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Sustainable Reuse of Construction and Demolition Waste for Geopolymer-Based Soil Stabilization

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Abstract
Low bearing capacity, high compressibility, and excessive settlement or instability in civil engineering structures can occur with soft clay soils. Cement and lime usually stabilise these types of soil, but their manufacturing processes produce significant amounts of greenhouse gases and environmentally harmful chemicals. In addition to these traditional methods, a new sustainable method to improve soil properties through polymer technology has become popular. Due to the lower carbon footprint associated with polymer products compared to cement-based products, geopolymer technology has received increasing use to enhance soil properties by providing excellent binding properties. Construction and demolition waste (CDW) contain a lot of silica and alumina and, therefore, can be used as a precursor or starting point in producing geopolymeric binders that will help stabilise soft clay soils. This research project evaluated the effectiveness of using CDW-derived geopolymeric binders for stabilising soft clay soils. Of the various variables evaluated during study, results demonstrated that NaOH molarity has a major impact on the development of strength in CDW-derived geopolymeric binders and the subsequent improvement in geotechnical properties of the solidified soil. The improvement of geotechnical (engineering) properties is exemplified through the increased strength and reduced compressibility of the solidified soil when using a geopolymeric binder derived from CDW. Further, as CDW can be reused, this approach supports green waste management and efficient use of resources. Ultimately, the use of CDW-derived geopolymers provides an environmentally friendly and financially viable solution to stabilising soft clay soils.
Keywords: Construction and Demolition Waste, Geopolymer, Soil Stabilization

1.Introduction
There has been an increase in urbanisation and associated infrastructure development over the last several decades and as a result, more construction is occurring on weak and problematic soils. Also, soft clay soils are common and can be defined by their very low shear strength, large compressibility, and low load-bearing capacity. Because of this, excessive settlement and long-term instability of buildings and structures built on these soils are often evident. Consequently, decades of research and development in geotechnical engineering has resulted in the use of soil stabilization practices becoming an integral part of the industry with the intention of improving their strength, stiffness and durability. Traditionally, cement and lime have been the most common materials used in soil stabilization because of their effectiveness in improving the physical properties of soil. However, the manufacturing processes of these products are highly energy intensive and produce substantial amounts of carbon dioxide emissions contributing to environmental concerns. Therefore, the use of geopolymer technology, which involves generating strong binding gels from the combination of aluminosilicate materials and alkaline activators, offers many advantages over conventional stabilization methods as a sustainable alternative. In addition to soil stabilization, construction and demolition waste (CDW) is one of the largest streams of global solid waste and presents numerous

challenges in terms of disposal. However, due to their high silica and alumina content, CDW are suitable for use as a precursor material in the manufacture of geopolymers. Therefore, using CDW for geopolymer-based soil stabilization not only improves the engineering properties of the soil but simultaneously supports recycling and promotes sustainable development.

2.Literature Review

Geotechnical engineers have employed soil stabilization for decades to enhance the utility of weak soils for construction. Cement and lime have been widely used as traditional stabilizers to both strengthen soil and lower compressibility. However, cement and lime manufacturing processes consume large amounts of energy and release an enormous amount of CO_2, leading many researchers to be concerned about their environmental impact and seek alternative, more sustainable, and environmentally friendly solutions for enhancing soil properties.

Geopolymer technology has been identified within the last decade as a viable option for achieving these objectives. In the late 1970s, Joseph Davidovits demonstrated that it was possible to create high-performance binding agents with extended service lives by reacting aluminosilicates with alkaline solutions. The research conducted by Provis and Van Deventer provided engineers with new insights into the mechanisms of the reactions and examples of potential engineering projects that rely on the use of alkali-activated materials, making them a viable alternative to traditional cement-based materials. This research has motivated further exploration of geopolymeric materials for geotech-related projects.

Many researchers have conducted studies to assess the value of geopolymeric binders as stabilizers for soil. All the studies concluded that alkali-activated materials, particularly fly ash-based geopolymeric binders, significantly enhance the compressive strength and durability of soils. For example, multiple studies have demonstrated that clay soils treated with geopolymers exhibit significantly higher load resistance and greater stability compared to those treated with conventional methods. Researchers have also pointed out that numerous factors affect the efficacy of soils stabilized with geopolymers, including: concentration of alkali activator; curing conditions; and amount of moisture.

3.Objectives of the Study

The purpose of this research project is to evaluate the feasibility of using construction and demolition (C&D) materials as precursors for geopolymer-based soil stabilization. The specific objectives of this study are:

1. to evaluate the effect of NaOH molarity on the strength development of soil stabilized with geopolymer technology,
2. to assess the improvement in engineering properties of clay soils, including strength and compressibility, following stabilization with geopolymer,
3. to encourage the sustainable reuse of C&D waste materials in geotechnical engineering applications so as to advance environmentally-compatible construction practices.

