Effect of Granulated Blast Furnace Slag on the compressibility of highly compacted expansive soil

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Abstract: Expansive soils pose significant challenges in geotechnical engineering due to their tendency to swell and shrink with changes in moisture content, leading to detrimental effects on infrastructure stability. This study investigates the effect of incorporating Granulated Blast Furnace Slag (GBFS) on the compressibility behavior of expansive soils. A series of laboratory tests including compaction, swell, and consolidation tests were conducted on expansive soil samples mixed with varying percentages of GBFS. The results reveal that the addition of GBFS modifies the compressibility characteristics of expansive soil significantly. The optimum percentage of GBFS addition is identified based on the reduction in swell potential and compressibility parameters such as coefficient of compressibility and consolidation characteristics. The findings of this study provide valuable insights into utilizing GBFS as a sustainable and effective solution to mitigate the compressibility issues associated with expansive soils, thereby enhancing the performance and longevity of civil engineering structures built on such problematic soils. Further research could explore the long-term performance and environmental impacts of GBFS-treated expansive soils under various loading and environmental conditions.

Keywords: Expansive soil, Compressibility, GBFS, Clay minerals, Pozzolanic reaction

1. Introduction

Expansive soil poses significant problems for the structure constructed on it due to the presence of clayey minerals such as montmorillonite[1] This type of soil is characterized by its high ability to the compressibility especially during its shrinkage state and to minimize this phenomenon various techniques of stabilization were employed such as chemical stabilization. Expansive soils, characterized by their ability to undergo significant volumetric changes with variations in moisture content, pose substantial challenges to infrastructure development and stability in many regions worldwide[2,3]. The expansive nature of these soils often leads to severe distress in civil engineering structures such as buildings, roads, and pipelines, resulting in substantial economic losses and safety hazards[4,5]. Traditional methods for addressing the problems associated with expansive soils typically involve costly engineering solutions such as soil stabilization, moisture control, and structural modifications.

Granulated Blast Furnace Slag (GBFS), a byproduct of iron and steel manufacturing processes, has emerged as a promising alternative for enhancing the engineering properties of problematic soils. GBFS possesses pozzolanic and cementitious properties, making it suitable for soil stabilization applications. Previous studies have demonstrated the efficacy of GBFS in improving the mechanical, hydraulic, and durability characteristics of various soil types, including expansive soils.

The compressibility behavior of expansive soils plays an important role in determining their response to applied loads and environmental conditions. High compressibility of expansive soils results in excessive settlements, differential movements, and structural damage, posing significant challenges to infrastructure sustainability. Therefore, there is a growing interest in exploring sustainable and cost-effective approaches to mitigate the compressibility issues associated with expansive soils.

This study aims to investigate the effect of incorporating GBFS on the compressibility behavior of expansive soils. By systematically evaluating the influence of GBFS on key compressibility parameters such as swell index, coefficient of compressibility, and consolidation characteristics, this research seeks to provide insights into the feasibility and effectiveness of GBFS as a soil stabilization agent for mitigating the compressibility of expansive soils.

Understanding the mechanisms underlying the interaction between GBFS and expansive soils is essential for optimizing the design and implementation of GBFS-based soil stabilization techniques. By elucidating the effects of GBFS on the compressibility behavior of expansive soils, this study aims to contribute to the development of sustainable and environmentally friendly solutions for addressing the challenges associated with expansive soil management in civil engineering practice.

2. Material and method

In this study, different materials were used to conduct the research, including bentonite, silty sand (kaolin), granulated blast furnace slag (GBFS), and hydrated lime, which acted as an activator to enhance the pozzolanic reaction between clay minerals and the GBFS. The clayey soil used in this study consisted of 35% bentonite and 65% kaolin. Subsequently, varying percentages (0%, 5%, 10%, 15%, 20%, and 25%) of granulated blast furnace slag are added, always keeping the bentonite content at 35%. The kaolin content was gradually replaced by granulated blast furnace slag. The bentonite is sourced from Maghnia in western Algeria and is supplied by ENOF. Kaolin was sourced from Jijel in Algeria, supplied by SOALKA SPA, while granulated blast furnace slag was collected from El Hajar in Annaba, located in eastern Algeria. The bentonite percentage was always maintained at 35%, and the kaolin percentage was gradually replaced by granulated blast furnace slag. Odometer testing was performed according to American standard ASTM D4546[6]. The amount of material required for each test was calculated based on the maximum dry density (MDD) and optimum moisture content (OMC) from the compaction test. The dry mass of the sample was mixed well with a predetermined amount of water then satically compacted based on the compaction characteristics. A constant normal load was applied vertically to the sample inside the die (seating load) starting at 6.25 kPa and gradually increased to 3266 kPa, after which it started to decrease again to 6.25 kPa. **Figure 1** depicts the methodolgy adopted.

