

Utilization of a vinyl based copolymer for improvement of a kaolin type clay

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Abstract. Geopolymers are obtained by use of alteration of chemical composition and crystal structures of different minerals. Use of geopolymer is an effective and environmental friendly solution in stabilization of clayey soil. The vinyl based copolymer is used as an agent as dust controller, highway soil stabilizer, asphalt admixture, concrete production, etc. In this study, strength of a clay is improved by use of a commercial geopolymer. In this regard, soil was amended with polymer ranging among 0 % to 4 %, by volume of dry soil. Unconfined compression and oedometer tests were carried out to evaluate the effects of temperature, initial water content, compaction energy on strength and compression properties of a clay soil – within an experimental framework. The results revealed that, temperature has a considerable effect on geopolymerization. Besides, under constant moisture content during curing, increasing geopolymer content and curing period causes a slight increase in strength of specimens.

1 Introduction

Geotechnical properties of fine grained soils are poor, and these materials are not preferred as a foundation, or a base/subbase material. Since clay soils are highly sensitive to total/differential settlements with the increase in water content of the soil, aiming to use water for hydration of binders, many agents including cement, lime, fly ash, blast furnace slag, etc are used for stabilization of these types of soils, which provide development in strength, compression and index characteristics. However, the problem here is that these materials are not environmental-friendly, as an example, during cement production, CO₂ emission, excessive use of natural resources and dust generation can be pronounced as the most important problems. Other types of pozzolanic stabilizers enlisted above are composed of hazardous compounds providing negative environmental impacts.

On the other hand, utilization of geopolymers for soil stabilization is increasing due to environmental concerns, and it is previously reported that alkali activation causes an increase in peak strength [1] and increasing geopolymer content causes increase in unconfined compressive strength of soil [2]. In essence, polycondensation of SiO₄ and alumina causes formation of geopolymer, which is defined as an inorganic aluminosilicate material. [3,4]. By use of metakaolin based geopolymer for stabilization, Zhang et al [5] report marked improvements in strength, ductility and stiffness of the soil. The authors also stress that the shrinkage of soil is lowered by geopolymer use.

The geopolymerization mechanism consists of two different processes. First one is the dissolution of

amorphous aluminosilicate materials by alkali hydroxide solution and/or alkaline silicate solution, leading to formation of reactive silica and alumina; and second one is the polycondensation of dissolved species into amorphous or semi-crystalline oligomers, resulting the formation of synthetic aluminosilicate materials [6,7]. Geopolymer can be synthesized among 25–80 °C [8]. It should be noted that geopolymers are strong and durable materials resisting on detrimental effects of heat, organic solvents and acids. Many industrial wastes and aluminosilicate materials can be used to synthesize geopolymers including metakaolin, fly ash, furnace slag, rice husk ash, etc [9-12]. A short literature survey also revealed that stabilization by polymers is an advantageous method to reduce the shrinkage potential [13-14]. A recent study focused on use of geopolymer and ordinary Portland cement for stabilization of a clayey soils [15]. The authors concluded that, use of geopolymer and ordinary portland cement are viable on dry and wet of optimum, respectively. Moreover, it is stressed that ductility of geopolymer-stabilized specimens are markedly higher than those stabilized with OPC.

Studies above reveal that use of geopolymer has considerable influence on strength, in this study, preliminary results of an experimental study concerning use of geopolymer for stabilization of clay soil was presented. Effects of compactive effort, geopolymer content and temperature was discussed.

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2 Materials and Methods

2.1 Materials

For a better evaluation of the effects of copolymer, a commercial type of kaolin is used. Firstly, index properties and optimum water content were obtained in accordance with ASTM 4318 and ASTM 698 standards, respectively clay. Index properties of kaolin clay were presented in Table 1.

Table 1. Index properties of kaolin

Value (%)	Kaolin
Liquid limit	56
Plastic limit	30
Plasticity index	26
Optimum water content	30

2.2 Unconfined compression tests

All specimens were prepared under Standard Proctor effort on the dry side of the optimum water content. Proctor tests at 0 % and 5% copolymer contents were carried out - no significant change in moisture content and maximum dry unit weight of soil was observed. Compaction curves of kaolin and kaolin with 5% copolymer content were presented in Figure 1.

