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EFFECT OF SUPERPLASTICIZER ON THE STRENGTH OF FLY ASH BASED GEOPOLYMER CONCRETE

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Abstract.

In this research, the effect of a polycarboxylate based superplasticizer on the strength of Geopolymer Concrete (GPC) was investigated. A fixed amount of superplasticizer (1.5 % of Fly Ash weight) was utilized along with alkali activators Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3). The Ultrasonic Pulse Velocity Test determined the strength development of concrete. The quality of the GPC improved when a higher concentration of alkali activator was applied based on the Concrete Quality Designation. In detecting the color development of GPC, samples were put through MATLAB and specimens became lighter as time passes due to dehydration (a process where water escapes from the sample). Stress strain diagrams were generated which generally indicate that GPC specimens are ductile. The researchers were able to assess the workability of the mix designs using a rating from 1 to 5, with 1 being the least workable and 5 being the most workable.

Keywords: Alkali activators, color detection, fly ash based geopolymer concrete, MATLAB, polycarboxylate based superplasticizer, ultrasonic pulse velocity test.

1. Introduction

Throughout the years, the construction industry has developed and changed, paving the way to new improvements and innovation, especially to construction materials such as concrete. Concrete consists of cement, fine aggregates, coarse aggregates, water, and additives to aid in the preparation of the mix. Approximately 86.3 million metric tons of cement was manufactured in the United States and 4,100 million metric tons were produced worldwide in 2017 [1]. As the world continues to develop, more infrastructures are being made to meet the demands and necessities of people, which results in the increased usage of concrete. Unfortunately, concrete usage greatly affects the environment since it is known to contribute around 5% of total world carbon emissions [2]. In the production of concrete, ordinary Portland cement (OPC) is commonly utilized as the binder. Though OPC may be a commonly used binder, it also has its downsides. A considerable amount of natural resources is depleted in order to produce ordinary Portland cement [3]. The OPC production emits large amounts of carbon dioxide. It contributes around 1.35 billion tons yearly or around 7% of the total greenhouse gas (GHG) emissions to the atmosphere of the earth [4]. Cement production also requires a considerable amount of energy.

In response to this, actions have been done to lessen the carbon emission. In the study regarding the reduction of the concrete industry's impact on the environment, [5] suggested that less materials and energy should be used, and carbon dioxide emissions should be lessened. In order for the concrete to be more ecological, the OPC used must be replaced with other binders. Alternative binders such as rice-hull ash (RHA) and fly ash (FA) are currently being used and tested to lessen carbon emission while maintaining the needed mechanical properties of a concrete mix as per ASTM. Additionally, [6] presented in their review that it is feasible to reduce up to 80% to 90% of the current CO_2 emissions globally through the use of geopolymer technology. Apart from reducing greenhouse gas emissions from the cement production, it also mitigates the issue of solid waste.

Geopolymer, an inorganic alumino silicate polymer made from secondary product materials which contain silicon and aluminum, can be utilized as an alternative to cement paste in the production of concrete [4]. Geopolymer concrete undergoes the process of geopolymerization, similar to the hydration of cement. Geopolymer concrete requires by-products with high aluminum and silicate content to react with an activator. Different by-products may be utilized as a material for geopolymer binders, such as fly ash.

Fly ash, a by-product generated from coal fired power production, can be an alternative for cement. It is considered the fifth largest raw material resource in the world as 500 million tons of it, which is about 75% – 80% of the total ash, are produced annually [7]. Fly ash is considered as an environmental pollutant when released into the atmosphere, however

Component	Composition (%) Point 1	Point 2	Point 3	Average
Calcium (Ca)	7.11	7.13	7.07	7.10
Silicon (Si)	22.37	22.37	22.24	22.33
Aluminum (Al)	9.34	9.5	9.58	9.48

Table 1. XRF Result of Coal Fly Ash.

there are numerous areas wherein fly ash can be applied, such as cement clinkers, road basement material, waste stabilization or solidification, concrete production, and geopolymer concrete [8]. As an additive to the cementitious material, fly ash decreases heat of hydration, reduces thermal cracking of concrete in early stages, improves mechanical and durability at late ages, and improves workability. A research conducted by [9] presented the different properties of a fly ash based geopolymer concrete and concluded that fly ash based geopolymer concrete has a compressive strength that is of high quality and can be used for construction purposes, and that its elasticity is similar to that of OPC concrete, has excellent resistance against sulfate and acid, and undergoes minimal creep and drying shrinkage.