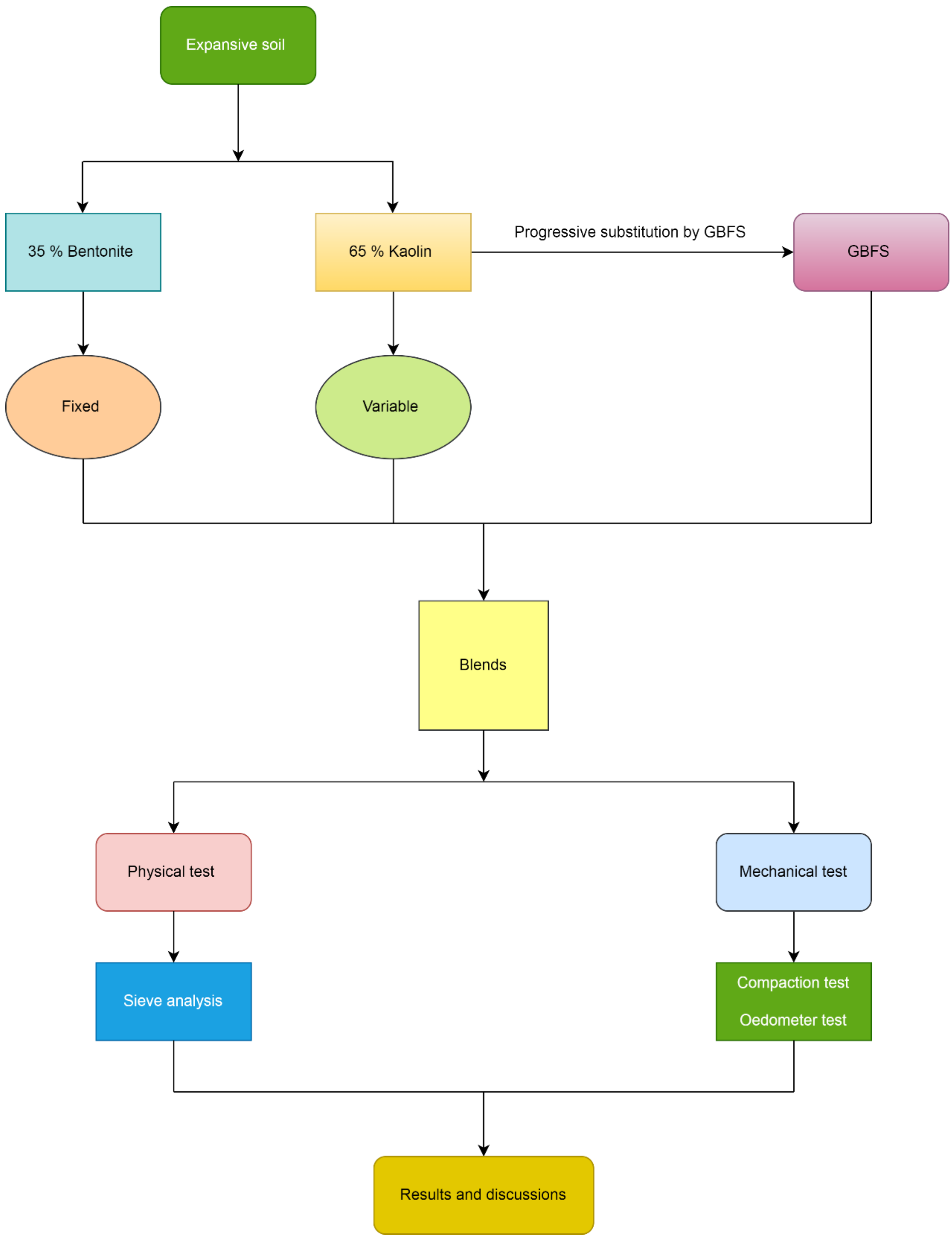
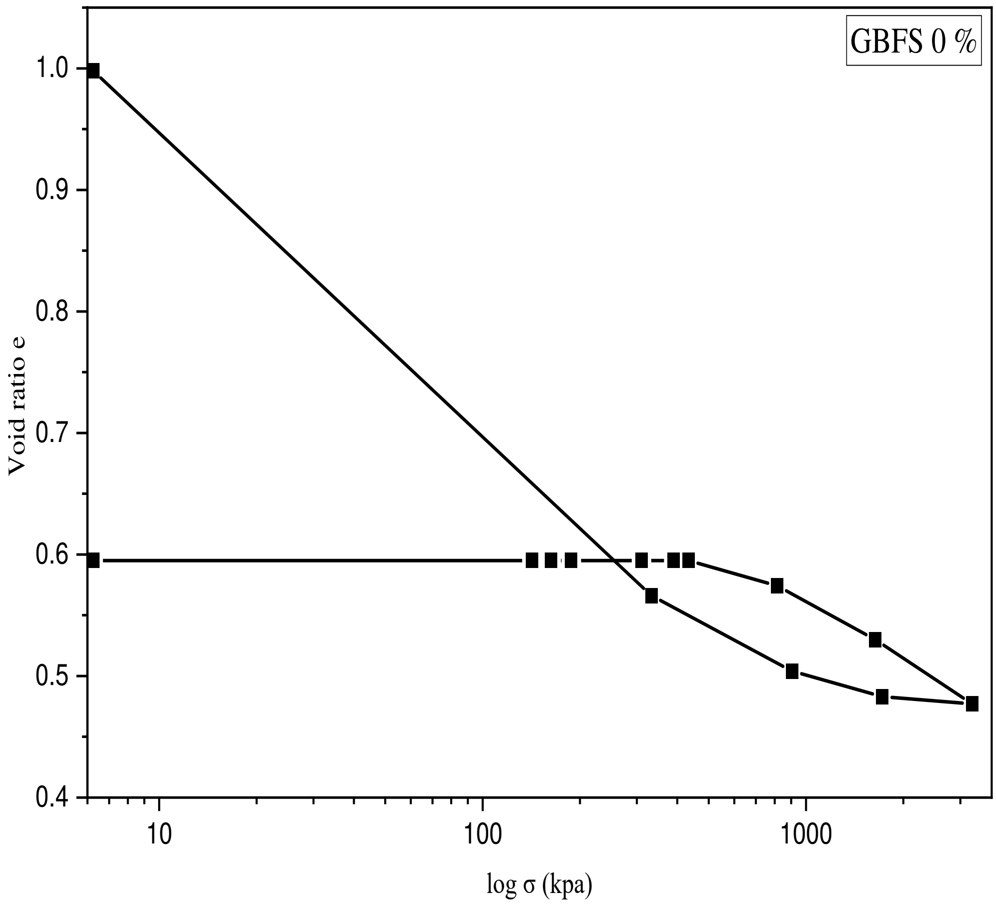