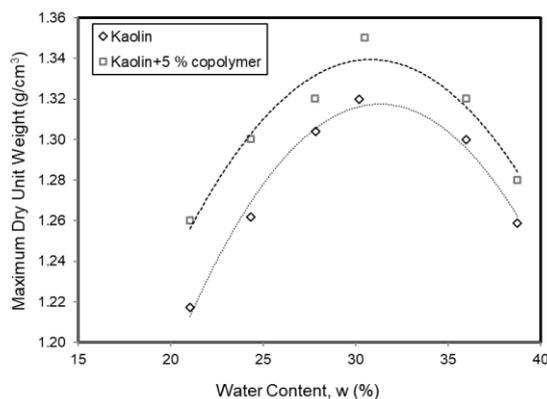


Fig. 1. Compaction curves of kaolin and kaolin stabilized with 5% of copolymer by weight.

Copolymer inclusion levels were decided as 1.25%, 2.5%, 3.75% and % 5 by dry weight of clay. The copolymer content was determined based on economic considerations (the cost of copolymer should well compete with alkaline stabilizers). Geopolymer used in this study is in liquid form. Therefore, in the specimen preparing procedure, firstly copolymer and water were mixed together and then mixed with the kaolin.

In the first step, the weight of the copolymer was calculated according to the dry weight of kaolin used in the mixture. The mixture water was heated to the desired temperature (room temperature, 40 °C or 100 °C) to observe the effect of temperature. Water and copolymer were mixed for 2 minutes by using a stirrer to prepare the liquid mixture. Then, liquid mixture was poured into the mixer bowl containing kaolin and mixed for 3 minutes until a homogenous mixture was obtained. The

mixture was placed on the moulds with 50 mm diameter and 100 mm height by applying the standard proctor energy. In order to apply standard proctor energy with nonstandard moulds, a special hammer (1/2 scale of standard proctor hammer) was used. This mould and special hammer were shown in Figure 2.

The specimens were covered with stretch wrap to prevent moisture loss and left in a curing room (at 25 °C temperature and 97% relative humidity) for 1 and 7 days after removal from the moulds. 28-day curing was not advised by the manufacturer; the strength gain is relatively fast. However, several strength test results which are not include here revealed 7 and 28 days strength of specimens are close to each other. Unconfined compression tests were conducted on the specimens at an axial deformation rate of 1.42 mm/min.



Fig. 2. Compaction mold and special hammer to apply standard proctor energy used in this study

2.3 Oedometer tests

For the oedometer testing the specimens, the mixture preparation procedure was same with that of unconfined compression test specimens. This time, the mixture was directly placed into the oedometer ring. The weight of mixture was obtained by using unit weight of soil at 25% water content–dry of optimum. This method was preferred to achieve minimum disturbance of specimen due to cutting or fitting. Similar to UCS specimens, the oedometer specimens were also cured under same condition. After curing, specimens with ring were placed into the oedometer and interlaid between two filter papers and porous stones. The pressure applied was among 11 and 176 kPa. Specimens are coded from SPG0 to SPG4, in which the number represent the geopolymer content by weight.

3 Results and Discussion

3.1. Effect of geopolymer content

Variation of the unconfined compressive strength of specimens containing four different ratios of geopolymer is presented in Figure 3. Due to decrease in void ratio and increase binder activity, a considerable increase in strength was observed which is also obtained in previous

studies [16]. In 1-day cured specimens prepared at 20 °C temperature, strength increases according to geopolymer content were observed. However, analyzing results of UCS tests of specimens prepared at 40 and 100 °C, it is understood that greater polymer content did not have a considerable influence or strength increase. This is evident for 1.25 and 5 % geopolymer contents. Generally, geopolymer mixtures are subjected to the heat treatment between 40- 100°C to maintain polymerization process. As mentioned in specimen preparation process, the specimens prepared at three different temperatures (room temperature, 40 and 100 °C) and cured in a 25 °C. Therefore, temperature differences between preparation and curing of the specimens probably affected on polymerization rate and strength gain. This phenomenon is more pronounced in the samples cured for 7-day.

