Coupling effects of fiber and nano-geopolymer on improving the mechanical performance of swelling soils

Mohammad Ali Pashabavandpouri[a], Amir Reza Goodarzi[b*], Seyed Hamid Lajevardi[a]
[1]Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran
[2]Department of Civil Engineering, College of Engineering, Hamedan Branch, Islamic Azad University, Hamedan, Iran

ABSTRACT

Despite the widespread use of traditional calcium-based stabilizers (such as lime) for soil stabilization, adopting such a strategy may face significant challenges. Hence, this study assessed the effects of using an innovative nano-geopolymer (SNZBG) enhanced by polypropylene fiber on improving the geo-mechanical performance and durability of highly expansive clays. The experimental results showed that the addition of low contents of lime alone may have a relatively favorable influence in controlling the swelling potential of soil; however, the improvement of mechanical parameters requires considerable amounts of additives and long curing times. It was found that harsh conditions (including frequent periods of freezing and thawing, F-T) would lead to the destruction of soil structure and eventually the deterioration of engineering properties. In contrast, the application of the proposed geopolymer could not only diminish (by nearly 4 folds) the required lime and time of curing for successful modification of soil but also significantly increase the durability of the composites. Based on the outcomes of microstructural analyses, the improved performance upon the application of SNZBG can be attributed to enhanced solidification processes and a reduction in the tendency of clay surfaces to absorb water due to the increased formation of geopolymeric nanostructures and the generation of a physical clogged fabric. However, in the SNZBG system, similar to the lime's performance, there was a dramatic reduction in strength when subjected to increasing external loading (i.e., the brittle failure pattern). It was also found that inclusion of fibers plays a significant role in enhancing the ductility of soil-geopolymer matrix. This can be attributed to the bridging effect and formation of a well-intertwined matrix. The combined effect of SNZBG and fibers leads to a twofold increase in the tensile capacity as well as a significant reduction (up to 60%) in the degree of damage caused by the F-T action compared to lime-treated soil samples. In general, it can be concluded that the treatment of swelling clayey soils with SNZBG/fiber is an effective approach compared to the traditional stabilization method.

KEYWORDS

Expansive soils, lime treatment, harsh conditions, matrix instability, SNZBG/fiber, improved geo-mechanical performance.

* Corresponding Author: Email: Amir_r_goodarzi@yahoo.co.uk

1. Introduction

Despite the existence of various techniques to control the volume change behavior of expansive clay soils, such as mechanical compaction and installation of special foundations, the use of calcium-based additives (such as lime) is very common due to their accessibility and ease of implementation. However, the production process of these types of materials can generate high levels greenhouse gases, and the long-term stability of soils stabilized with them may face significant challenges under harsh conditions [1]. Therefore, many researchers are currently focusing on developing new amendments to replace the traditional additives. This aims not only to solve the aforesaid limitations but also to reduce the costs associated with the soil stabilization process while simultaneously enhancing the geo-mechanical performance of treated soils. In line with this approach, the application of various industrial wastes (IWs) for soil improvement could be an effective strategy offering numerous benefits, especially preventing the uncontrolled release of waste into the environment and preserving primary resources [2, 3]. Notably, several studies have been performed on the distinct applications of IWs; however, research on the use of composite geopolymers that combine lime-slag, pozzolanic nano waste materials along with polypropylene fibers to modify the behavior of fine-grained soils (especially to control their volume change behavior) is quite limited. Hence, in this research by performing a series of macro and micro level tests, the following objectives were sought:

I) Assessing the effects of using composite geopolymer on improving the mechanical parameters of swelling clays as compared to treatment with lime.

II) Investigating the effect of fibers/geopolymer mixture on enhancing the durability index of expansive soils.

2. Materials and methods

In this research, an almost pure clay sample was used. After performing identification tests, the mineralogical characteristics and geotechnical characteristics of the used soil were determined, as summarized in Table 1. The materials for preparing the composite nano-geopolymer included a combination of lime, steelmaking slag, pozzolanic waste along with an alkaline solution containing sodium silicate and sodium hydroxide. Finally, the optimal composition for the proposed single-phase nano-geopolymer (SNZBG) was determined to be a ratio of 1:4 of lime to slag and replacing 30% of the solid weight of slag with nano-zeolite combined with an alkaline solution equivalent to the optimal moisture content of the clay sample.

Table 1. Characteristics of the used expansive soil

Parameter	Quantity
Plasticity index (PI), %	327
Soil classification	CH
Swelling potential, %	163
Maximum dry density, g/cm^3	1.31
Optimum moisture content, %	45.8
CEC, Cmol/kg	80.2
Mineral composition	Mainly Montmorillonite

After that, a series of macro level experiments including the swelling potential (Sp), the unconfined compressive strength (UCS) and also the indirect tensile capacity (ITS) were conducted to evaluate the possible effects of the studied additives (i.e., lime alone, SNZBG blend and its combination with fibers) on the geo-mechanical parameters of the highly expansive soil sample. Moreover, to assess the long-term stability of SNZBG treatment, Freezing-thawing (F-T) tests (in accordance with ASTM D-560) were performed on three groups of soil samples inc. I) stabilized with lime alone, II) stabilized with SNZBG blend and III) stabilized with SNZBG blend and fibers. In addition to the mechanical experiments, the microstructural characteristics of the stabilized soil were also evaluated through the velocity of the ultrasonic pulse (UPV), scanning electron microscope (SEM) and X-ray diffraction (XRD) analyses.

3. Results and Discussion

Fig. 1 shows the UCS changes of the samples with different dosages of lime as the curing time increased.

