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Compressibility Characteristics of an Organic Soil Treated with Fly Ash and Fly Ash-Based Geopolymer

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ABSTRACT

Organic soils are problematic soil for various engineering applications due to their high compressibility and low shear strength which need to be improved. For many soil improvement techniques, using waste materials, such as fly ash (FA), is a practical and sustainable process. In this research, FA and geopolymer were used e used to reduce organic soil's compressibility. A one-dimensional consolidation test was performed to evaluate the organic soil's consolidation and compressibility properties. The geopolymer was prepared using 20% FA and of sodium hydroxide ratio and sodium silicate alkali solutions. The geopolymer specimens were first cured for 2 hours at 45 and 65 ºC, then cured for further 28 days at room temperature. The consolidation test results showed that FA-based geopolymer is effective in stabilizing organic soils due to the observed improvement in the compressibility, consolidation, and permeability characteristics. The compression index decreased by 98.16%, and the permeability decreased by 95%.

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1. Introduction

Problematic soils may need to be modified for some engineering projects in order to have better geotechnical characteristics. Organic soils are problematic soils with high compressibility and low shear strength due to the content of organic matter (Sharma, Swain, & Sahoo, 2012). Different additives have been utilized to improve the strength and compressibility characteristics of organic soils. Fly ash is a cost-efficient and sustainable addition because it is an industrial by-product. Using FA helps reduce the pollution produced by disposing of FA into the environment (S. K. Mohanty, Pradhan, & Mohanty, 2017). The compression and swelling properties of soils can be improved by using fly ash or geopolymer additives. Turan et al., (2019) indicated that increasing FA content from 15 to 25% lead to a gradually a decrease in both the compression index (C_c) and swelling index (C_s). The study of (Ranjbar, Kuenzel, Spangenberg, & Mehrali, 2020) conducted consolidation tests on FA-treated soil and concluded that the swelling potential and swelling were significantly improved by adding the FA. Another study (Phani Kumar & Sharma, 2004) reported that by adding 20% FA to lean clay, the swelling pressure and swelling potential decreased up to 50%. Still, the increase in the amount of fly ash added beyond 20% had no clear effect

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on reducing the swelling potential and swelling pressure. The change in swelling was not clear during the first 8 hours of the test, but after that, the amount of swelling decreased significantly, and the percentage of swelling, in general, decreased with the increase in the percentage of FA. With the increase in the FA content in the soil, it was observed a gradual decrease in the coefficient of compressibility (a_v), the coefficient of volume change (m_v), and the compression index. Furthermore, the coefficient of consolidation (C_v) gradually increased with the soil's FA content increase. It was observed that the values of coefficient of compressibility (a_v), coefficient of volume change (m_v), and compressibility index decreased to 54, 26, and 54%, respectively when 30% of the FA was added to the soil. The reason for these changes is that the FA continuously reduces the plasticity of the soil as the FA increases (S. Mohanty, Pradhan, & Mohanty, 2016). The study by (Jaditager & Sivakugan, 2018) indicated the evaluation of the effect of FA-based-geopolymer on clay soil. The results showed that the C_v values increased with the increase in the FA-based geopolymer. When applying a stress level of 40 kPa at the proportions of FA in the geopolymer of 6, 12, and 18%, the C_v values were 0.8, 1.2, and 1.8 m2/year, respectively, compared to 0.6 m2 /year for the untreated soil. This increase in the C_v value is due to the modification in the soil structure due to the addition of an FA-base geopolymer.

Many past studies have used FA and FA-based geopolymers to stabilize different types of soils. However, the stabilization of organic soils with these materials has not been previously evaluated. This study aims to assess of using fly ash and fly ash-based geopolymer as an inexpensive and environmentally acceptable binder to stabilize organic soils. Different ratios of alkali solutions were used to prepare the geopolymer.