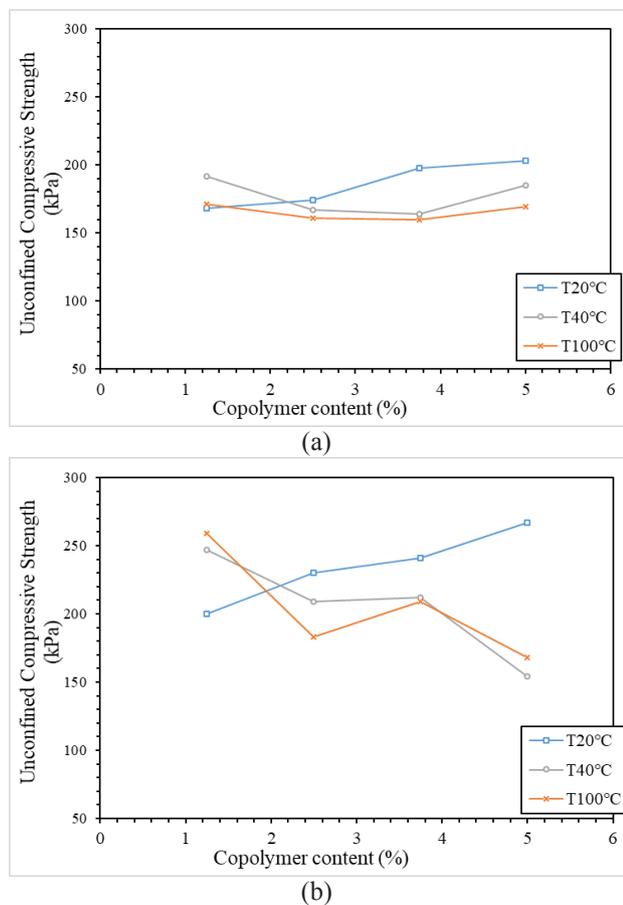


Fig. 3. Effect of geopolymer content on (a) 1-day cured (b) 7-day cured specimens

3.2. Effect of curing period

The variation of unconfined compressive strength of the specimens depending on the curing period is given in Figure 4. As expected, the unconfined compressive strength of specimens prepared at 20°C increased with increasing curing time. However, a different behaviour is observed for the specimens prepared at 40 and 100 °C. At these temperatures, the greater strength was obtained at lowest geopolymer contents. Moreover, rate of strength increases was similar for specimens of different geopolymer content at 40 °C. The increase in strength of

the specimen prepared at 100 °C decreases with increase in geopolymer content due to decreasing geopolymerization rate due to changing temperature between preparation and curing stages.

