Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Influence of Coconut Coir on The Strength Characteristics of Silica Fume Based Geopolymer Expansive Clay Blends

T V Nagaraju[1] and Ch Vinay Kumar[1]

[1] Department of Civil Engineering, S.R.K.R. Engineering College, Bhimavram, India -534204
varshith.varma@gmail.com, tvnraju@srkrec.edu.in

Abstract. Effective utilization of industrial by-products in construction enables improvement in engineering properties of materials and reduction in cost. Geopolymerization of soils is an alternative method for altering soil properties in an efficient way. However, geopolymer blends possess mild brittle behavior due to the dense geopolymer products. This paper presents the laboratory studies on the effect of coconut coir on the strength characteristics of the silica fume based geopolymer clay blends. The expansive clay is mixed with 15%, 20% and 25% of silica fume and the coconut coir contents used in the each mix are 0.1%, 0.3%, 0.5%, 0.7% and 0.9%. Unconfined compressive strength and split tensile strength was increased with increase in precursor content as well as coconut coir content. The paper also explores the micro-structural behaviour of the geopolymer blends using scanning electron microscopy (SEM) analysis. The SEM micrographs revealed that the dense matrix of geopolymer products was developed for higher precursor content. The presence of coir fibers embedded in the dense phases of geopolymer products improves the flexural resistance of the geopolymer blends.

Keywords: Expansive Clays, Geopolymers, Micro Structure, Strength.

1 Introduction

Ordinary Portland cement (OPC) and lime are commonly used as chemical additives to alter the properties of expansive clays. Moreover, recent and past in many projects the foundation expansive soils was improved with the lime and cement (Prusinski and Bhattacharja, 1999; Asgari et al. 2015). However lime and cement are not eco-friendly and during in the manufacturing process emits CO_2 and energy intensive. Eco-friendly materials alternatives to cement and lime are increased in the current constructions. Many eco-friendly materials such as industrial by-products (inert materials), geopolymers and biopolymer were emerged. Industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), silica fume and rice husk ash (RHA) could be used as a partial replacement of expansive clays and thereby it enhances the properties of clays. The ion exchange takes place between the clays and pozzolanic leads to flocculation and strong cementitious compounds (Kumar and

Sivapullaiah, 2012; Goodarzi et al. 2016; Phanikumar and Nagaraju, 2018). Further, improves the strength characteristics and reduces the swell-shrink behavior of expansive clays. Geopolymers are present scenario one of the best environmental friendly and alternative for OPC, this are prepared based on the synthesis of alumino silicate materials (Davidovits, 2005). In general geopolymerization requires rich source of silica and alumina for effective and efficient synthesis. So, many industrial by-products rich in silica content like RHA, GGBS and silica fume can be used as precursors for effective and efficient geopolymerization (Singhi et al. 2016; Parhi et al. 2017).

Several researchers have carried research on the effect of geopolymers on soils and their applications. Moreover, the factors affecting the geopolymer soil blends for contributing higher compressive strength, reducing swell-shrinkage characteristics, and improving compressibility. The strength of the geopolymer soils depends on the precursor content, Na/Al, Si/Al, molarity of NaOH solution, Na_2SiO_3/NaOH ratio and processing temperature (Sukmark et al. 2013; Mozumder and Laskar, 2015). As an alternative to OPC, geopolymers have shown its significance in chemical amelioration of soils (Zhang et al. 2013; Du et al. 2017; Ghadir and Ranjbar, 2018). In previous studies (Zhang et al. 2013; Du et al. 2017; Ghadir and Ranjbar, 2018), geopolymer soils with metakaolin based can be used as a stabilizer of clayey soils. Moreover, the UCS values of geopolymer soils can be attained higher when compared to the OPC stabilized clays. Volcanic ash based geopolymer stabilized clayey soil showing significant improvement in UCS of 200%. Furthermore, geopolymer specimens act as a ductile material due to high energy absorption. By comparison, lightweight geopolymer stabilized soil attaining higher strength than light weight cement stabilized soil due to the tendency of geopolymers having higher amount of hydration products.

Therefore, as a part of research on the geopolymers treated expansive soils and their applications, this work focus on the potential application of silica fume based geopolymers with coconut coir as a reinforced material in blended clays. Unconfined compressive strength of the silica fume based geopolymer clays was determined with varying silica fume content as 0%, 15%, 20% and 25% by dry weight of oven dried soil. Subsequent, split tensile tests was conducted for the aforementioned blends by additional reinforced material coconut coir varied as 0.1%, 0.3%, 0.5%, 0.7% and 0.9% by dry weight of oven dried soil. And also, scanning electron microscopy tests were conducted for the silica fume based geopolymer soils blends to know the microstructure and geopolymer products.

