Mechanical evaluation of CFBFA-GGBS geopolymer grouting material for subgrade remediation: Compatibility, interfacial bonding, and performance optimization Postprint

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Abstract

Road trenchless grouting is widely used for subgrade remediation due to its convenient application, low-carbon, and low-disturbance features. This study focuses on the circulating fluidized bed fly ash (CFBFA) - ground granulated blast furnace slag (GGBS) grouting material, researching its preparation and remediation effect of subgrade distress via laboratory tests. Results show that as CFBFA content rises, the grouting material's fluidity increases, bleeding rate decreases, setting time prolongs, and compressive and flexural strengths decrease. Through a self-designed test, the subgrade soil type, distress type, grouting pressure, and material compatibility are explored. The grouting material significantly affects the remediation of subgrade voids and slurry-soil interfaces. For example, at a 10 mm loose thickness and 1.5 MPa grouting pressure, the optimal remediation effect can reach 2.66 times of the strength of 96% compacted sandy clay of low liquid limit (CLS) subgrade soil, with a 59.10% increase in shear strength. Clayey sand (SC) has better loose remediation and interface shear strength than CLS subgrade soil. Based on data analysis, suitable grouting materials and pressures are recommended for different soil and distress types. Further X-ray diffraction (XRD), scanning electron microscope (SEM), and energy dispersive spectroscopy (EDS) tests are conducted. XRD pattern shows a weak geopolymerization reaction between grouting material and subgrade soil, with SC having stronger reactivity. SEM and EDS results demonstrate that the grouting material effectively binds subgrade soil particles and fills voids, with the combined effect of soil particle participation in the reaction and cementation significantly enhancing the bonding efficiency. This study classifies the grouting remediation effect into filling, slurry-soil reaction, cation exchange, and bonding effect, systematically explores the compatibility of subgrade factors with grouting materials and pressures, and provides new methods and ideas for improving

the remediation effect.

Full Text

Preamble

Mechanical evaluation of CFBFA-GGBS geopolymer grouting material for subgrade remediation: Compatibility, interfacial bonding, and performance optimization

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Abstract

Road trenchless grouting is widely employed for subgrade remediation due to its convenient application, low-carbon footprint, and minimal disturbance characteristics. This study investigates a geopolymer grouting material composed of circulating fluidized bed fly ash (CFBFA) and ground granulated blast furnace slag (GGBS), examining its preparation and effectiveness in remediating subgrade distress through comprehensive laboratory testing. The results demonstrate that as the CFBFA content increases, the grouting material exhibits enhanced fluidity, reduced bleeding rate, prolonged setting time, and decreased compressive and flexural strengths. Through a specially designed experimental program, the study explores the influence of subgrade soil type, distress type, grouting pressure, and material compatibility on remediation performance.

The grouting material demonstrates significant effectiveness in remediating subgrade voids and enhancing slurry-soil interfacial bonding. For instance, at a loose layer thickness of 10 mm and a grouting pressure of 1.5 MPa, the optimal remediation effect achieves a strength 2.66 times that of 96% compacted low-liquid-limit sandy clay (CLS) subgrade soil, accompanied by a 59.10% increase in shear strength. Comparative analysis reveals that clayey sand (SC) exhibits superior loose layer remediation capability and interfacial shear strength compared to CLS subgrade soil.

Based on comprehensive data analysis, the study recommends appropriate grouting material formulations and pressure parameters tailored to different soil types and distress conditions. Advanced characterization through X-ray diffraction

(XRD), scanning electron microscopy (SEM), and energy dispersive spectroscopy (EDS) provides mechanistic insights. XRD patterns indicate a weak geopolymerization reaction between the grouting material and subgrade soil, with SC demonstrating stronger reactivity than CLS. SEM and EDS results confirm that the grouting material effectively binds subgrade soil particles and fills voids, with the synergistic effect of soil particle participation in the reaction and cementation significantly enhancing bonding efficiency.

This study systematically classifies the grouting remediation mechanisms into four categories: void filling, slurry-soil reaction, cation exchange, and bonding effects. By exploring the compatibility between subgrade conditions and grouting materials/pressures, the research provides novel methodologies and insights for optimizing remediation effectiveness.

Key words: Subgrade grouting, Geopolymer grouting material, Void repair, Loose repair, Repair mechanism

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