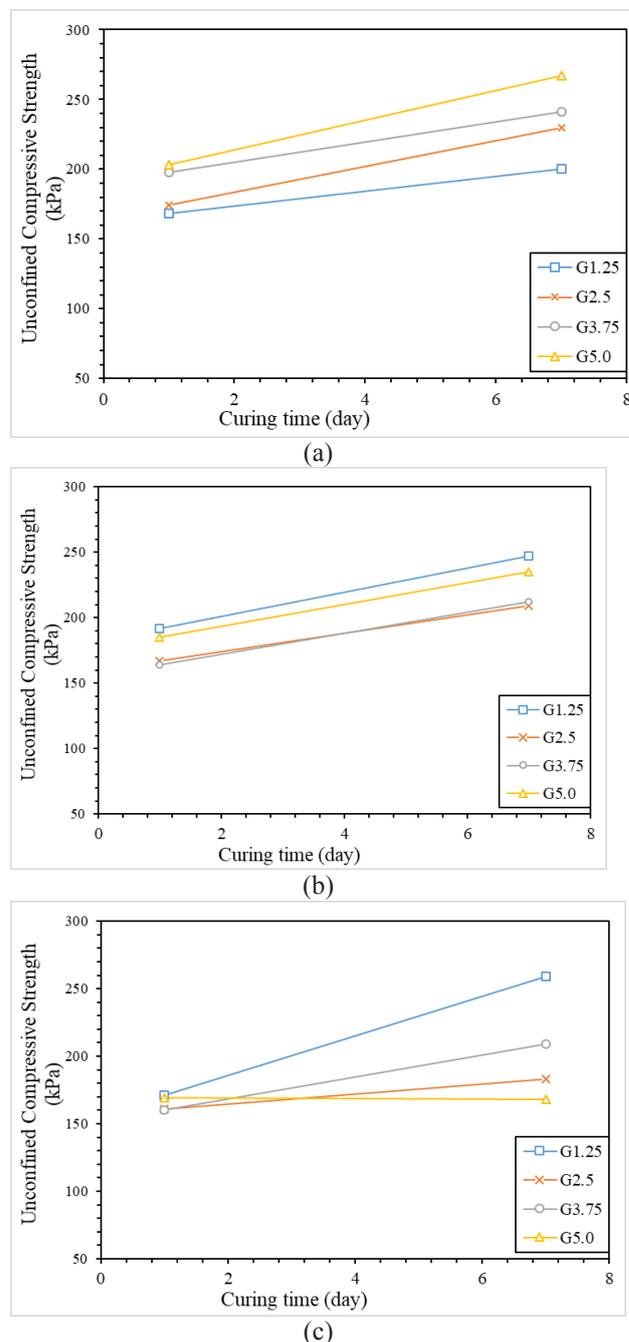


Fig. 4. Effect of geopolymer content on (a) 1-day cured (b) 7-day cured specimens

3.3 Compression properties

The results obtained from the oedometer tests are summarized in Table 2. As can be seen from the Table 2, a significant decrease in the compression indices of the specimens occurred with increasing geopolymer content. This phenomenon can be explained by two mechanisms: void-filling action and binding ability of copolymer enhances the compression properties.

Table 2. Compression properties of kaolin treated with geopolymer

	SPG0	SPG1	SPG2	SPG3	SPG4
C_c	0.55	0.41	0.32	0.24	0.11
e_0	0.91	0.90	0.88	0.87	0.85

3.4 Microstructural analysis

In order to investigate the microstructure of geopolymer treated clay SEM (Scanning electron microscope) analysis were conducted on kaolin and SPG3 and SPG5 specimens. As can be seen from Figure 5, kaolin itself has a platy structure, and no signs of binding gel formation was observed.

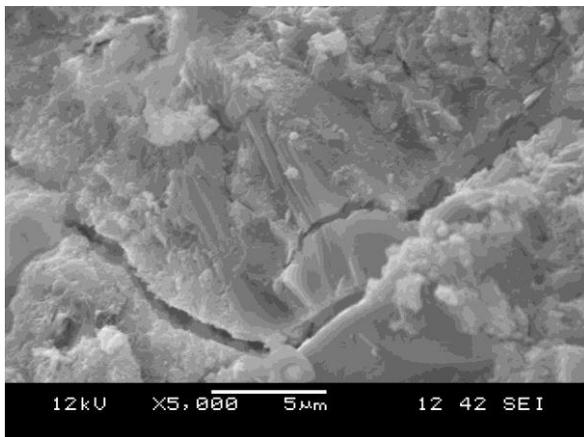


Fig. 5. SEM investigations on kaolin clay

Analyzing the structure observed in SPG3 and SPG5 specimens, as referred in Figures 5 to 6, solidification of platy structures is observed. From microphotos, it is hard to make an assessment of the amount of clustering of particles, however, it is bare that existence of geopolymer somehow affected on clustering of kaolin particles, which possible affected on strength increase. From Figures 6 and 7, it is also clear that, the structure of geopolymer treated kaolin has a complete inhomogeneous structure, and a considerable portion of the image contains unreacted materials.

