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THE INFLUENCE OF INITIAL MATERIALS ON THE COMPRESSIVE STRENGTH OF GEOPOLYMER SOILS

HONG CHAN NGUYEN[1], ANH TUAN LE[2], and NAMSHIK AHN[1]

[1]*Dept of Architectural Engineering, Sejong University, Seoul, S. Korea*
[2]*Dept of Civil Engineering, Vietnam National University of Ho Chi Minh City, Ho Chi Minh City, Vietnam*

In recent years, geopolymers have received significant attention because they show environmental benefits, such as a reduction in the consumption of natural resources and a decrease in the net production of CO_2. In addition, as green material, soil has low carbon dioxide production emissions compared to other building materials. In this research, soil was combined with activator alkaline to produce hardening materials as geopolymer soils. An alkaline solution with sodium hydroxide, sodium silicate and fly ash was used. The influence of clay content on the geopolymer soils' compressive strength was investigated. The best strengths were obtained from 5% to 12% clay content. SEM photos were also taken from specimens to investigate the structure of geopolymer soils. When combined with soil and fly ash in geopolymerization, fly ash reacted to the alkali solution quickly. The relationships between many variables such as clay content, fly ash, alkaline solution, curing time, and curing temperature were investigated by using a statistical analysis program with over 100 initial parameters. These results also indicate that the use of soils in geopolymer soil should have been limited. Additionally, increasing the sodium silicate in the alkaline liquid affected the geopolymerization reaction significantly. However, the suitable Si on the alkaline solution and soil should be limited.

Keywords: Carbon dioxide emissions, Clay content, Fly ash, Compressive strength.

1 INTRODUCTION

Nowadays, a serious problem worldwide is global warming. The cement industry is seen as a primary factor for this phenomenon. Enormous efforts have been made throughout the world to reduce the use of Portland cement in order to address global warming issues. These efforts include the utilization of waste by-products and the development of alternative binders to Portland cement (Duxson 2005). Therefore, new potential and enviro-friendly cements are urgently required. In this case, geopolymeric material is a remarkable development as an alternative to Portland cement. Geopolymer concrete is a revolutionary development related to novel materials, resulting in low-cost and environmentally-friendly material as an alternative to the Portland cement (Van Jaarsveld 2003).

Geopolymer is the mineral polymers resulting from geochemistry, or geosynthesis since 1978. The materials can be produced by natural stone, soil, aggregate and hardening agents. The polymerization reaction involves a substantially fast chemical reaction in the production of Si-O-Si bonds (Hardjito 2005). In geopolymers, an activator agent combined with sodium hydroxide and sodium silicate leads to more mechanical strength, compared to the mixture combined with sodium hydroxide (Duxson 2005).

In this research, an alkaline solution with sodium hydroxide and sodium silicate was used. The alkaline-fly ash ratio and fly ash-soil ratio were 0.3, 0.4 and 0.45 respectively by weight. The mix proportions were fixed with a sodium hydroxide-sodium silicate ratio of 0.5, 1 and 2 respectively. The curing temperature ranged from 80^{o}C to 140^{o}C, and curing time was from 4 to 10 hours.

The used materials and test methods are described in section 2, the testing results and the properties of geopolymer soils are shown in section 3. It also includes some investigation by using SEM photos. From the testing result, the relationship among variables is given. Finally, section 4 will be conclusions.

2 MATERIALS AND METHODS

2.1 Materials

The materials used for making geopolymer soils specimens are soil, sand, fly ash alkaline liquids, and water.

2.1.1 *Soil and sand*

Clay contents were 31.05% in soil. Sand was added to control clay contents in mix proportions. 1.2 mm passing grid-dried sand with a specific gravity and bulk density of 2.45 and 1.34 g/cm^3 respectively was used. The physical and chemical properties of soil are shown in Table 1.

Table 1. Properties of soil.