4.Materials and Methodology

a. Collection of Soil Samples

Clay soil samples were obtained from the study area for laboratory analysis. The sampled soil was air dried to evaporate moisture, ground to break soil aggregates, and sieved to standardize the soil sample for testing.

b. Collection and Processing of CDW

CDW Collection and Processing Construction and Demolition Waste (CDW) was collected from surrounding construction sites. The CDW was cleaned and crushed into very fine powder for use in the production of geopolymers.

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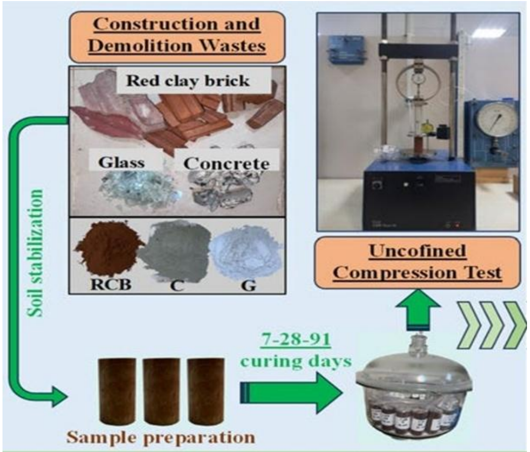

Figure 1: Collection and Processing of CDW

c. Preparation of Geopolymer Binder

The geopolymer binder was created by mixing the processed CDW powder with sodium hydroxide (NaOH) as an alkaline activator. Different molarity concentrations of alkaline activators were used to study the effect on the geopolymerization process and strength development.

d. Soil Stabilization

The mixture of soil and geopolymer binder was mixed thoroughly at various proportions and then compacted into standard molds and cured under specified conditions prior to laboratory testing for engineering properties.

e. Laboratory Tests

The following tests will be performed to evaluate the properties of the soil:

a. Atterberg Limits
b. Standard Proctor Compaction
c. Unconfined Compressive Strength

Figure 2: Desiccator

Figure 3: Unconfined Compressive Strength

5.Results and Discussion

This study examined the effect of Construction and Demolition Waste (CDW) on the physical and mechanical properties of stabilized clay soils through unconfined compressive strength (UCS) testing. The experimental results are summarized in Table 1.

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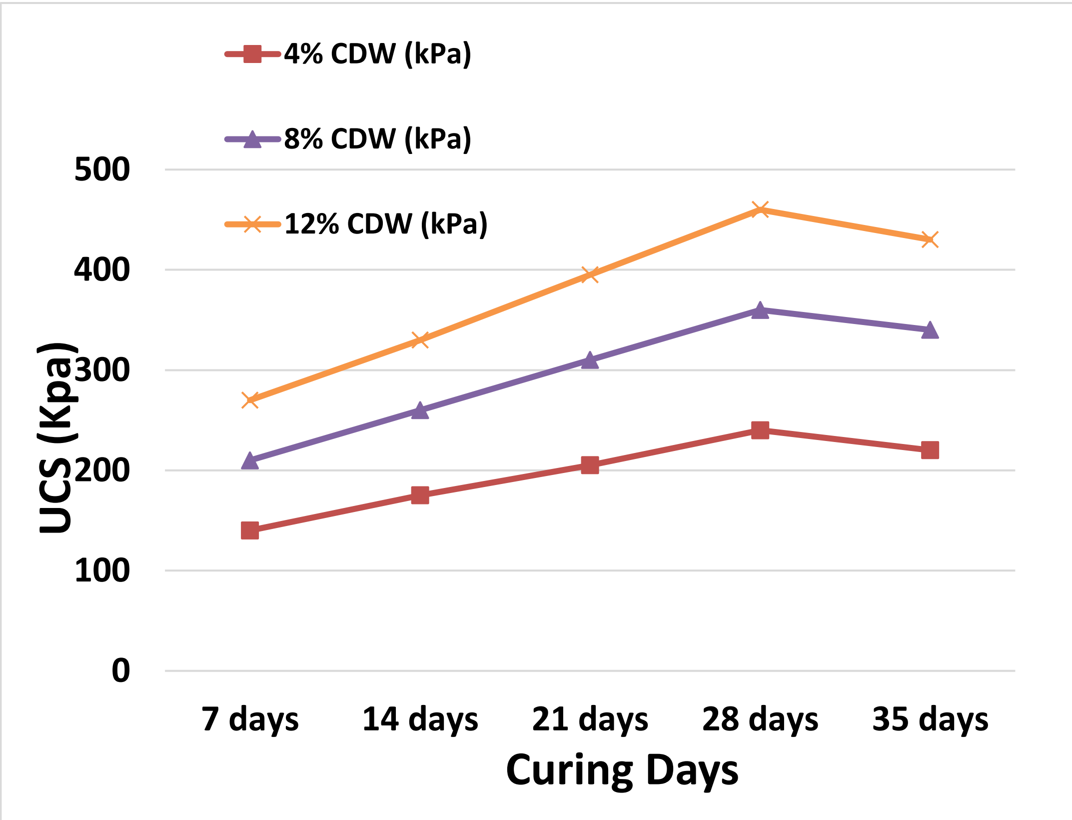
Table 1: Effect of CDW Content and Curing Period on UCS