Figure 1 methodology of samples preparation

3. Results and discussions


GBFS 0 %
Void ratio e
1.0
0.9
0.8
0.7
0.6
0.5
0.4
10
100
1000
log σ (kpa)

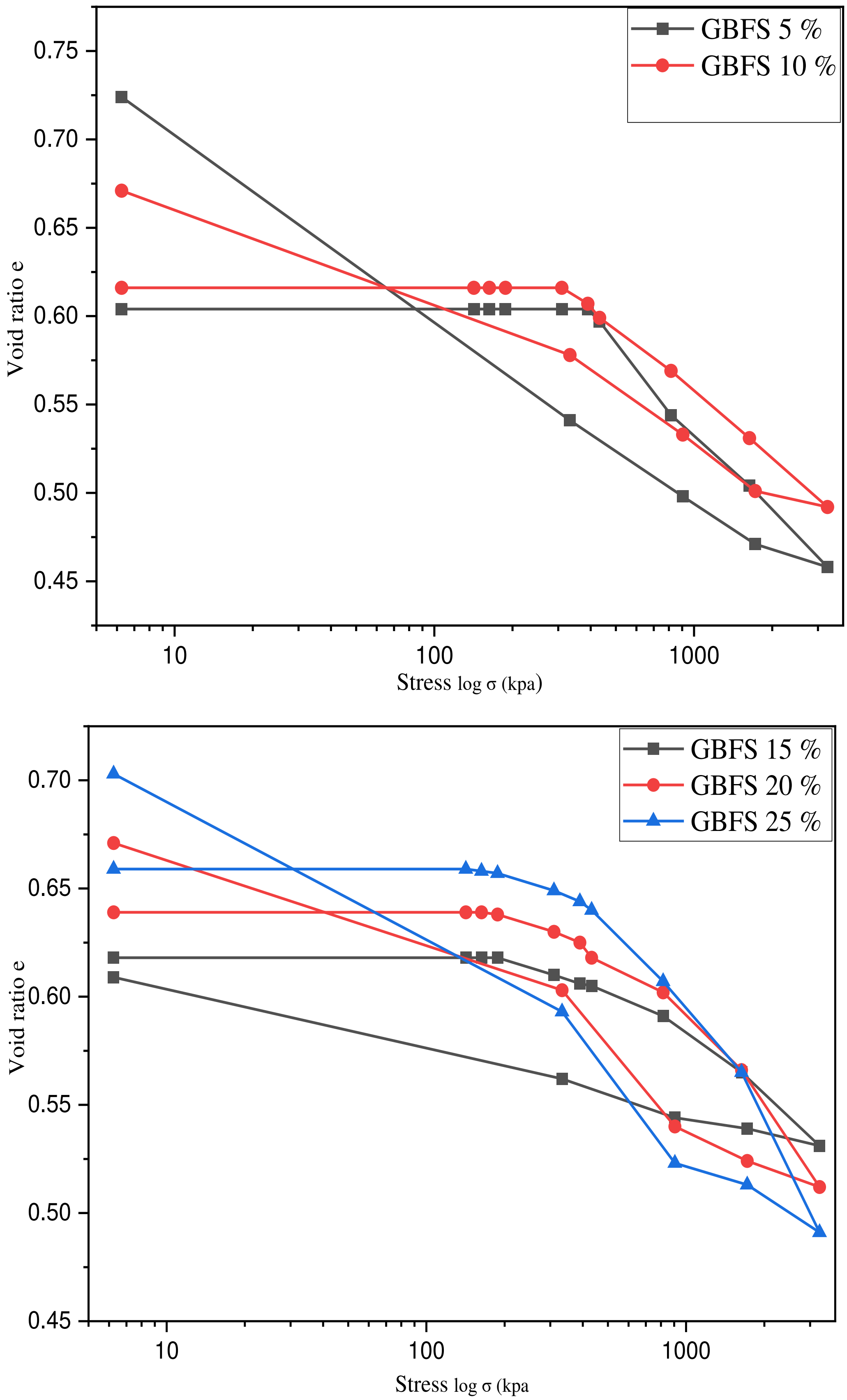


Figure 2 stress versus void ratio of GBFS

Table 1 compressibility index and swelling index of GBFS

Specimen	Compressibility index Cc	Swelling index Cs
GBFS 0 %	0.14565	0.43
GBFS 5 %	0.1324	0.10599
GBFS 10 %	0.125789	0.053864
GBFS 15 %	0.08607	0.02722
GBFS 20 %	0.1191685	0.03938
GBFS 25 %	0.13903	0.06371

Figure 2 displays the variation of void ratio as a function of stress of the clayey soil treated with different amount of GBFS. It can be seen that with the increase of stress the void ratio reduces in the loading and in the unloading the void ratio increases progressively. The optimum amount of GBFS content was found to be 15 %, for the better reduction in the settlement is may due to the active geopolymerization[7]. Moreover, untreated soil exhibits the higher void ratio after the unloading stage. During, unloading, the dissolution of pozzolanic precursors restricts the soil volumetric behavior through enwrapping the thin cementitious gel around the particles[8].

Table 1 reveals that as the proportion of GBFS increases, the compressibility index decreases until reaching 15 % GBFS; however, beyond this quantity, the compressibility index begins to rise. This reduction in compressibility index is due to the pozzolanic reaction and agglomeration of the fine grains, resulting in their coarsening. As the grains coarsen, compressibility decreases. However, beyond 15% GBFS, the compressibility starts to increase again, which may be attributed to the excess quantity of GBFS that remains unutilized during the pozzolanic reaction**.**

4. Conclusion

The investigation into the effect of Granulated Blast Furnace Slag (GBFS) on the compressibility behavior of expansive soils has provided valuable insights into the potential of GBFS as a sustainable soil stabilization agent. The findings of this study underscore the significant influence of GBFS on modifying the compressibility characteristics of expansive soils, thereby offering a promising solution to mitigate the detrimental effects associated with expansive soil behavior.