Chemical properties	SiO_2	Al_2O_3	CaO	K_2O	MgO	P_2O_5	Fe_2O_3	TiO_2	LOI
Content (%)	76.22	10.512	0.193	2.373	-	0.076	4.057	0.756	5.8
Physical properties	Specific gravity (g/cm^3)			Liquid limit (%)			Plasticity index (%)		
Content (%)	2.315			35.3			18.1		

LOI: Loss of ignition

2.1.2 *Fly ash*

Fly ash is used as a contained amount of silica and alumina element. The chemical composition is presented in Table 2. The shape is spherical, as shown in Figure 1, which makes fly ash react to geopolymers easily.

Table 2. Chemical properties of fly ash.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O and Na_2O	MgO	SO_3	LOI
Content (%)	51.7	31.9	3.48	1.21	1.02	0.81	0.25	9.63

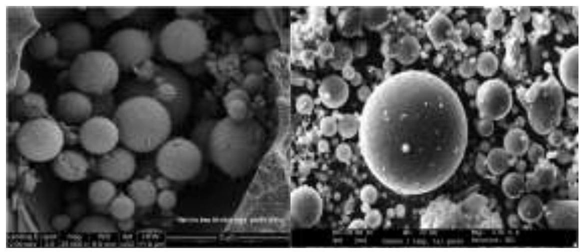

Figure 1. The structure of clay minerals, taken with SEM photo.

2.1.3 *Alkaline solution*

An alkaline agent combination of sodium silicate and sodium hydroxide solution were used. Sodium hydroxide of 98% purity was used to prepare the sodium hydroxide solution. Sodium silicate with a ratio SiO_2/Na_2O in weight percent was equal to 3.20. The sodium hydroxide was 12 moles.

2.2 Test Methods

The compressive strength of geopolymer soils specimens was measured by testing a cylinder of 100mm in diameter and 200mm in height with the ASTM C39/C 39M-99.

3 TEST RESULTS AND INVESTIGATIONS

3.1 Influence of Clay Content and Curing Temperature on the Compressive Strength of Geopolymer Soils

In Figure 2, the curing temperature ranged from 80^{o}C to 140^{o}C. With rising temperature, the strengths are increased.

And in Figure 2, the clay content was increased by substituting it for the sand in soil. The compressive strength decreased with increasing clay contents. Between 4.79% to 12.43% clay content, the best strengths are obtained. It can be known that the strength of geopolymer soil is dependent on the content of Si on soil and alkaline solution. Therefore, Si for geopolymerization should be limited.

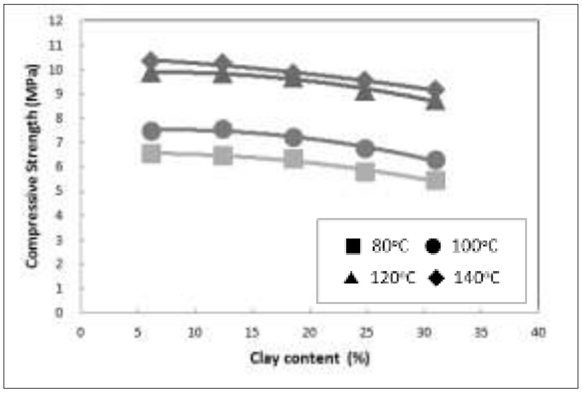

Figure 2. Behavior between clay and temperature curing.

3.2 Investigations with SEM Photos

SEM photos were taken from specimens to show the structure of geopolymer soils, and to explain the influence of fly ash on the compressive strength.

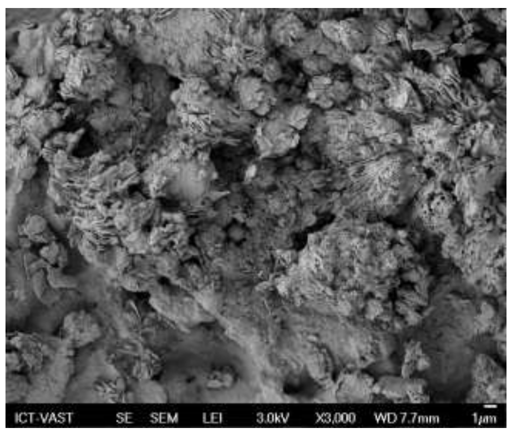

Figure 3. SEM surface photos of specimen.