2. Experimentation program

2.1 Materials

The organic soil was collected from a region in Iraq, west of Ramadi, at a depth of 1 meter below the surface of the earth. Before the experiments began, the soil sample was air dried. The organic content was calculated to be 21.4% based on the ASTM D2974-20 standard. The classifications and physical characteristics of the organic soil are shown in Table 1. According to the ASTM D2487-17, which defines the Unified Soil Classification System (USCS), the organic soil was classified as organic silty clay (OL). Fig. 1 shows the gradation curves of the organic soil as determined by sieve analysis and hydrometer tests, in accordance with ASTM D422-07. The Atterberg Limits were calculated in accordance with ASTM D4318-17. The fly ash (FA) was provided commercially by a local vendor and was classified as Class F with low calcium content (CaO) by ASTM C618-12(ASTM, 2012). Chemical composition of the soil and fly ash is shown in Table 2.

Table 1. The classifications and physical characteristics of the organic soil

Engineering properties	Value
Specific Gravity (G_s)	1.69
Sand (%)	12
Silt (%)	42
Clay (%)	46
Liquid Limit (%)	45
Plastic Limit (%)	27
Plasticity Index (%)	18
Optimum Moisture Content %	22.82
Maximum dry unit weight (MDU) kN/m^3	15.87
Initial void ratio	1.03
Classification (USCS)	OL (Organic Silty clay)

Table 2. Chemical composition of the soil and fly ash

Oxide Composition	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	MnO
Soil (wt. %)	48.101	12.992	19.862	5.365	8.212	1.34	1.087	1.0131	0.0752
FA (wt. %)	51.09	36.75	0.3315	3.939	1.84	1.12	3.487	0.105	0.0134

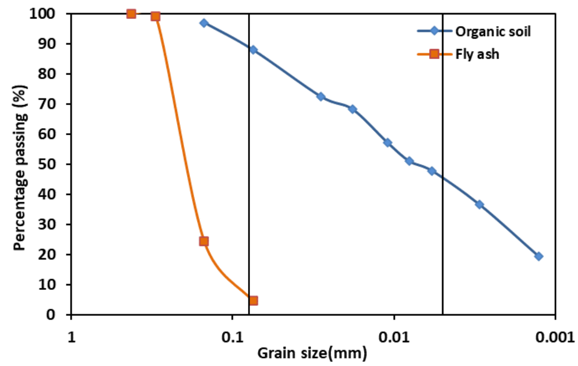

Fig. 1. Grain size distribution for the soil and fly ash

In this study, the FA was activated throughout the geopolymerization process by sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). NaOH (SH) and Na_2SiO_3 (SS) were blended by two ratios SH:SS=100:0, 50:50 to produce an alkaline activator. The NaOH solution was prepared by dissolving pure NaOH flakes in water at 8 molarities. According to previous studies, the ratios and concentrations were chosen (Abdulwahed, Mahmood, & Abdulkareem 2021). Sodium silicate is composed of 13% Na_2O, 32% SiO_2, and 54% water.

2.2 Methodology

1) Specimens preparation: The test specimens were made of soil-FA and soil-geopolymer mixes. The maximum dry unit weight (MDU) and optimum moisture content of the mixes were determined using the Standard Proctor procedure (ASTM D698-12). The maximum dry unit weight (MDU) of the untreated soil was 15.87 KN/m^3 and the optimum moisture content was 22.82%.The MDU and OMC for soil +20% FA were 11.42 kN/m^3 and 24.28%, respectively. The consolidation test was performed in accordance with the ASTM D2435-11 standards. The test was conducted on six specimens, as listed in Table 3. The specimens for the consolidation test were compacted in an odometer cell with dimensions of 50 mm diameter and 20 mm height according to the standard effort method (ASTM D698-07), as shown in Fig 2. The untreated soil specimen was direct tested. The treated soil specimens were covered by nylon and cured at two temperatures 45 and 65˚C for 48 hours. After then put the specimens for 28 days in a dry oven at 25ºC (Abdulwahed, Mahmood , & Abdulkareem 2021).

