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MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE WITH MINERAL ADMIXTURES

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Concrete has contributed to the development of modern architectural culture, but the cement as an adhesive agent for concrete produces large amounts of carbon dioxide emissions into the air during the manufacturing process. This study researches the practical use of structure, through the verification of structural stability, for geopolymer concrete. This is part of the development of core technology for greenhouse gas emission reduction by reducing energy consumption in construction, an industry that occupies 25% of the total energy consumption in South Korea. According to the experimental results of chemical reaction (i.e., acid reaction, sulfate resistance reaction and corrosion caused by sodium chloride) of fly ash-based geopolymer concrete, the theory and SEM analysis demonstrated that geopolymer concrete was acid resistant, sulfate resistant, and resistant to corrosion caused by sodium chloride. The basic properties were understood through qualitative analysis of a geopolymer concrete specimen using SEM, and through a study on the practical use of structure by verifying structural stability for geopolymer concrete, as part of development of technology. After future experiments and tests, the best geopolymer concrete ratio and curing method will provide a guideline.

Keywords: Fly ash, SEM, Corrosion rate, Sulfate resistance, Acid resistance.

1 INTRODUCTION

Concrete has greatly contributed to the development of modern architectural culture as a major construction material, but the cement as an adhesive agent for concrete consumes enormous energy (around 1300^{o}C in the process of plasticity), and releases large amounts of carbon dioxide emissions into the air during the manufacturing process. One kilogram of cement produces about 950 grams of carbon dioxide (CO_2), which occupies 7% in total worldwide, and the amount of emissions tends to increase by 3% every year (Bogue 1947).

Therefore, there is much research on the development of eco-friendly concrete worldwide. Among those studies, the most active is on the replacement of cement used for concrete, in order to reduce carbon dioxide emissions when manufacturing cement into other materials (Won 2011). As part of this study, fly ash, blast furnace slag, and other minerals as materials to replace cement are activated by alkali to act as a binder, called "geopolymer" (Khoa 2012).

Accordingly, this research studied the practical use of structure through the verification of structural stability for geopolymer concrete. This was done as part of development of core technology for greenhouse gas emission reduction by reducing energy consumption in construction, occupying 25% of total energy consumption in South Korea.

2 EXPERIMENTS

2.1 Materials

2.1.1 *Fly ash*

In this experiment, low calcium fly ash (ASTM class F) was used.

2.1.2 *Alkaline liquid*

An alkaline solution, the fundamental ingredient in geopolymer, is made with a combination of sodium hydroxide solution (90%) and sodium silicate solution (36-38%).

2.1.3 *Aggregates*

The aggregate is partially composed of 40% (20 mm), 30% (10 mm) and 30% (fine aggregate) by using 10 mm, 20 mm the coarse aggregate and fine aggregate saturated surface dry aggregate. The specific gravity of coarse and fine aggregate is 2700kg/m^3 and 2650kg/m^3 respectively.

2.2 Mix Proportions

Three mixing ratios of geopolymer concrete used in this study are shown in Table 1. Sodium hydroxide (NaOH) was fixed at 8M (Molars), and the ratio of water, glass, and NaOH was 0.4, 1.2 and 2.5 respectively. Also, the ratio of alkaline solution (water, glass, and NaOH) and fly ash was 0.34 and 0.44 respectively.

3 Test Results and Investigation

3.1 Corrosion Rate with NaCl Liquids

A series of tests were performed to investigate the corrosion rate of fly ash-based geopolymer concrete. The test specimens were immersed in 1M, 2M and 4M NaCl liquids. The corrosion rate was evaluated based on the change in compressive strength, and all specimens were heat-cured at 80^{o}C for 10 hours. Table 2 shows the results of the test for mixture proportion GF3.

Table 1. Mixing ratio by weight.

<table>
<tr><th rowspan="2">Mix proportion</th><th colspan="3">Aggregate</th><th rowspan="2">Fly ash (kg)</th><th rowspan="2">Sodium hydroxide solution (NaOH) (kg)</th><th rowspan="2">Water, glass (kg)</th><th rowspan="2">Water (kg)</th></tr>
<tr><th>20mm (kg)</th><th>10mm (kg)</th><th>Fine (kg)</th></tr>
<tr><td>GF1</td><td rowspan="3">375</td><td rowspan="3">450</td><td rowspan="3">675</td><td rowspan="3">500</td><td>100</td><td>120</td><td>131</td></tr>
<tr><td>GF2</td><td>48</td><td>120</td><td>156</td></tr>
<tr><td>GF3</td><td>120</td><td>48</td><td>152</td></tr>
</table>

Table 2. Compressive strength according to exposure time.

