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Effect of mix proportioning on the properties of pervious fly ash based geopolymer concrete

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Abstract: Thermal power plants in the Philippines generate every year millions of tons of coal fly ash and the disposal of such waste has been a burden to the generator. Therefore, the utilization of coal fly ash for various applications has gained the interest of the researchers. In this study, coal fly ash based geopolymer was explored as an alternative to Portland cement to produce pervious concrete. Geopolymer is an inorganic polymer with three dimensional structure which is formed from reacting silica-rich and alumina-rich materials in alkaline liquid. On the other hand, pervious concrete is becoming popular for Low Impact Development (LID) of infrastructure such as urban pavement which can be effective in treating contaminated water by removing the undesirable pollutants. This work explored the use of full factorial design of experiment for systematic mix proportioning of the raw materials. Then evaluating the effect of proportion on compressive strength of pervious coal fly ash based geopolymer concrete. Experimental factors including fly ash/coarse aggregate (FA/CA) ratio, coarse aggregate (CA) size, alkaline liquid/fly ash (AL/FA) ratio, and sodium hydroxide (NaOH) molarity were employed. Compressive strength was performed and considered as the response variable of the statistic design of experiment.

Key Words: geopolymer; pervious concrete; fly ash; compressive strength

I. INTRODUCTION

Pervious concrete (PC) a construction material which differs from conventional concrete because it contains small or no fine aggregates. This provides higher void content (15% to 25%) than conventional concrete to increase the rate of infiltration (Halim, 2018). These voids allow PC to have numerous benefits including water permeability, water purification, acoustic absorption, storm water reduction, etc. (The United States Environmental Protection Agency, 2014). However, this PC still uses Ordinary Portland cement (OPC) traditionally as a binder. Amongst all industrial processes, OPC production generates the most massive amount of carbon dioxide (CO_2) which represents around 5% of the global CO_2 emissions (Jo et al. 2015). Hence, finding an alternative material to substitute OPC is inevitable.

Because of that, the term of geopolymers appeared for OPC replacement which was first discovered by Davidovits back in the 1970s (Davidovits, 1991). Basically, geopolymers are three dimensional structures of inorganic polymer which have properties quite similar to OPC. In addition, the raw materials used for synthesis of geopolymers are derived from a variety of by-products and wastes (e.g. coal fly ash). Coal fly ash (CFA) has been the most widely utilized aluminosilicate material in the production of geopolymers.

The mix proportions of PC which typically comprised combination of OPC, CFA, and gravel have been produced in recent years. However, its properties are not well-known, and minimum information is available about pervious fly ash based geopolymer concrete. Thus, this paper explores the use of statistical design of experiment for a systematic mix proportion of the raw materials to evaluate the effect of on compressive strength proportion of PGC.

II. METHODOLOGY

2.1 Materials and Chemical

CFA was supplied by a power station in the Northern Philippines. Coarse aggregates used were gravels from Rizal, Luzon. CFA and gravels were then sieved in a set of American standard sieves to evaluate the particle size distribution of solid sources. Technical grade of sodium silicate with composition 44% SiO_2, sodium hydroxide micropearls with 99% purity were used.

2.2 Characterization of Raw Materials

Elemental analysis of raw material was conducted using techniques such as X-ray fluorescence dispersive (XRF).

2.3 Pervious geopolymer concrete preparation

In this work, the mix proportion of PGC includes CFA, gravels, and alkaline solution. Initially, CFA was mixed alkaline activator (i.e. anhydrous sodium hydroxide, sodium metasilicate) in a mechanical mixer for 5 minutes. Then gravels were added, continuously mixed for 5 minutes. The amount of solid components were measured for each designed PGC. The FA/CA ratio, AL/FA ratio were varied with the purpose of finding the optimal formula of PGC. Finally, the paste was poured into cylinder molds (Ø100 x 200 mm). Prior, the PVC molds must be greased for de-molding easily. Standard 200mm cylindrical molds were filled in 2 layers each. The mixture was pressed down tightly 10 times after placing each layer. All sediments were wrapped in plastic ziplock bags to minimize moisture loss before being cured for 24h at 80^{o}C in an oven.

PGC samples were prepared in a four-factor, two-level (2^4) full factorial design as shown in **Table 1**. Therein, four factors consist of fly ash/coarse aggregate (FA/CA) ratio, coarse aggregate (CA) size, alkaline liquid/fly ash (AL/FA) ratio, sodium hydroxide (NaOH) molarity.