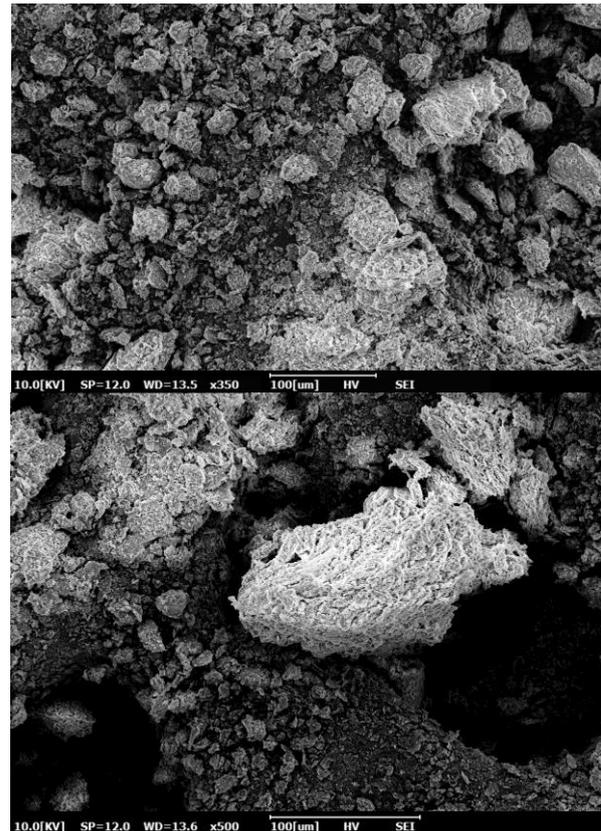


Fig. 6. SEM images on specimens of SPG3 specimens.

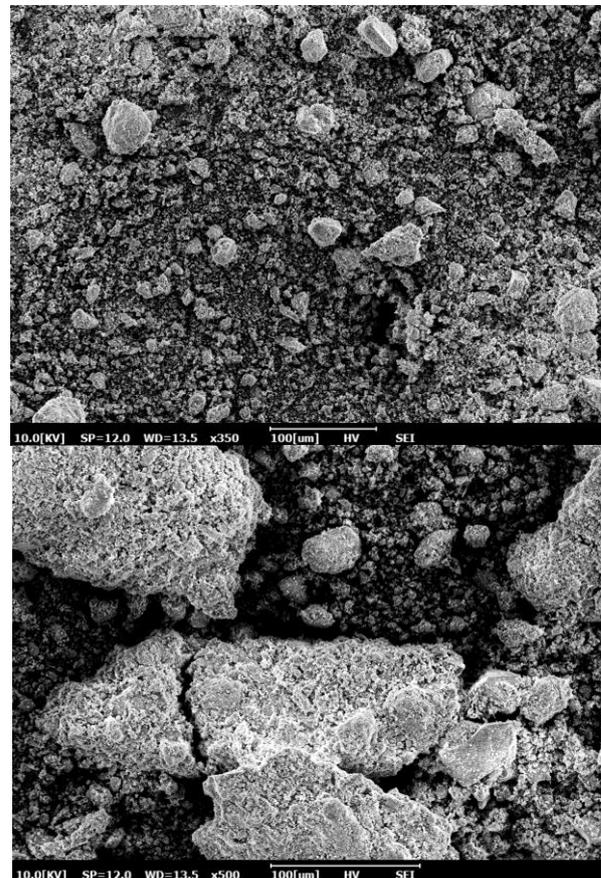


Fig. 7. SEM images on specimens of SPG5 specimens.

4. Conclusions

In this study, the effects of curing period, geopolymer content and temperature on geopolymer treated kaolin were investigated under certain curing conditions. Results of this study can be summarized as follows:

The temperature during preparation and curing stage is efficient on strength gain. Temperature must be constant during these stages in order to complete geopolymerization process, for ensuring a strength increase.

At constant temperature level, during preparation and curing, unconfined compressive strength of geopolymer treated specimens were increased with increasing geopolymer content.

Similarly, unconfined compressive strength of geopolymer treated specimens was increased with increasing curing period, if the temperature was constant.

Analyzing SEM images of three samples, it was observed that increasing geopolymer content resulted in solidification of kaolin, however, microphotos is far from being the evidence of increased amount of binding material formation.

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