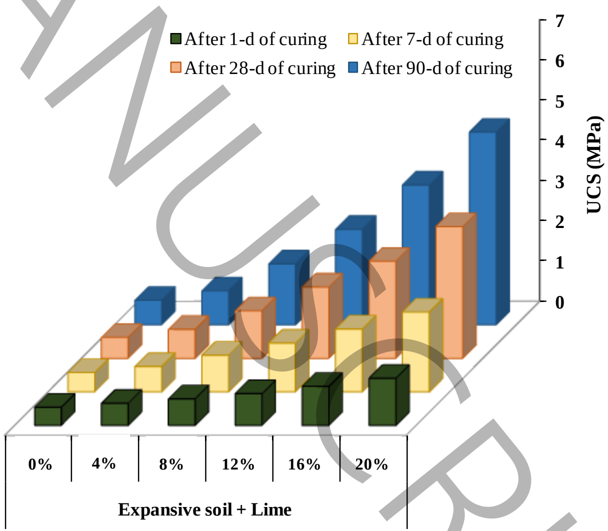

Fig. 1. Effect of lime alone on the UCS of soil sample at different times of curing.

As can be seen in Fig. 1, adding lime can significantly improve (up to 8 times) the soil strength. However, the results presented in Fig. 2, indicate that a substantial portion of the bearing capacity of these samples is lost when exposed to F-T action. On average, the damage index (DI) of the samples is about 58%, with samples containing less than 10% lime exhibiting a DI value as high as 90%.

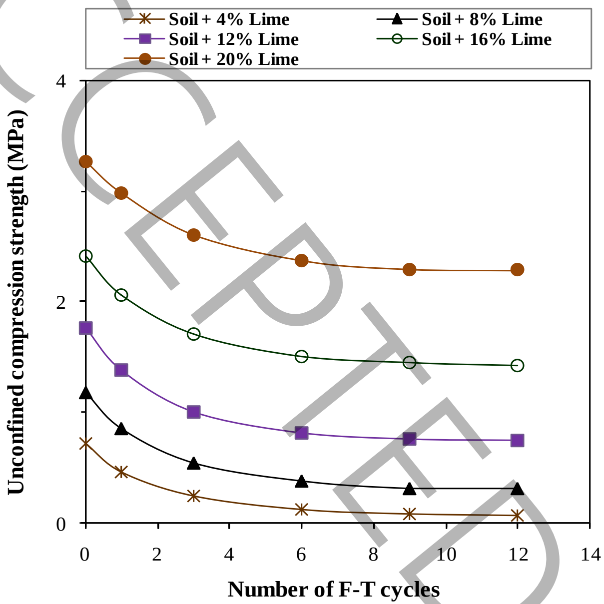

Fig. 2. Effect of F-T cycles on the mechanical properties of lime stabilized soil sample.

The data presented in Fig. 3 confirm that the DI in the samples stabilized with SNZBG and fiber is considerably lower than that of the composite with lime alone. Fig. 2 shows that under the conventional treatment, the average DI is 58%, while for samples containing SNZBG-F, the DI value is about 24%.

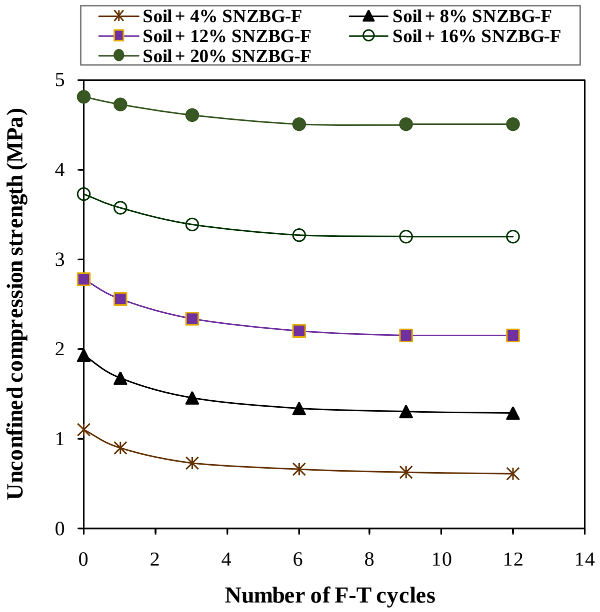

Fig. 3. Effect of F-T action on the mechanical properties of SNZBG-F stabilized soil.

The improved performance of SNZBG-F treatment can be attributed to a set of physicochemical mechanisms. In fact, as confirmed by the SEM images, the use of nano-geopolymer tends to provide a packed structure, resulting in a reduction in the size and volume of pores in the soil. Under this condition, the amount of initial moisture required for generating the ice crystals and subsequently creating the cracks in the matrix would be limited [1]. Moreover, the formation of an intertwined structure in the system containing the SNZBG-F will play a significant role in restraining the additional internal stresses caused by the F-T cycles.

4. Conclusions

The most important findings of the study are presented as follows:

I) The F-T action may lead to a dramatic decrease in the mechanical properties of highly expansive soil treated with lime alone.

II) The application of SNZBG would reduce the amount of lime required for effective soil modification. This improvement can be attributed to enhanced solidification processes and a decreased tendency of clay surfaces to absorb water. However, similar to lime's performance, there was a dramatic reduction in strength under increased external loads.

III) The inclusion of fiber plays a crucial role in enhancing the mechanical properties of the soil-geopolymer matrix. The combined effect of SNZBG/fibers significantly minimizes the damage to soil samples under the F-T scenario compared to the lime-treated composites.

5. References

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