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The Effect of High Temperatures on the Mechanical and Microstructural Properties of Geopolymer Concrete

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ABSTRACT: The concrete structures used in various applications including iron and aluminum foundries and hazardous waste disposal lose performance when subjected to heat. As aluminum silicate materials however, geopolymers behave in a much more stable manner than normal concrete when exposed to high temperatures. Calcium silicate hydrate (C-S-H) and calcium-aluminum-silicate-hydrate nanostructures, which are products of the geopolymerization process that strengthens geopolymer concrete, undergo many changes when exposed to heat. The study therefore investigates the effect of high temperatures on geopolymer concrete's strength parameters from a microstructural perspective and according to nanostructural changes of C-S-H and C-A-S-H. In this regard, about 300 samples were cured in the humidity bath for 1, 3, 7, 14, and 28 days. All samples were then put in of 25, 50, 100, 200, 300, 500, 700, and 900°C temperatures for 2 hours. Length and weight change percentages, compressive strength, and ultrasonic and cracking behavior tests were performed on all samples. Images from the scanning electron microscope (SEM) and the energy-dispersive X-ray (EDX) analysis were also used to evaluate the microstructural behavior of samples in various temperatures. According to the results, sample weight and length changes and compressive strength depended on the behavioral nature of C-S-H and C-A-S-H nanostructures. Nanostructural analysis of C-A-S-H points to high temperatures reducing compressive strength and weight as well as causing more cracks. The compressive strength of the 28 samples in 900°C temperature also decreased from 604 kg/cm2 to 75 kg/cm2. The complete disintegration of the C-S-H and C-A-S-H nanostructures and the decomposition of water from the chemical bond and the OH hydroxyl group are the reasons for this reduction.

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1. INTRODUCTION

When the concrete is exposed to fire or excessive heat, its bearing capacity may be significantly reduced due to reduced strength and hardness [1]. Structural durability against high heat is defined as one of the key building safety factors [2, 3]. High heat also affects the microstructure of concrete. Normal concrete does not exhibit stable behavior due to extensive physical and chemical changes at high temperature and hydroxide decomposition and consequently its strength decreases. At the temperature range of 100 °C to 300 °C, the water molecules of C-S-H nanostructure are going out, and this nanostructure is destroyed and decomposed as the temperature rises to 900 °C. In recent years, geopolymers have received more attention than Portland cement due to their chemical stability, high heat resistance and low shrinkage [4].

Although extensive studies have been performed on the effect of temperature on geopolymer concrete strength, no comprehensive study has been performed from the perspective of changes in calcium aluminosilicate hydrate (C-A-S-H) and calcium silicate hydrate (C-S-H) nanostructures and its effect on compressive strength changes. Consideringly, the purpose of this study was to investigate the behavior of nanostructures in concrete compositions and their role in the mechanical and resistive parameters of geopolymer concrete.

2. MATERIALS AND METHODS

In this research, slag is used as one of the raw materials of geopolymer concrete. The purpose of this selection was to investigate the physical and chemical changes of geopolymer concrete containing slag at high temperatures. Geopolymer cement is produced from recycled raw materials and scrap of the iron smelting industry. Most of the experiments performed in this study are based on the ASTM standard [5]. The chemical properties of the geopolymer cement were determined by XRF experiment and have presented in Table (1). Geopolymer concrete is made by mixing geopolymer cement with silicate and hydroxide activators. Geopolymer concrete grading for clay and sand is considered according to ASTM C136-96 and ASTM C136, respectively [5]. Geopolymer concrete was manufactured according to ASTM C192 / 192M-2. The mixing scheme of the prepared samples is presented in Table (2).

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Table 1. Chemical properties of the geopolymer cement

Type	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*CaO*	*MgO*	*K_2O*	*Na_2O*	*Cl*	*MnO*
Geopolymer	*35.7*	*11.2*	*1.2*	*37*	*11.0*	*0.68*	*0.6*	*0.2*	*1.58*

Table 2. Geopolymer concrete mixing scheme

Constituents	*Cement (kg/m^3)*	*Water:Cement (kg/m^3)*	*NaOH solution (kg/m^3)*	*$NaSio_4$ solution (kg/m^3)*	*Gravel (kg/m^3)*	*Sand (kg/m^3)*
Geopolymer	*400*	*0.32*	*38.13*	*121.58*	*984.9*	*656.6*

According to ASTM C31 standard, concrete made by pouring into the mold in 3 layers with 25 rod strikes (for compression) [5]. After molding and curing duration, samples of different ages are brought out from the water pond for testing. They are then placed in an electric oven at 25 to 900 C for 2 hours. Subsequently, compressive strength tests were performed on the specimens according to ASTM C39.