GF3	Compressive strength (MPa)		
NaCl / Exposure time (week)	1M	2M	4M
0	10.9	10.9	10.9
4	11.8	11.9	12.1
8	11.6	11.8	12.1

The test data presented in Table 2 show the relationship between the exposure time of specimens immersed into NaCl liquids and the compressive strength of geopolymer concrete. In Table 2, the compressive strength fluctuates slightly when the exposure time changes from 0 to 8 weeks. The fluctuation is around 11%. In general, up to 8 weeks, the corrosion rate of geopolymer concrete is inappreciable. The reason is that the combination of high alkalinity and dissolved silicates tend to stabilize. According to the SEM photos, the structure of geopolymer concrete is stable and no mechanism exists outside and inside the specimens.

3.2 Acid Resistance

A series of tests were performed to investigate the acid resistance of fly ash-based geopolymer concrete. The test specimens were immersed in 1M, 2M and 4M HCl liquids. The acid resistance was evaluated based on the change in compressive strength, and all specimens were heat-cured at 80°C for 10 hours. Figure 1 shows the results of test for mixture proportion GF2.

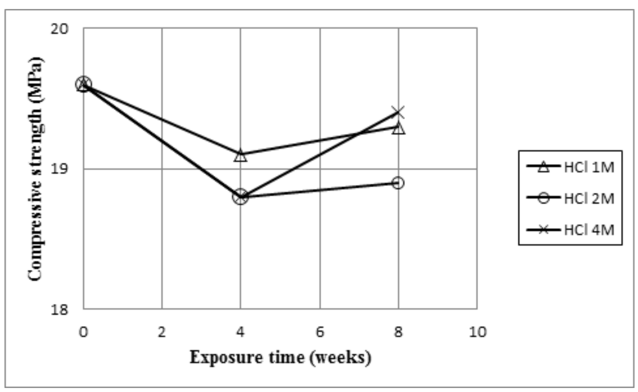

Figure 1. Compressive strength according to acid resistance (Khoa et al. 2013).

When the exposure time increases from 0 to 4 weeks, the compressive strengths of all specimens decrease regardless of the concentration of HCl 1M, 2M and 4M. However, as the time increases to 8 weeks, the compressive strength slightly increases.

It can be explained that one of components of concrete is a prevention role with regards to the penetration of acid. This component could be water glass or sodium silicate. At the Fukushima Daiichi nuclear power plant in Japan in April 2011, it was used as a chemical injected into the ground in order to harden it, thereby preventing leakage of highly radioactive water. As a result, the geopolymer concrete has a good acid resistance.

Also, SEM image was used for the experiment. 2a and 2b were taken outside the specimen, and Figure 2c and 2d were taken inside the concrete. Picture 2a and 2b show definite differences from Figure 2c and 2d. Figure 2a and 2b show a significant number of sticks, while there are no sticks but a simple sphere in Figure2c and 2d. This stick indicates sodium chloride obtained from chemical reaction:

$$NaOH + HCl \rightarrow NaCl + H_2O \qquad (1)$$

NaOH is a substance left by polycondensation reaction. The formation of NaCl means to prove the tolerance of geopolymer concrete, because it exists between sodium hydroxide and hydrochloric acid—that is, in the middle of them. NaOH weakens corrosion from HCI, meaning this is a good reaction to the acid resistance of geopolymer concrete (Khoa et al. 2013).

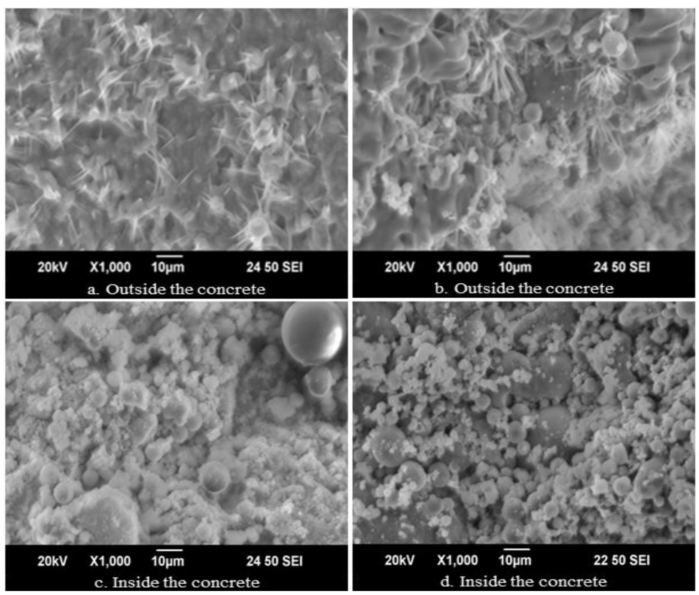

Figure 2. Analysis for the SEM photo (Acid resistance) (Khoa et al. 2013).