Curing Days	4% CDW (KPa)	8% CDW (KPa)	12% CDW (KPa)
7 Days	140	210	270
14 Days	175	260	330
21 Days	205	310	395
28 Days	240	360	460
35 Days	220	340	430

Our results show an increase in UCS values with the addition of CDW as well as with an increase in the length of the curing period (up to 28 days). The 12% CDW-stabilized soil exhibited the highest UCS values over all three curing periods, with the highest value recorded at 460 kPa after a curing period of 28 days. The increases in strength due to the geopolymerization reaction that creates stronger binding gels in the soil matrix.

After the 35-day curing period, a slight drop in strength was experienced in the UCS values for all percentages of CDW. This decrease in strength may be linked to microstructural changes, moisture loss, and/or inadequate long-term bonding in the stabilized matrix. Overall, the results from this research study demonstrate that 28 days is the optimum duration for curing to allow for maximum strength gain of the treated soil; any curing beyond 28 days results in little to no further increase in strength. The above data is pictured in the next graph.

Figure 4: Effect of CDW Content and Curing Days on UCS



The UCST results, or Compression Tests, demonstrate a strong correlation of Curing Time vs. Gains in Strength on CDW – treated specimens for all percentages of CDW (4%, 8% and 12%) continue to increase their compressive strength with three weeks (21 days) of curing time due to the gradual development of Cementation and Binding compounds (or Cementation) occurring within the Soil Matrix. The enhanced bonding strength between the Soil Particles (resulting in

Reduced Void Space) is generated through the development of Geopolymerization Reactions during the prolonged curing period, which creates denser and more fluid-like structures in the soil, resulting in improved overall Structural Integrity, as well as increasing the Soil's Load-Bearing Capacity from extensive development of Bound Inter-Particle Bonding.
The majority of Beneficial Reactions—Primary Strength Gaining Reactions—have occurred at 28 days curing time, thus reaching the Maximum Strength for all CDW Percentages. After 35 days of curing time for all CDW Percentages, however, a small decline in UCST Results for all Mixes can be attributed to Micro-Cracks/Redistribution of Moisture within Treated Soils; Shrinking Existing-Stress along Treated Soils caused by Shrinking Stresses across the Bonded Soil Matrix caused by External-Forces; and Internal Stresses generated through the Curing Process of these treated soils; which each decrease the Bonding Strength producing Minimal Lost Strength over Time. Overall— Geopolymer Treated Soils will continue to demonstrate the Normal Rate of Development, as demonstrated by the Results of UCST A of Compressed Soil—will continue to gain Strength Due to Continuous Physicochemical Reactions—Will reach a Max. @ the Optimum Referring to an Engineering Perspective—Therefore, in Recap 28 Days.

7. Conclusion

The purpose of this investigation was to assess how well geopolymer binders created from construction and demolition waste (CDW) can help stabilize clay soils.

According to UCS testing results, soil strength was greatly increased when CDs were added to the soil. And as percentages of CDW increased, insulating properties improved as well. The most successful combination of soil and CDW occurred at 12 percent.

The length of time soils were cured resulted in a significant increase in strength over the applied period of 'cure' of the geopolymer. Geopolymerization would be responsible for this continued increase in strength, as would the development of a tightly packed soil structure. By 35 days, a slight decrease in strength occurred. The reasons for this loss of strength may include micro-structural changes (shrinkage) and the development of internal stresses.

From the results of this study, we can conclude that CDW is a viable, sustainable, alternative to conventional soil stabilization techniques in the production of geopolymer-based materials for use in stabilizing weak clay soils. Additionally, by using CDW, we will be reusing construction waste, therefore minimizing the negative environmental effects of disposing of CDW. Thus, using CDW in the stabilization of soil using geopolymer materials is an affordable, sustainable option compared to traditional stabilization techniques.

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