Through a series of laboratory tests including compaction, swell, and consolidation tests, it was observed that the addition of GBFS resulted in notable improvements in the compressibility parameters of expansive soils. The optimum percentage of GBFS addition was identified based on the reduction in swell potential and enhancements in coefficient of compressibility and consolidation characteristics. These results highlight the effectiveness of GBFS in reducing the susceptibility of expansive soils to volumetric changes and associated deformation under applied loads and environmental conditions.

The use of GBFS as a soil stabilization agent not only improves the engineering properties of expansive soils but also offers environmental benefits by utilizing industrial byproducts in a sustainable manner. By reducing the reliance on traditional soil stabilization techniques that may involve environmentally harmful materials or costly engineering interventions, GBFS presents a cost-effective and eco-friendly alternative for addressing the challenges posed by expansive soils in civil engineering projects.

Furthermore, the findings of this study provide a foundation for future research endeavors aimed at exploring the long-term performance, durability, and environmental impacts of GBFS-treated expansive soils under realistic field conditions. Additionally, further investigations could focus on optimizing the dosage and application methods of GBFS to maximize its effectiveness in mitigating the compressibility issues of expansive soils across different geotechnical contexts.

In conclusion, the study underscores the potential of GBFS as a viable solution for enhancing the compressibility behavior of expansive soils, thereby contributing to the advancement of sustainable geotechnical engineering practices and the development of resilient infrastructure systems. The implementation of GBFS-based soil stabilization techniques holds promise for improving the performance and longevity of civil engineering structures built on expansive soils, while also promoting environmental stewardship and resource efficiency.

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