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Swelling Characteristics of Fly Ash Based Geopolymer Expansive Clay Blends

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Abstract. Chemical amelioration of expansive clays using cement and lime was quite successful, to improve swelling and shrinkage behaviour. However, these traditional additives were energy intensive and can produce large amount CO_2 in their production process. This paper discusses the effect of fly ash based geopolymer on swelling behaviour of a remoulded expansive clay. One-dimensional swell-consolidation tests were performed on fly ash based geopolymer expansive clay blends by varying different percentages of fly ash as 5%, 10%, 15%, 20% and 25% by dry weight of soil. Rate and amount of heave, swell potential (S%) and swelling pressure (p_s) were studied by varying fly ash content. Test results showed that the amount of heave and swell potential and swelling pressure of blends decreased with increasing fly ash content. The paper also explores the micro-structural behaviour of the fly ash based geopolymer clay blends using scanning electron microscopy (SEM). The SEM results revealed that the formation of Si-O-Si bonds and flocculation of particles.

Keywords: Swelling, Shrinkage, Expansive Clay, Micro Structure

1 Introduction

Expansive clay pose a great damage to lightly loaded infrastructure such as pavements, embankments, retaining walls and buildings due to their drastic swell-shrink behavior (Chen, 2012). The swell-shrink behavior of expansive clays causes due to the expanding lattice structure of montmorillonite mineral (Basma et al. 1996; Chen, 2012). Expansive clays are most common deposits available in many parts of India, especially in east coast (Nagaraju and Satyanarayana, 2019).

There are many modification techniques are in practice to alter the properties of expansive clays viz. chemical amelioration, mechanical stabilization, under-reamed piles, stone columns, surcharge loading and sand drains (Welsh, 1986; Kumar and Thyagaraj, 2020). Among all the modification techniques, chemical amelioration of expansive clays is quite successful in pavement subgrades, embankment fills and foundation soil. In chemical amelioration, many chemical additives were emerged past and present. However, choosing of sustainable eco-friendly material and their applications is much needed. Cement and lime are common additives to improve swell-shrink behavior (Saride et al. 2013). These are particularly effective in increasing the strength characteristics due to the formation of clay flocks and cementitious products (C-S-H and C-A-H) (Sirivitmaitrie et al. 2008; Saride et al. 2013). However, cement and lime are energy intensive and emits CO_2 during the manufacturing process (Gartner, 2004). Other hand, there are many industrial by-products available to enhance engineering behaviour of expansive clays. Industrial by-products having higher amount of Ca, Si and Al oxides contributes pozzolanic reaction, which after pozzolanic reaction generates strong cementitious compounds. Fly ash, silica fume, ground granulated blast furnace slag (GGBS) and rice husk ash (RHA) were pozzolanic materials used as a stabilizer shows significant improvement in the swell-shrink behavior of expansive clays (Phanikumar and Nagaraju, 2019; Bose, 2012). Swell-shrink properties of expansive clays such as rate of heave, swell potential, swelling pressure, compressibility and linear shrinkage were improved with pozzolanic materials due to formation of flocculation of grains and cementitious compounds (Phanikumar and Nagaraju, 2019).

Recent years, geopolymers are using as a sustainable alternative for lime and cement. Geopolymers are prepared based on the inorganic alumino-silicate polymer. Geopolymer binders are depends on many factors which includes molarity of alkali solution, precursor (mineral composition), texture of materials (glassy phase or amorphous phase), Si/Al ratio, thermal exposure and fineness of materials. Several attempts (Zhang et al. 2013; Singhi et al. 2016; Onyelowe et al. 2018; Nagaraju and Prasad, 2020) have been made to study the role of geopolymers in altering the properties of soils. The competitiveness of geopolymerization blends increased because of the improvement in strength, ductility, shrinkage strains and stiffness. During geopolymerization process, oligomers were formed due to the Si and Al oxides dissolution. Further, hardening of geopolymer gel contributes dense geopolymer products with distribution of pores. Syed et al. (2020) reported that volumetric instability of expansive clays can be improved by using geopolymers, they form a strong cementitious products. By comparison, clayey soils treated with geopolymers attain higher strength improvement but not more than cement stabilized clays. However, geopolymer blends show ductile behavior when compared with ordinary Portland cement blends (Ghadir and Ranjbar, 2018).

This paper presents the swell-shrink behavior expansive clays stabilized with fly ash based geopolymers. One dimensional swell consolidation tests were carried on the fly ash based geopolymers with varying precursor content as 5%, 10%, 15%, 20% and 25% by dry weight of clay. Furthermore, tested oedometer samples were analyzed for micro-structural behavior using scanning electron microscopy.