Table 3: mixtures and curing of consolidation test

No.	%Soil	%FA	SH:SS	Curing temperature (ºC)
1	100	0	0	No curing
2	80	20	0	25
3	80	20	100:0	45
4	80	20	100:0	65
5	80	20	50:50	45
6	80	20	50:50	65

Fig. 2 The specimens of the consolidation test

2) Laboratory Procedures: The consolidation test was performed in accordance with the ASTM D2435-11[16] standards. Each prepared specimen was placed in the cell of the odometer and immersed in water for 24 hours to saturate the specimen and measure the swelling. The specimens were loaded with a load increment ratio of 1 starting from 12.5 to 400 kPa. The axial displacement was measured at 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480, and 1440 minutes. After applying the last load (400 kPa), the specimens were unloaded in to two stress levels of 200 and 400 kPa, with the value of swelling in each step being measured simultaneously for 24 hours.

3. Results and discussion

Soils having organic content are usually the poorest engineering materials to bear the loads of the structures. A consolidation test was performed on untreated organic soil and soil mixed with 20% of FA at two ratios of alkaline activator at the MDU and OMC

3.1 The Effect of Fly Ash on Soil Compressibility

Results of the consolidation tests are shown in Fig. 3. The initial void ratio ($e_\circ$) decreased by 49% for the soil stabilized with 20% FA. Also, the coefficient of permeability (k) was reduced in the soil specimens stabilized with the FA by 89% compared to the untreated soil specimens. This decrease in e_o and k could be attributed to the formation of cement compounds in the new mixture that fill the soil voids. The properties of consolidation such as (C_v, C_c, C_s), as shown in Fig.4. The C_v values of untreated soil is 0.0068 cm^2/min, which increased by 92% for the treated soil. This improvement in C_v is attributed to the FA that is incorporated into the treated soil and decreases the plastic properties (S. Mohanty et al., 2016). The C_c of the untreated soil is 0.2014, which decreased by 93% with adding 20% of FA. This decrease in C_c of the stabilized soil is due to the plastic properties of the soil that reduced. Moreover, C_s was 0.1055 for untreated soil, which decreased by 97% with adding 20% of FA. The change in the C_s values can be attributed to the non-expansive structures, size, and shape of the FA particles, which reduced the organic soil's tendency to swell, as indicated by (Prabakar, Dendorkar, & Morchhale, 2004).

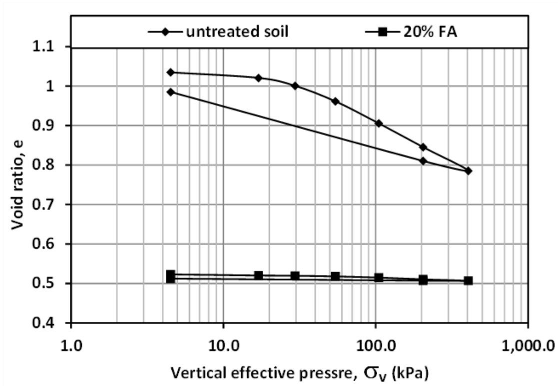

Fig. 3 Compression curves of untreated soil and soil+20% FA.

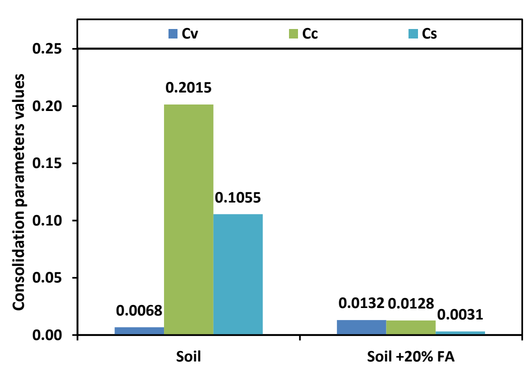

Fig. 4 Variation of compressibility parameters of soil+20% FA.