3. RESULTS AND DISCUSSION

3.1. Examination of compressive strength changes

Fig. (1) shows the curves of compressive strength changes of 1, 3, 7, 14 and 28 days aged geopolymer concrete samples at temperatures of 25 to 900 °C. The compressive strength of the specimens cured at room temperature after 1, 3 and 28 days were 312 kg/cm², 336 kg/cm² and 604 kg/cm², respectively. The high-temperature compressive strength depends on the size of the specimens. There is also a significant difference between the surface and the center of the sample and the heat conductivity decreases with increasing sample size. Therefore, in this study, the compressive strength test was performed on 5×5×5 cm specimens.

It was observed that by rising the temperature from 50 to 200 °C, the compressive strength is increased. By evaporation of superficial water and drying of samples, the compressive strength increases due to the internal vapor stresses being offset by water vapor pressure. At 100 °C, the compressive strength of the specimens with 1, 3, 7, 14 and 28 days lifetime are 324 kg/cm², 412 kg/cm², 488 kg/cm², 520 kg/cm² and 556 kg/cm², respectively. By rising the temperature to more than 100 °C, the internal water of the geopolymer structure is evaporated and the vapor pressure is constantly increasing. As the temperature rises to 200 C, the vapor pressure in the geopolymer structure increases continuously. Compressive strength of 1, 3 and 7 day aged samples at this temperature has increased by about 5.12, 26.19 and 5.6%. But with age increasing, the compressive strength decreased. The 14 and 28-day aged samples had a 6% decrease in compressive strength at 200 °C.

According to the results shown in Fig. 1, the compressive strength of the specimens decreases with increasing temperature. At the temperature of 500 °C, the compressive

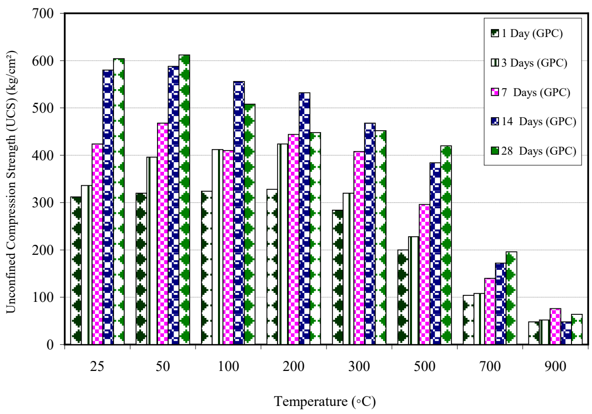

Fig. 1. The curve of compressive strength variations of geopolymer concrete at different temperatures

strength of 7, 14 and 28 days aged samples decreased by 36.2%, 33.79%, and 30.46%, respectively. In fact, due to the structural changes of alumino silicate and its conversion to crystalline structure, the formation of cracks and cavities has reduced the compressive strength. The dihydroxylation process, which is started at 500 °C, also has an effect on reducing compressive strength. Also, at a temperature of 700 °C, the compressive strength decreases as 70.34% and 67.54% in 14 and 28-day aged samples, respectively.

Finally, at 900 °C, the compressive strength of 1 and 28 days aged samples was 50 kg / cm2 and 75 kg / cm2, respectively. In fact, high temperatures completely destroy the C-A-S-H and C-S-H nanostructures. At 700 °C and 900 °C, the geopolymer structure is transformed into a low-strength porous ceramic structure. Therefore, the porous and semi-stable ceramic (glass) structure is obviously the main cause of the decrease in compressive strength.

4. CONCLUSION

According to the data of this laboratory study, the most important results are as follows.

1. With increasing temperature up to 200 °C, the vapor pressure in the geopolymer structure is increasing continuously. For a short time, water can easily evaporate, thanks to the deficiency and incompleteness of geopolymer structure. But with increasing age, as the geopolymer structure becomes denser with increasing the curing age and its permeability decreases, the water vapor pressure reaches its maximum value and the dense geopolymer structure is not able to withstand high thermal stress. As a result, the compressive strength is reduced, reaching about 6%.

2. At the temperatures over than 700 °C, stable crystalline compounds and structures are observed. On the other hand, it is seen that the pores and cracks increase in the geopolymer structure. At 900 °C, a highly porous ceramic structure is formed so that the volume increases and the compressive strength decreases by 89% (It lowers to 75 kg/cm2). In fact, at this temperature, the geopolymer structure has become crystalline.

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