2 Experimental Investigation

2.1 Materials

The materials used in this investigation were high plasticity expansive clay (CH), silica fume, alkali-activators and coconut coir. Soil is collected from the depth of

0.5m in Bhimavaram, India, which is a coastal area in India. The soil is highly swelling clay with free swell index of 180%. The index properties of soil consists liquid limit as 86%, plastic limit as 24% and plasticity index as 62%. Coconut fibers used in this study was having length 1cm and average diameter of 0.3mm. Silica fume, sodium hydroxide pellets and sodium silicate gel were collected from local market, Vijayawada, India.

2.2 Sample preparation

For geopolymers, solution was prepared using 10 molar NaOH solution and Na_2SiO_3 gel, and ratio of Na_2SiO_3/NaOH is maintained as 2.5. Collected expansive clay was oven dried at 110^oC for 24hours and then pulverized in to fine particles and sieved through 4.75mm I.S. sieve. Geopolymer soil blends were prepared by mixing prefixed quantities of soil and solution including precursor (Nagaraju and Prasad, 2020). For testing, cylindrical specimens of diameter 38mm and height 76mm were prepared by means of static compaction effort in standard cylindrical mould. The casted specimens were oven-cured for 1hour at a temperature of 100^oC.

2.3 Methods

Unconfined compressive strength (UCS) tests were conducted on the cylindrical specimens of geopolymer soil blends with varying precursor content (silica fume) as 15%, 20% and 25% by dry weight of soil. After testing, a small amount of blended sample is taken for conducting micro-structural analysis using scanning electron microscopy (SEM).

Split tensile strength (indirect tensile strength) test is conducted for the cylindrical samples placed horizontally in between the compression blocks of compression test by taking care of uniform loading on the surface (Kumar et al. 2007). Tensile strength tests were conducted on untreated and geopolymer treated cylindrical specimens (diameter 38mm and height 76mm) with varying coconut coir as a reinforced material (percentages of 0.1%, 0.3%, 0.5, 0.7% and 0.9% by dry weight of soil). The casted specimens were place horizontally in the testing machine and mounted with loading. The load is applied on the surface center line on each side of support. Tensile strength under load was measured using dialguage. The tensile strength (T_s) calculated using equation 1.

$$Ts = 2P_{ult}/\Pi td \quad (1)$$

Where, P_{ult} is ultimate load (N), t is thickness of the cylindrical sample (mm), and d is the diameter of sample (mm).

3 Test Results and Discussion

3.1 Effect of varying precursor content on UCS

In the test results performed in the laboratory, the geopolymer clay specimens were by varying precursor content. The results obtained from UCS test shows in Table 1 and stress strain curves shown in Figure 1. As seen from the Table 1 and Figure 1, the UCS values were significantly improved with varying silica fume content in the geopolymer clay blends. It is observed that drastic increase in the UCS value at higher percentages of precursor in the geopolymer clay blends. This is due to the effective condensation and geopolymerization process takes place in the blends. Further, a geopolymer product offers resistance against the axial compression for a given strain.

Table 1. Effect of silica fume on UCS

Property	Silica fume content					
	0%	5%	10%	15%	20%	25%
UCS (kg/cm^2)	8.18	22.03	29.42	33.67	40.54	47.78

