Feasibility of Using Building-Related Construction and Demolition Waste-Derived Geopolymer for Subgrade Soil Stabilization (Postprint)

Authors: Fan Gu, Jianwei Xie

Date: 2025-07-17T00:00:00+00:00

Abstract

In China, annual generation of building-related construction and demolition waste (brCDW) exceeds 2 billion tons, with a recycling rate of less than 40%, significantly lower than the European average. The majority of unrecycled brCDW is either landfilled or stockpiled in suburban areas, leading to severe environmental pollution and resource wastage. Therefore, developing high-value utilization strategies is crucial to improving the overall recycling rate of brCDW. To address the aforementioned issues, this study developed a novel approach by synthesizing a brCDW-derived geopolymer to stabilize high liquid limit subgrade soil. The unconfined compressive strength (UCS) test, shear strength test, resilient modulus test, and permanent strain test were conducted to investigate the effects of brCDW-derived geopolymer dosage, curing time, stress state, and moisture condition on the engineering properties of geopolymer stabilized soil. Mechanistic-empirical models were employed to accurately estimate the stress-dependent resilient modulus and permanent strain of geopolymer stabilized soil at any given stress state. In addition, the Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) test were performed to investigate the strengthening mechanism of brCDW-derived geopolymer stabilization of subgrade soil. Finally, the sustainability of brCDW-derived geopolymer stabilization approach was assessed in terms of material production cost, carbon dioxide emission, and energy consumption. These test results demonstrated that increasing the geopolymer dosage effectively improved the UCS, shear strength and resilient modulus of stabilized soil and reduced the permanent strain of stabilized soil. The addition of 8% and 12% geopolymer showed significant improvement on the soil strength, while 4% geopolymer had negligible impact on the soil strength. The UCS test results indicated that 8% geopolymer provided the most economical improvement on the stabilized soil. Increasing the brCDW-derived geopolymer dosage effectively improved the resilient modulus of stabilized soil, but did not affect the stress-dependent behavior of stabilized soil. Increasing confining pressure or decreasing deviatoric shear stress still resulted in a higher resilient modulus for geopolymer stabilized soil. The resilient modulus of the geopolymer stabilized soil was sensitive to moisture condition. When the moisture content increased from optimum moisture content (OMC) to 1.15 OMC, the resilient moduli of geopolymer stabilized soil reduced approximately by 20%. Increasing the brCDW-derived geopolymer dosage reduced the accumulated permanent strain of stabilized soil. A mechanistic-empirical rutting model was used to predict the permanent strain of geopolymer stabilized soil at any given stress state. The high liquid limit soil stabilized by 8% geopolymer had sufficient resistance to permanent deformation. But when the moisture condition reached 1.15 OMC, the 8% geopolymer might not provide the stabilized soil an adequate resistance to permanent deformation. The SEM test results indicated that the porosity of stabilized soil was significantly decreased when the geopolymer dosage increased to 8%. The EDS test results demonstrated that the predominant gel types generated from the geopolymer stabilization might be Calcium-Aluminum-Silicate-Hydrate (C-A-S-H), Calcium-Silicate-Hydrate (C-S-H), and Calcium-Aluminate-Hydrate (C-A-H) gels. There was also a small amount of Sodium-Alumino-Silicate-Hydrate (N-A-S-H) gel detected in the geopolymer stabilized soil. Compared to the traditional soil stabilizers (e.g., conventional Portland cement and quick lime), the production of brCDW-derived geopolymer saved material cost by 31-36%, carbon dioxide emission by 44-55%, and energy consumption by 48-49%. In general, the utilization of brCDW-derived geopolymer was a sustainable approach for soil stabilization.

Full Text

Preamble

Feasibility of Using Building-Related Construction and Demolition Waste-Derived Geopolymer for Subgrade Soil Stabilization

Fan Gu1, *Jianwei Xie1*
1National Engineering Research Center of Highway Maintenance Technology, Changsha University of Science & Technology, Changsha, 410114
Corresponding author: fan.gu@csust.edu.cn*

Abstract: In China, annual generation of building-related construction and demolition waste (brCDW) exceeds 2 billion tons, with a recycling rate of less than 40%—significantly lower than the European average. The majority of unrecycled brCDW is either landfilled or stockpiled in suburban areas, leading to severe environmental pollution and resource wastage. Therefore, developing high-value utilization strategies is crucial to improving the overall recycling rate of brCDW.

To address these issues, this study developed a novel approach by synthesizing a brCDW-derived geopolymer to stabilize high liquid limit subgrade soil. A series of mechanical tests were conducted to investigate the effects of brCDW-derived geopolymer dosage, curing time, stress state, and moisture condition on the engineering properties of stabilized soil, including unconfined compressive strength (UCS), shear strength, resilient modulus, and permanent strain. Mechanistic-empirical models were employed to accurately estimate the stress-dependent resilient modulus and permanent strain at any given stress state. In addition, scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) were performed to investigate the strengthening mechanism. Finally, the sustainability of this stabilization approach was assessed in terms of material production cost, carbon dioxide emissions, and energy consumption.

The test results demonstrated that increasing geopolymer dosage effectively improved the UCS, shear strength, and resilient modulus of stabilized soil while reducing its permanent strain. The addition of 8% and 12% geopolymer showed significant improvement in soil strength, whereas 4% geopolymer had negligible impact. UCS test results indicated that 8% geopolymer provided the most economical improvement. While increasing brCDW-derived geopolymer dosage improved the resilient modulus, it did not affect the stress-dependent behavior of stabilized soil; increasing confining pressure or decreasing deviatoric shear stress still resulted in higher resilient modulus. However, the resilient modulus was sensitive to moisture conditions—when moisture content increased from optimum moisture content (OMC) to 1.15 OMC, resilient moduli reduced by approximately 20%.

Increasing brCDW-derived geopolymer dosage also reduced accumulated permanent strain. A mechanistic-empirical rutting model successfully predicted permanent strain at any given stress state. High liquid limit soil stabilized by 8% geopolymer exhibited sufficient resistance to permanent deformation, though this resistance became inadequate when moisture conditions reached 1.15 OMC.

SEM analysis revealed that porosity of stabilized soil decreased significantly when geopolymer dosage increased to 8%. EDS results demonstrated that the predominant gel types generated were Calcium-Aluminum-Silicate-Hydrate (C-A-S-H), Calcium-Silicate-Hydrate (C-S-H), and Calcium-Aluminate-Hydrate (C-A-H) gels, with a small amount of Sodium-Alumino-Silicate-Hydrate (N-A-S-H) gel also detected.

Compared to traditional soil stabilizers (e.g., conventional Portland cement and quick lime), production of brCDW-derived geopolymer saved material costs by 31–36%, reduced carbon dioxide emissions by 44–55%, and decreased energy consumption by 48–49%. In general, utilization of brCDW-derived geopolymer represents a sustainable approach for soil stabilization.

Keywords: Geopolymer, Construction and demolition waste, Soil stabilization, Resilient modulus, Permanent strain

Note: Figure translations are in progress. See original paper for figures.