2 Experimental Investigation

2.1 Materials

Expansive clay used in this study, which is highly swelling clay in coastal region of Andhra Pradesh, India. Table 1 shows the index properties of the expansive clay, while Figure 4a shows the SEM micrograph of expansive clay. Fly ash was considered as precursor in this study, which is collected from NTPC, Vijayawada, India. Table 2 shows the chemical composition of both soil and fly ash. Alkali-activators for altering expansive clays were prepared using sodium hydroxide pallets and sodium silicate gel.

Table 1. Properties of soil

Properties	Liquid limit, %	Plastic limit, %	Soil Classification (IS)	Specific gravity	Fines, %	Free swell index, %
Value	85	23	CH	2.65	94	180

Table 2. Chemical composition of clay and fly ash

Material	SiO_2, %	Al_2O_3, %	Fe_2O_3	CaO, %	MgO, %
Clay	63.15	19.35	4.35	0.67	1.79
Fly ash	33.5	23.05	6.10	27.1	4.6

2.2 Laboratory tests

Geopolymers were prepared by maintaining 10M of NaOH solution and ratio Na_2SiO_3/NaOH as 2.5. geopolymer specimens were prepared at initial density 12kN/m^3. Moreover, in the tests on fly ash based geopolymer clay blends, the soil was replaced by the required amount of precursor content. The geopolymer blend was compacted four layers of each 5mm thickness using manual static compactor. One-dimensional swell-consolidation tests were conducted on fly ash based geopolymer clay blends according to ASTM D4546-03. Rate of heave, swell potential, swelling pressure, rebound and linear shrinkage of geopolymer clay blends were determined. The rate of heave was monitored until the equilibrium heave reaches, generally undergo swell by inundation for 4320minutes (3 days). Swell potential was measured under an initial surcharge of 5kPa when the sample was inundated with water. Swelling pressure (p_s) was determined with the help of e-logp curves with respect to their initial void ratio.

In addition to swell compressibility tests on geopolymer blends, micro-structural tests were conducted on the blends. Scanning electron microscopy (SEM) analysis was carried to know the behavior of texture and morphology of the geopolymer blends with the intension of relating these results to associated swell-shrink behaviour.

3 Results and Discussion

3.1 Swell-shrink behaviour

Fig 1 plots indicate that the variation of rate of heave with respect to time interval when the geopolymer specimens inundated with water. Rate of heave decreased with increasing fly ash content in the fly ash based geopolymer clay blends. The reduction in have is due to the fly ash micro spheres counteracts the expanding silica lattice of montmorillonite mineral. Moreover, clay pockets were interlocked with strong geopolymer products.

Test data shows that with increasing fly ash content in the fly ash based geopolymer clay blends rebound and linear shrinkage were improved. Significant reduction in rebound (axially) and shrinkage (laterally) was due to the resistance offered by the inter molecule geopolymer products.

Table 3. Test data

Property	Fly ash content					
	0%	5%	10%	15%	20%	25%
Rate of heave (mm)	1.81	1.63	1.56	1.40	1.29	1.22
Swell potential (%)	9.05	8.15	7.80	7.00	6.45	6.10
Swelling Pressure (kPa)	112	152	214	225	--	--
Rebound (mm)	0.43	0.26	0.20	0.14	0.11	0.06
Linear Shrinkage (%)	8	7	4	2	--	--