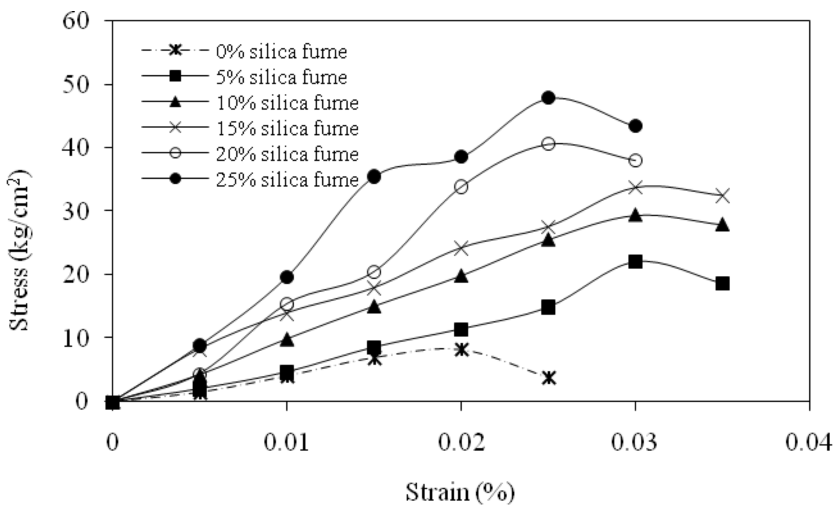


Fig. 1. Stress strain behavior of silica fume based geopolymer clays

3.2 Effect of varying coconut coir content on split tensile strength

Split tensile strength (STS) results indicated that without inclusion of geopolymer clay gives a STS value of 0.58 kg/cm^2 whereas geopolymer clay embedded with coconut fiber (0.7% by dry weight of soil) gives a STS values range 4.20 to 13.86

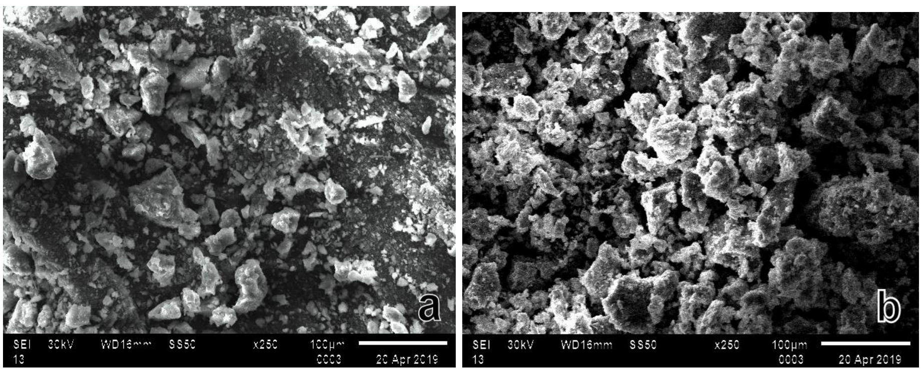
kg/cm^2 kg/cm^2. The significant improvement in STS of geopolymer clays reinforced with coir fibers was only up to the addition of 0.8% coir fibers. This can be attributed due to the fibers embedded in geopolymer matrix prevents the micro-cracks or acts as intersect between the etched holes. Further, internal friction or adhesion within the geopolymer products gives better tensile strength. However, inclusion of higher percentage of fibers (greater than 0.7% coconut coir fibers) in the geopolyme clay leads to decrease in adhesion and tensile strength.

Table 2. Effect of silica fume and coconut coir fiber on the split tensile strength

Silica fume content	Split tensile strength (kg/cm^2) of geopolymer soil blends with varying coconut coir content as					
	0%	0.1%	0.3%	0.5%	0.7%	0.9%
0%	0.58	1.05	2.45	3.40	4.20	3.88
15%	0.71	3.15	6.33	7.48	10.05	8.45
20%	0.92	4.12	8.55	9.45	11.85	9.65
25%	1.21	4.86	10.12	12.12	13.86	11.22

3.3 Microstructural studies

To understand the formation of geopolymer products and surface texture in the geopolymer treated clays, SEM analysis was carried on silica fume based geopolymers. A lower content of precursor content in the blend allows the flocculation of grains but no dense phase of geopolymer matrix (See Figures 2a, b and c). Figure 2d displays the evidence of leaching Si and Al oxides from silica fume by alkali dissolution and allows forming geopolymer products. Moreover, Ca^{+2} ions of clay and SiO_2 of silica fume allow formation of cementitious products (calcium silica hydrate).



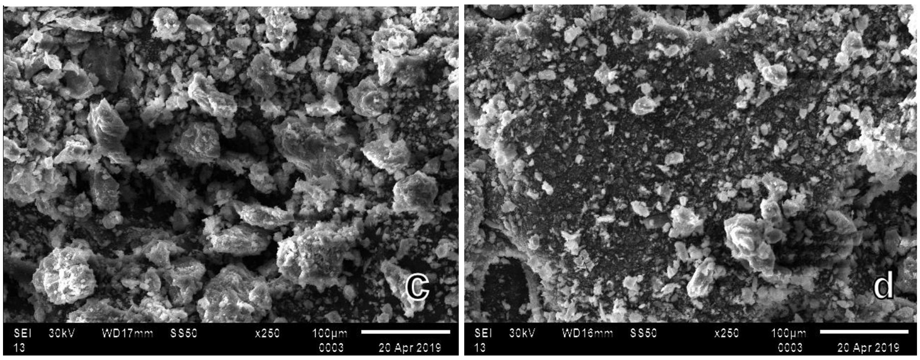


Fig. 2. SEM micrographs of silica fume based geopolymers with varying silica fume a) 0% precursor content b) 5% silica fume c) 15% silica fume and d) 25% silica fume