3.2 The Effect of Alkaline Activator Type on the Compressibility

3.2.1 Specimens Treated with (SH:SS=100:0)

The compressibility behavior of the organic soil stabilized by the geopolymer was investigated at 45 and 65ºC using NaOH as an alkaline activator with 20% of the FA content. The initial void ratio decreased by 49% with adding the geopolymer and curing the stabilized soil at 45 and 65ºC, as shown in Fig 5. Also, the permeability decreased by 94 and 89% at 45 and 65ºC, respectively. With adding geopolymer. The C_v of the stabilized samples increased by 91 and 502% at 45 and 65ºC, respectively compared to the untreated soil. The increased C_v value due to the bonding of cementation and pozzolanic reaction impact of geopolymer that contributes to the improvement of the soils' mechanical properties, including consolidation characteristics. The C_c values decreased by 94.8 and 98.16%, respectively. The geopolymer increased the soil stiffness, which led to a decrease in compressibility (Jaditager & Sivakugan, 2018). The C_s values decreased by 99%. The swelling reduction is due to the strong bonds produced by the geopolymer in the structure of the soil. The changes in consolidation parameters with the addition geopolymer using NaOH as an alkaline activator at different temperatures are illustrated in Fig. 6.

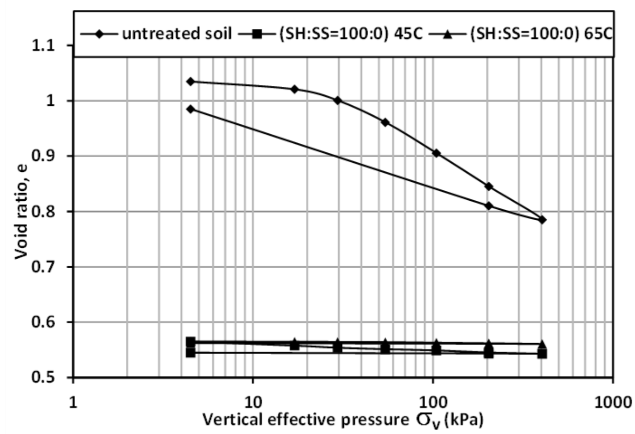

Fig. 5 Compression curves of untreated soil and soil-geopolymer (SH:SS=100:0)

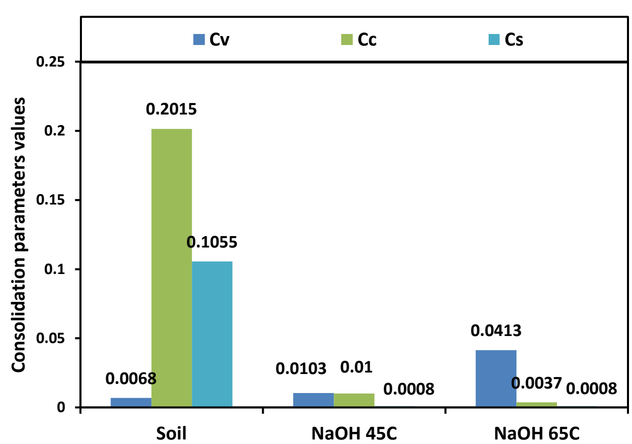

Fig. 6 Variation of the geopolymer-treated soil compressibility parameters (SH:SS=100:0).

3.2.2 Specimens Treated with (SH:SS=50:50)

With the addition of the geopolymer (SH:SS=50:50) and curing the stabilized soil at 45 and 65ºC, the initial void ratio decreased by 45 %, as shown in Fig 7. At 45 and 65ºC, the k values dropped by 89 and 95%, respectively. The production of geopolymer, which fills the voids in the soil structure, the reason for the decrease in soil voids.