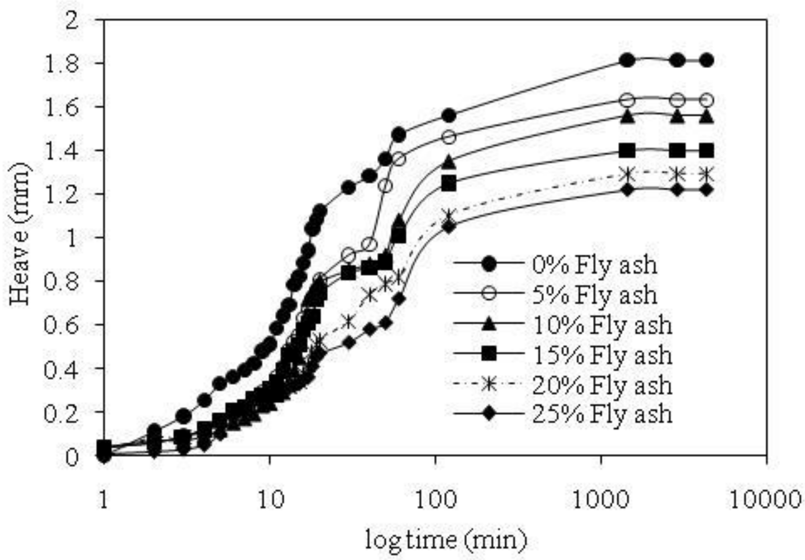

Fig. 1. Rate of heave with varying precursor content

Figure 2 shows that fly ash based geopolymers caused an appreciable decrease in swell potential (from 9.05 to 6.10) at the addition of 25% fly ash content. An improvement in swell potential is due to the flocculation of clays with alkali-activators.

Figure 3 plots shows the e-logp curves of geopolymer treated expansive clay and fly ash based geopolymer treated clays with varying fly ash content. Swelling pressure *(p_s)* increased with increasing fly ash content in the blends up to 15%. Thereafter, increasing fly ash content, swelling pressure could not be determined due to dense geopolymer matrix.

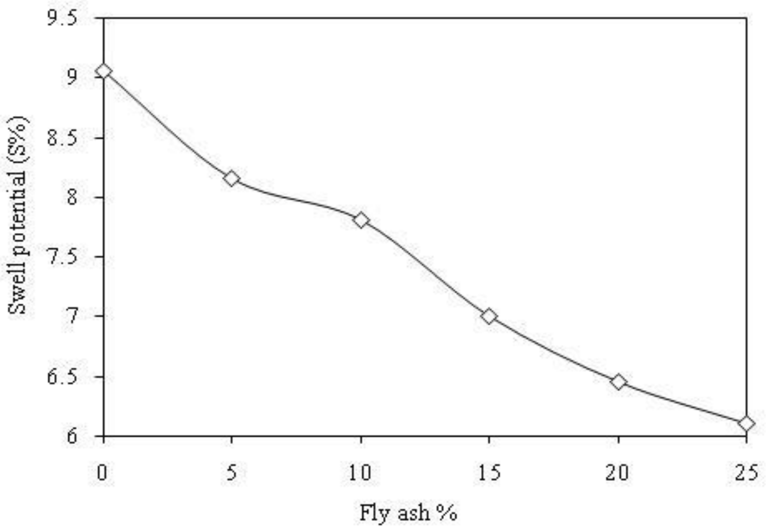

Fig. 2. Swell potential with varying precursor content

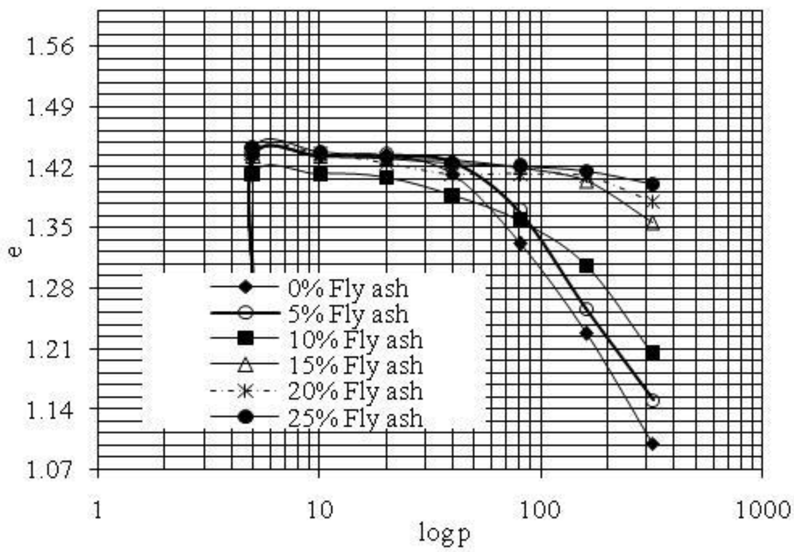

Fig. 3. e-logp curves with varying precursor content

3.2 Micro-structure studies

The micrographs of fly ash based geopolymer blends were clearly evident that morphology and geopolymer products were improved with the increasing precursor content.

