils with traditional calcium-based stabilizers generally results in enhanced mechanical properties due to the formation of pozzolanic compounds. When sulfate-rich native soils are encountered, traditional calcium-based stabilizers often become counter-productive due to the formation of highly expansive minerals like ettringite and thaumasite. Geopolymers have received much attention for its eco-friendly and sustainable nature and its cementitious properties. Although several research studies have been performed to understand the effect of geopolymer treatment on different soil types, the majority of the studies did not focus on sulfate-rich soils. Geopolymers' eco-friendly and sustainable nature over conventional chemical stabilizers and issues regarding sulfate-induced heave necessitated the investigation on the feasibility of stabilizing sulfate-rich subgrade soils using geopolymers.

Project Summary

The overall objective of the project is to synthesize an innovative, sustainable, and eco-friendly geopolymer suitable for stabilizing sulfate-rich expansive soils for subgrade of transportation infrastructure in Region 6, using natural and waste materials that are abounded in the region. This research will bring major benefits in the design of distress-free pavement infrastructure in severe problematic subgrade conditions that prevail in Region 6.

An expansive natural soil was collected from a road construction site in north Texas, and the sulfate level was modified using gypsum to represent low-sulfate (LS) (<3000 ppm), moderate-sulfate (MS) (3000-8000 ppm), and high-sulfate (HS) (>8000 ppm) levels. These soils were treated with 6% lime, and 8% and 30% metakaolin-based geopolymer. The swell-shrink potential and strength properties of the treated soils were studied after different curing periods (6 hours, 3 days, and 14 days). The test results affirm that unlike calcium-based stabilizers, geopolymers are effective in stabilizing expansive soils with low to high sulfate contents. The beneficial effect of geopolymer treatment increased with dosage and curing period. Tests results affirm that geopolymers have a strong potential for utilization as a sustainable soil stabilizer.

Status Update

Metakaolin-based geopolymers of different compositions were synthesized in the laboratory with potassium hydroxide as the alkali activator (Figure 1). Geopolymer (GP) with SiO_2/Al_2O_3 = 3, water/solids =3 and K/Al =1 was selected as the most effective soil stabilizer based on the workability and improvement in engineering properties. Expansive soils with low, moderate, and high sulfate levels were treated with lime and geopolymer, and the improvements in engineering properties were compared (Figure 1).

Figure 1. Synthesis of geopolymer and its utilization for soil treatment

One-dimensional (1D) free swell tests, linear shrinkage bar tests, and unconfined compressive strength tests were performed on the cured treated specimens as per the respective ASTM or TxDOT standards. The 1-D free swell test results of the untreated and 3-day cured chemically treated soil specimens are presented in Figure 2. The untreated soil experienced a free swell strain of 12.2% due to clay mineral swelling, and a major part of the swell strain was accumulated within one day of moisture exposure. Lime treatment of the LS, MS, and HS soil groups resulted in an immediate reduction in the clay mineral-induced swelling due to modification of the soil by cation exchange, flocculation-agglomeration, and reduction in the thickness of the double diffuse layer around the clay minerals. However, beyond one day of submergence in water, the lime-treated high-sulfate (L-HS) specimens started swelling due to ettringite formation, crystal growth, and hydration. The ettringite-induced heaving was not prominent in the lime-treated moderate-sulfate (L-MS) and lime-treated low-sulfate (L-LS) specimens due to the lower concentration of soluble sulfates as compared to the L-HS specimens. Overall, the swell test results of the lime-treated specimens indicate that lime stabilization was ineffective in stabilizing sulfate soils.

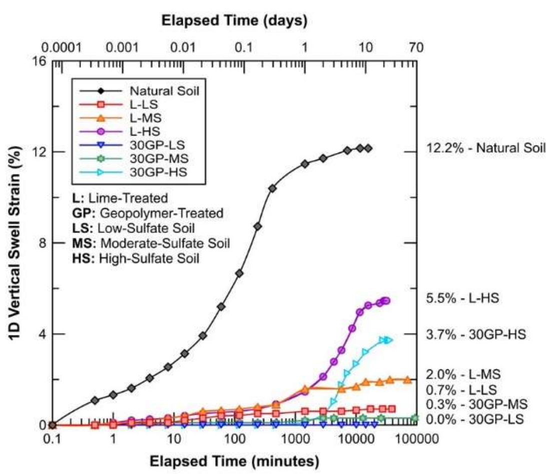

Figure 2. 1D free swell strain test results

The swell strains accumulated in 30GP-HS specimens were much less than the lime-treated specimens, and this indicates that geopolymer is effective in treating sulfate-rich expansive soils. The 30GP-MS and 30GP-LS specimens exhibited negligible swell strains as compared to the other specimen groups.

Results of linear shrinkage strain tests and unconfined compressive strength tests also indicated that geopolymer is effective in reducing the shrinkage potential and enhancing the shear strength properties of the soil. The shrinkage strains and strength properties of the 6% lime treated- and 8% geopolymer treated-soils were comparable. Whereas, 30% geopolymer treatment reduced the shrinkage strains by approximately 50% and increased the strength properties by almost 100%, compared to 6% lime or 8% geopolymer treatment. Overall, the engineering test results affirm that metakaolin-based geopolymer has a strong potential for utilization as a sustainable soil stabilizer.

Impacts

The findings of this research should provide major benefits in the design of resilient and eco-friendly transportation infrastructure in Texas and other regional states in Region 6, where soil conditions, such as high-sulfate content, often induce additional stress to transportation infrastructure. Soil stabilization with geopolymers will provide a sustainable, greener alternative for transportation infrastructure that will be durable with low distress problems. Therefore, this study focuses on developing alternative soil stabilizers to improve the mechanical properties and durability of treated geomaterials, extend the infrastructure's life, and preserve the environment. The outcome of this study is expected to be important to the transportation and geotechnical engineering community.

Tran-SET

Tran-SET is Region 6’s University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 “to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes”.

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