Additionally, the geopolymer may close the drainage channels, reducing the soil permeability. At 45 and 65ºC, the Cv values of the stabilized specimens increased by 164 and 91%, respectively. The Cc values decreased attributed to the increase in soil stiffness as a result of adding the geopolymer, which caused the compressibility to decrease, as indicated by (Jaditager & Sivakugan, 2018). Furthermore, (Azzam, 2014) indicated that the additional polymer molecules forms nanocomposites in the interassembling voids within the stabilized soil matrix. Cs decreased by 99 and 99.3% at temperatures of 45 and 65°C, respectively. This change in swelling behavior caused by increased the pozzolanic reaction due to the strong bonds formed by the geopolymer in the soil structure. The changes in consolidation parameters with addition geopolymer using (SH:SS=50:50) as an alkaline activator at different temperatures illustrated in Fig 8.

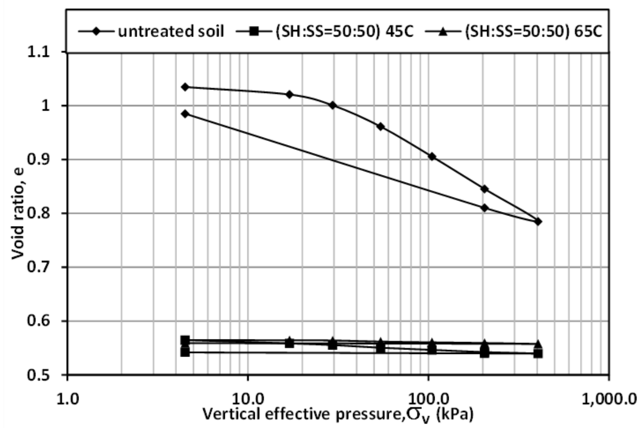

Fig. 7 Consolidation results of organic soil and soil- geopolymer blends using (SH:SS=50:50) at 8M

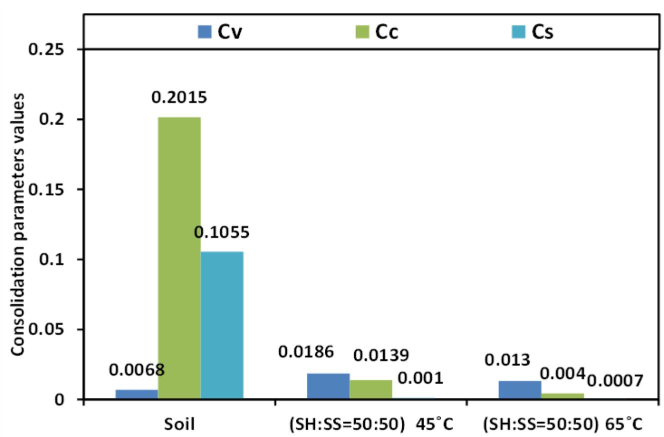

Fig. 8 Variation of consolidation parameters with (SH:SS=50:50) at different temperatures

4. CONCLUSIONS

The influence of fly ash and fly ash-based geopolymer on the compression properties of an organic soil was evaluated in this study. Compressibility, consolidation, and permeability characteristics were reported from the consolidation test conducted on the organic soil and the soil stabilized by fly ash and geopolymer. The following conclusions were reached based on the results of the test:

1- The consolidation properties of the organic soil were significantly improved by adding the geopolymer.
2- The consolidation test results showed that the FA-based geopolymer is effective in stabilizing of organic soils as it highly reduces the compressibility.
3- The Cv values of the soil with (SH:SS) of (100:0) and (50:50) increased by 502 and 164%, respectively.
4- The Cc, Cs, eo and k decreased by 98.16, 99, 45 and 94%, respectively for soil with (SH:SS) of (100:0),

and by 97 ,99.3, 45 and 95%, respectively for soil with (SH:SS) of (50:50).
5- The fly ash-based geopolymer bonding activity is responsible for improving in the compressibility and permeability properties of the organic soil that has been stabilized by geopolymers.

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