3.3 Sulfate Resistance

Sulfate resistance of fly ash-based geopolymer concrete was studied by soaking concrete in various concentrations of sodium sulfate solution for 1 and 2 months. The sulfate resistance of geopolymer concrete was evaluated based on changes in compressive strength after exposure. Mixture proportion GF1 was chosen for this test.

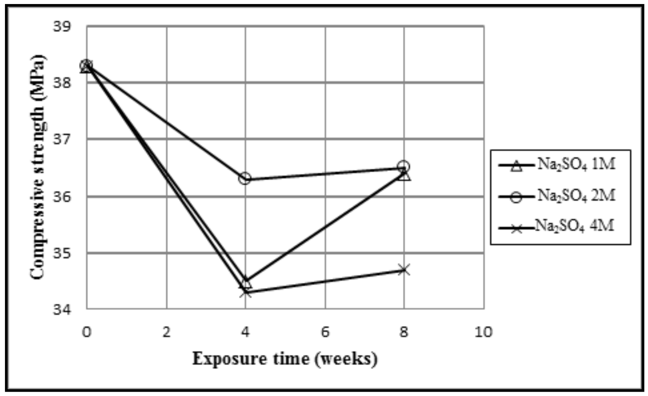

Figure 3. Compressive strength according to exposure time.

There are two parts in Figure 3. First, when the exposure time increases from 0 to 4 weeks the compressive strengths of all specimens decrease regardless of the concentration of Na_2SO_4 1M, 2M and 4M. However, as the time increases to 8 weeks, the compressive strength slightly increases.

For the experimental test of concrete, when the change of compressive strength is less than 2%, the effect of that factor would be ignored. This also means there are no effects of sulfate factor to geopolymer concrete after 4 weeks.

Because there is generally no gypsum or ettringite formation in the main products of geopolymerization, there is no mechanism of sulfate attack in heat-cured low calcium fly ash-based geopolymer. Furthermore, according to Figure 4, photos taken of the specimens after the test indicate that there are only spheres. This suggests that no mechanism between concrete and sulfate factor or geopolymer concrete is notable with sodium sulfate.

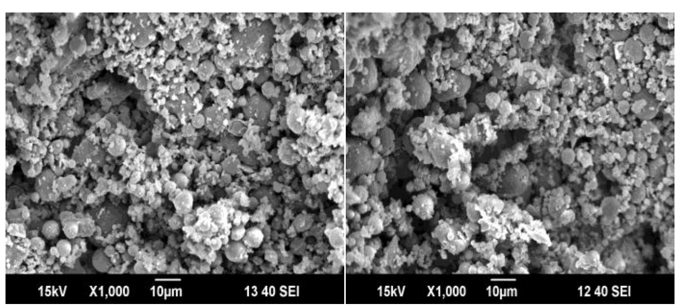

Figure 4. Analysis for the SEM photo (Sulfate resistance).

4 CONCLUSION

This study aims to conduct qualitative analysis of a geopolymer concrete specimen using SEM, and to comprehend basic properties. The following results were extracted from the consideration of the experimental result of fly ash-based geopolymer concrete.

(1) According to the experimental result of chemical reaction (acid reaction, sulfate-resistance reaction, and corrosion caused by sodium chloride) of fly ash-based

geopolymer concrete, the theory and SEM analysis demonstrated that geopolymer concrete was acid resistant, sulfate resistant, and resistant to corrosion caused by sodium chloride.

(2) When the exposure time increases from 0 to 4 weeks, the compressive strengths of all specimens decrease regardless of the concentration of HCl 1M, 2M and 4M. The formation of NaCl means to prove the tolerance of geopolymer concrete, because it exists between sodium hydroxide and hydrochloric acid, that is, in the middle of them. NaOH weakens the attack from HCI, and this is a good reaction to the acid resistance of geopolymer concrete.

(3) When the exposure time increases from 0 to 4 weeks the compressive strengths of all specimens decrease regardless of the concentration of Na_2SO_4 1M, 2M and 4M. Because there is generally no gypsum or ettringite formation in the main products of geopolymerization, there is no mechanism of sulfate attack in heat-cured low-calcium fly ash-based geopolymer.

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