Figure 3 is taken from the specimens after tests. The geopolymer soil's surface has fewer pores, and the minerals of soil have been arranged in a specific order. It is totally different from the structure of clay minerals in Figure 1. It also means the geopolymerization reaction was almost complete. While geopolymer soil takes a long time to react, our specimens had almost hardened after 10 hours of curing. The reason for that is when we combined soil and fly ash in geopolymerization, the fly ash reacted to the alkali solution quickly. These reactions created many alkali cations, and these cations promote soil to react faster.

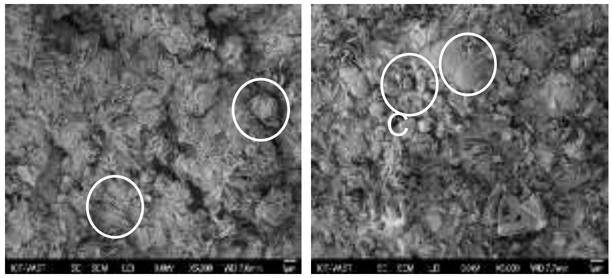

Figure 4. The different kinds of crystal structure of geopolymer soils.

Figure 4 shows the crystal structure created after geopolymerizing by the clay and fly ash. Inside, the crystal structure includes incomplete hardening crystals (A), complete hardened crystals covering zeolite (B), separated zeolite (C), and non-reaction clay (D). We also see the zeolites were hardened from the surface, and after that, spread inside.

On a different surface, Figure 5 shows the hydrosodalite crystal clearly. Here, the geopolymerization reaction was incomplete and the connections inside the geopolymer were incomplete. It can be known that the curing method in the oven, the constant heating time, and the curing time in air temperature was not optimal. Also, the mixing processes were heterogeneous, so the alkali solution was not dispensed equally.

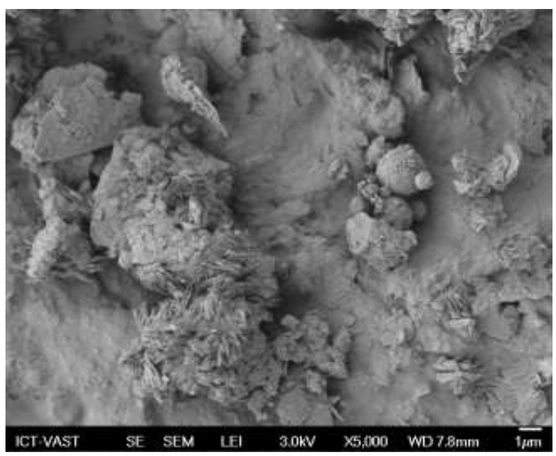

Figure 5. Crystal structure inside geopolymer soils.

3.3 The Relationship between Variables: Lay Content, Fly Ash, Alkali Solution, Curing Time, Curing Temperature and Compressive Strength

From the testing data, the relationship among the variables was obtained by the SPSS statistical program. In Table 3, a minus appears when two variables have opposing influences. For example, between clay content and compressive strength, when the percent of clay increases the compressive strength will decrease. Also, according to Table 3, clay content has an opposing influence to compressive strength, which means the use of soils in geopolymer soil should have been limited.

Table 3. The relationship among variables.

	Strength	Clay	Fly ash – Alkali solution	S. Hydroxide – S. Silicate	Curing Time	Curing Temp.
Strength	1					
Clay	-0.45	1				
Fly ash – Alkali solution	0.378	0.459	1			
S. Hydroxide - S. Silicate	-0.006	0.112	-	1		
Curing Time	0.585	-	-	-	1	
Curing Temp.	0.373	-	-	-	-	1

4 CONCLUSION

The paper presented the influence of many variables on the compressive strength of fly ash-based geopolymer soil. Increasing the sodium silicate in the alkaline liquid had a significant effect on the geopolymerization reaction. When the ratio of sodium hydroxide and sodium silicate increased from 0.5 to 2, the experimental results gave optimum values at a ratio of 1:1. Fly ash strongly affected the compressive strength of geopolymer soils. However, the suitable Si on alkaline solution and soil can be limited.

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