4 Conclusions

Geopolymer soils are one of the most sustainable alternatives to cement and lime treated soils. Reinforced geopolymer clays have a wide range of applicability in civil engineering constructions. From the study of effect of geopolymers and coconut coir on the UCS and STS, the following conclusions may be drawn:

UCS results show that axial resistance of silica fume based geopolymer clay blend improved significantly with increasing precursor content. This is attributed to formation of geopolymer products as well as cementitious compounds.

Tensile behavior of geopolymer clay blends were improved with the inclusion of coir content. Optimum STS values are obtained with the inclusion of up to 0.7% coconut coir content.

Micrographs of geopolymer clay blends are clear evident of formation of dense geopolymer products.

References

1. Asgari, M. R., Dezfuli, A. B., & Bayat, M.: Experimental study on stabilization of a low plasticity clayey soil with cement/lime. *Arabian Journal of Geosciences*, *8*(3), 1439-1452 (2015).
2. Davidovits, J. (Ed.).: Geopolymer, green chemistry and sustainable development solutions: proceedings of the world congress geopolymer 2005. Geopolymer Institute (2005).
3. Du, Y. J., Yu, B. W., Liu, K., Jiang, N. J., & Liu, M. D.: Physical, hydraulic, and mechanical properties of clayey soil stabilized by lightweight alkali-activated slag geopolymer. *Journal of Materials in Civil Engineering*, *29*(2), 04016217 (2017).
4. Ghadir, P., & Ranjbar, N.: Clayey soil stabilization using geopolymer and Portland cement. *Construction and Building Materials*, *188*, 361-371 (2018).

5. Goodarzi, A. R., Akbari, H. R., & Salimi, M.: Enhanced stabilization of highly expansive clays by mixing cement and silica fume. *Applied Clay Science*, *132*, 675-684 (2016).
6. Kumar, A., Walia, B. S., & Bajaj, A.: Influence of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. *Journal of materials in civil engineering*, *19*(3), 242-248 (2007).
7. Kumar Sharma, A., & Sivapullaiah, P. V.: Improvement of strength of expansive soil with waste granulated blast furnace slag. In *GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering*, pp. 3920-3928 (2012).
8. Mozumder, R. A., & Laskar, A. I.: Prediction of unconfined compressive strength of geopolymer stabilized clayey soil using artificial neural network. *Computers and Geotechnics*, *69*, 291-300 (2015).
9. Nagaraju, T. V., & Prasad, C. D.: New Prediction Models for Compressive Strength of GGBS-Based Geopolymer Clays Using Swarm Assisted. In *Advances in Computer Methods and Geomechanics: IACMAG Symposium 2019* (Vol. 1, p. 367). Springer Nature (2020).
10. Parhi, P. S., Garanayak, L., Mahamaya, M., & Das, S. K.: Stabilization of an expansive soil using alkali activated fly ash based geopolymer. In *International Congress and Exhibition" Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology"*, pp. 36-50, Springer, Cham (2017).
11. Phanikumar, B. R., & Nagaraju, T. V.: Effect of fly ash and rice husk ash on index and engineering properties of expansive clays. *Geotechnical and Geological Engineering*, *36*(6), 3425-3436 (2018).
12. Prusinski, J. R., & Bhattacharja, S.: Effectiveness of Portland cement and lime in stabilizing clay soils. *Transportation research record*, *1652*(1), 215-227 (1999).
13. Singhi, B., Laskar, A. I., & Ahmed, M. A.: Investigation on soil–geopolymer with slag, fly ash and their blending. *Arabian Journal for Science and Engineering*, *41*(2), 393-400 (2016).
14. Sukmak, P., Horpibulsuk, S., Shen, S. L., Chindaprasirt, P., & Suksiripattanapong, C.: Factors influencing strength development in clay–fly ash geopolymer. *Construction and Building Materials*, *47*, 1125-1136 (2013).
15. Zhang, M., Guo, H., El-Korchi, T., Zhang, G., & Tao, M.: Experimental feasibility study of geopolymer as the next-generation soil stabilizer. *Construction and Building Materials*, *47*, 1468-1478 (2013).