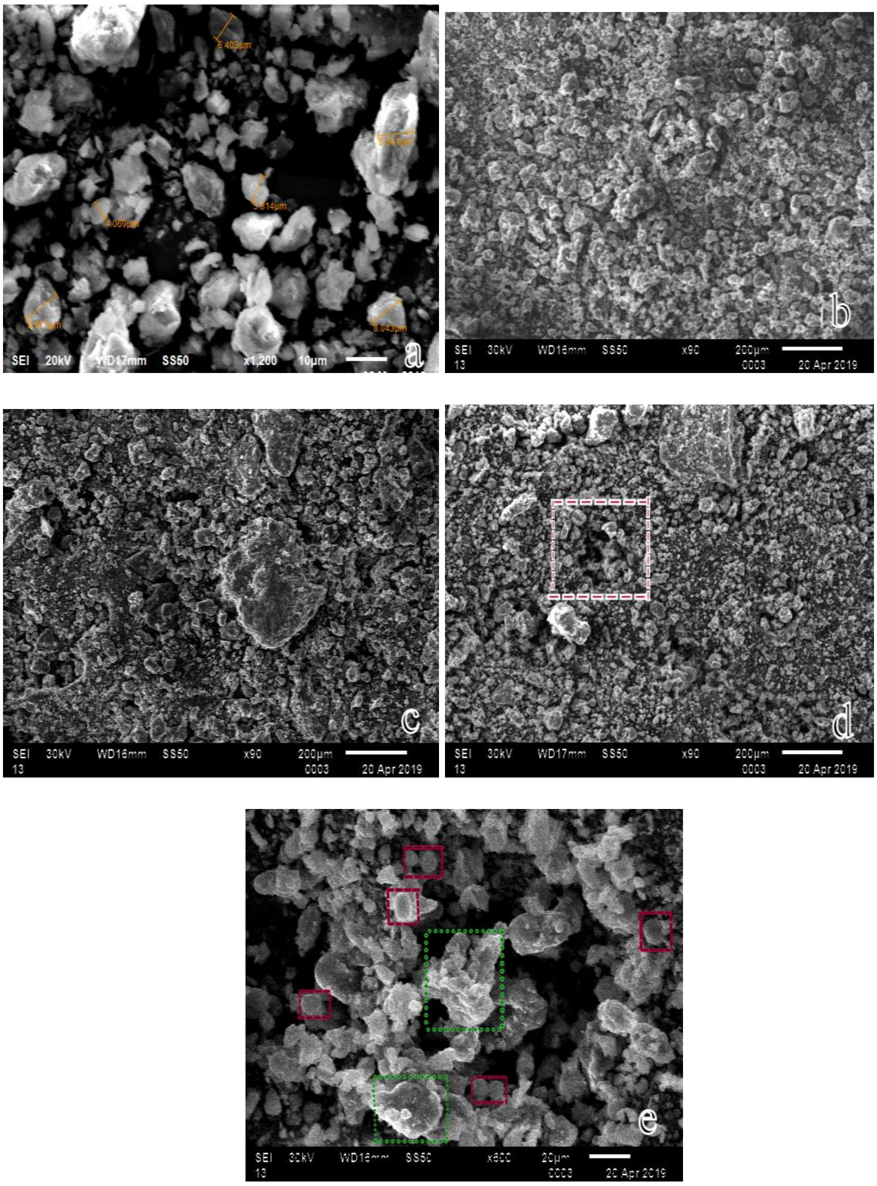

Fig. 4. SEM micrographs of clay treated with fly ash geopolymers with varying fly ash content a) virgin expansive clay b) 15% fly ash c) 20% fly ash and d) 25% fly ash

Figure 4c and 4d shows the geopolymer gel phases and interface between the geopolymer products and clay particles. Moreover, unreacted fly ash particles (spherical particles) also found in the geopolymer blends at higher precursor content (255) addition (vide Figure 4e). In figure 4d, morphology highlighted in box shaped, clearly evident that fly ash particles (Al and Si oxides) were dissolved and exhibits compacted micro-structure. This indicates an effective geopolymerization and resulted in higher resistance against swelling and shrinkage.

4 Conclusions

The following broad conclusions drawn from the above experimental study:

1) Rate of heave, swell potential, rebound and linear shrinkage were decreased with increasing fly ash content in the fly ash based geopolymer clays. Swell potential showing an improvement of 32.5 percentage when fly ash content increased from 0% to 25%.
2) Swelling pressure ($_{ps}$) of the fly ash based geopolymers improved with addition of fly ash content in the blends. However, determination of swelling pressure was not possible for blends having higher fly ash content 20% and 25%, due to the strong geopolymer matrix.
3) SEM micrographs show that the geopolymer gel phases and compacted micro-structure resulted in higher resistance against both swelling (axially) and shrinkage (laterally).
4) Swell-shrink behavior of expansive clays treated with fly ash based geopolymers can be utilized as construction material in pavement sub-grades, backfill and cushion layer.

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