Table 1. Full factorial design of pervious geopolymer concrete preparation

Factors	Levels		Reference
	Low	High	
FA/CA ratio	1:9	1:6	Arafa et al. (2017)
CA size (mm)	5-10	14-20	Arafa et al. (2017)
AL/FA ratio	0.45	0.65	Tho-In et al. (2012)
NaOH Molarity (M)	10	15	Zaetang et al. (2015)

2.4 Compressive Strength Test

In prior, the exposure area was measured for the compressive strength test. Then, Φ100 x 200 mm cylindrical sample after 28 curing days will be placed on the holder put in the specimen chamber of UTM machine. Notably, both of the surfaces exposed to the force should be smooth to avoid high deviation during the testing process. The speed of loading was adjusted at 2.4 kN per minute.

III. RESULTS AND DISCUSSION

3.1 Characterization of Raw Materials

Table 2. Chemical composition of raw materials

Chemical Compound	Fly Ash (%wt.)
SiO_2	24.65
Fe_2O_3	44.63
Al_2O_3	8.55
CaO	16.04
TiO_2	1.32
K_2O	1.18
SO_3	1.63

The elemental analysis of fly ash in oxides form, conducted by ITDI-DOST as shown in **Table 2** are composed of oxides of silica (SiO_2), iron (Fe_2O_3), aluminum (Al_2O_3), and calcium (CaO). Fly ash is classified as ASTM class F fly ash or low-calcium fly ash considering that the total SiO_2, Al_2O_3, and Fe_2O_3 is more than 70%. The presence of alumina and silica in fly ash is an indication that it can be used as geopolymer precursor.

3.2 Compressive Strength Property

Figure 1 below shows the compressive strength after curing 28 days of pervious geopolymer concrete at different mix proportion of CFA, CA size, and alkali liquid.

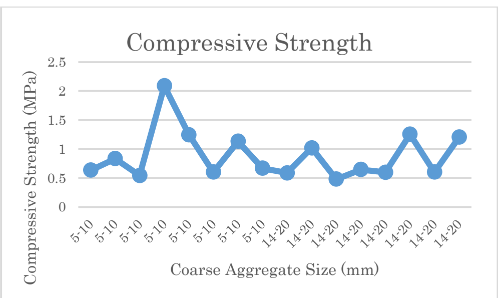

Figure 1. Compressive strength of PGC at different mix proportion.

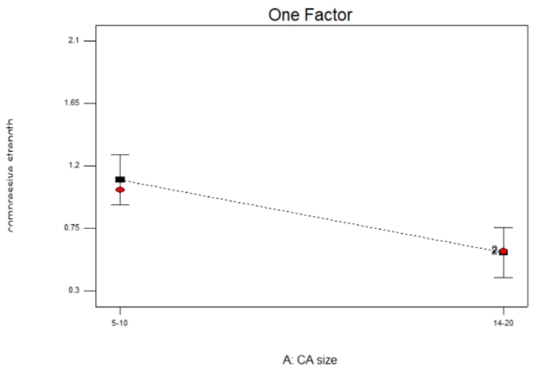

Figure 2. Relationship between compressive strength and CA size.

The compressive strength of PGC was ranged from a minimum 0.331 MPa to a maximum 2.089 MPa. The samples with CA size of 5-10 mm, FA/CA ratio of 1:6, AL/FA ratio of 0.65, and NaOH concentration of 15M were the highest values of compressive strength among other runs. The samples with CA size of 14-20 mm, FA/CA ratio of 1:6, AL/FA ratio of 0.45, and NaOH concentration of 10M were the lowest values of compressive strength among other runs. Moreover, all samples with CA size of 14-20 mm showed significantly lower values of compressive strength than all runs with CA size of 5-10 mm as shown in **Figure 2**.

This may be due to the CA size increases, the bulk density of CA decreases, and the porosity of PGC is increased. Based on that, the compressive strength is decreased (Arafa et al., 2017).

The measured compressive strength values were response to the four factors. Among these factors, only CA size was detected to be significant statistically based on the analysis of variance (p-value < 0.05). The measured R^2 model was 0.5120 (Adj $R^2 = 0.4772$). The R^2 value was not high due to noise that can be explained by the pore roughness, the pore size distribution from the CA (Tho-In et al., 2012). Therefore, these reasons effected to the compressive strength of PGC.

IV. CONCLUSION

This study has developed the pervious geopolymer concrete by mixing coal fly ash and alkaline liquid (i.e. anhydrous sodium hydroxide, sodium metasilicate). The following finding can be drawn:

- The mix proportion with CA size of 5-10 mm, FA/CA ratio of 1:6, AL/FA ratio of 0.65, and NaOH concentration of 15M were the highest compressive strength value of 2.089 MPa (28 curing days).
- Coarse aggregate size is only one factor effects to compressive strength response. The smaller coarse aggregate, the higher compressive strength of pervious geopolymer concrete.

This work also recommends for future studies to focus on improving compressive strength of pervious geopolymer concrete by keep constant coarse aggregate size (5-10mm), then evaluating the effect of fly ash/coarse aggregate ratio, alkaline liquid/fly ash ratio, sodium hydroxide molarity on compressive strength.

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