Despite the numerous research involving geopolymer concrete in the present time, studies on the utilization of admixtures in improving the strength of geopolymer concrete is still fairly limited. There is a need to further investigate the effect of the utilization of superplasticizer in GPC, as well as the impact of the curing methodology to be used in order to investigate it as the binder for concrete in construction. The objective of this study is to determine the optimum strength and workability of geopolymer concrete (GPC) with superplasticizer through the use of both mechanical and non-destructive testing. Nondestructive testing in concrete has been advancing using nonlinear ultrasonic test [10, 11] and acoustic emission test [12, 13]. In this paper, ultrasonic pulse velocity test was used since it is practical and can estimate concrete strength [14].

2. Materials

The study used an alumino-silicate coal fly ash obtained from a coal-fired power plant located in Batangas, Philippines. A hand-held X-Ray Fluorescence (XRF) spectrometer was used in order to acquire the elemental composition of the material, as per ASTM C188 shown in Table 1.

ASTM Standards state that fly ash can be classified into three types: Class F, C and N. Commonly, Class C and Class F fly ash, which vary in terms of their calcium content, are used for the concrete binder. Class C fly ash is high in calcium, while Class F fly ash comprises less than 10% of Calcium content [15]. Observing Table 1, it can be seen that the fly ash in this study contains low calcium and high silicon content. Thus, the fly ash used in this study is a Class F. A low calcium fly ash is favorable in making geopolymer concrete to obtain optimal binding properties [16].

Sodium Hydroxide also known as caustic soda flake; this alkali activator has a 98% minimum NaOH purity. In this research, a molarity of 12M was used. In order to obtain such molarity, 480 grams of NaOH pellets were gradually added to every 1 liter of distilled water. Another alkali activator is the Sodium Silicate which is a colorless liquid. The said activator is known to be the most preferred activator for fly ash based geopolymer concrete [17]. The superplasticizer utilized in this research was a water-reducing admixture. Its chemical base is a polycarboxylate ether with a white to yellowish color in appearance. The recommended consumption of the said admixture ranges from 0.8% - 2.0% of the weight of the cementitious material.

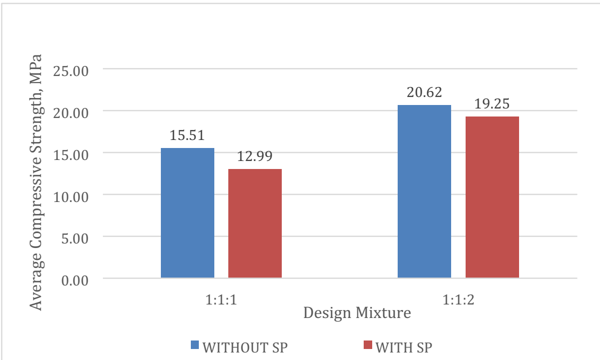


Figure 1. Compressive Strength of GPC without SP and GPC with SP.

3. Methodology

The study compared the GPC and GPC with superplasticizer with the aid of destructive and nondestructive tests. The destructive tests are ASTM C39 Compressive Strength Test and Strain Gauge Test. The nondestructive tests are Ultra Pulse Velocity Test (UPV) and Color Detection Test which were performed before and after the destructive testing. The following procedures were done upon mixing the raw materials: Preparation of 12M NaOH Solution - add 480 g of NaOH pellets to every 1 liter of water; Mix the Dry Materials such as Fly Ash, Sand, and Gravel; Mix the wet materials such as Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3);

	Materials (grams)							
Ratio	Fly	Ash	Sand	Gravel	Na_2SiO_3	NaOH	Water-Biner	*SP (1.5% of FA)
1:1:1	**1** 982.953	**1** 887.953	**1** 880.814	351.055	140.422	245.738	14.7	
1:1:2	**1** 737.215	**1** 665.964	**2** 1321.221	263.291	105.316	184.303	11	

Note: *SP is only for one set of specimens (those with Superplasticizer)

Table 2. Design Mix of Geopolymer Concrete.

Design Mix Ratio	Rating	Description/Remarks
1 : 1 w/o SP	3	Difficulty in mixing was observed. The mixture can be mixed while exerting effort.
1 : 1 w/SP	5	The lightest and easiest to mix. The mixture easily spreads out.
1 : 2 w/o SP	2	Notable lack of flow and relative dryness were observed. Additional water was put so that it could be consolidated.
1 : 2 w/ SP	4	The mixture spreads out slowly with ease. The mix was dry before the superplasticizer was added.

Table 3. Assessment of the Workability of the Geopolymer Samples.

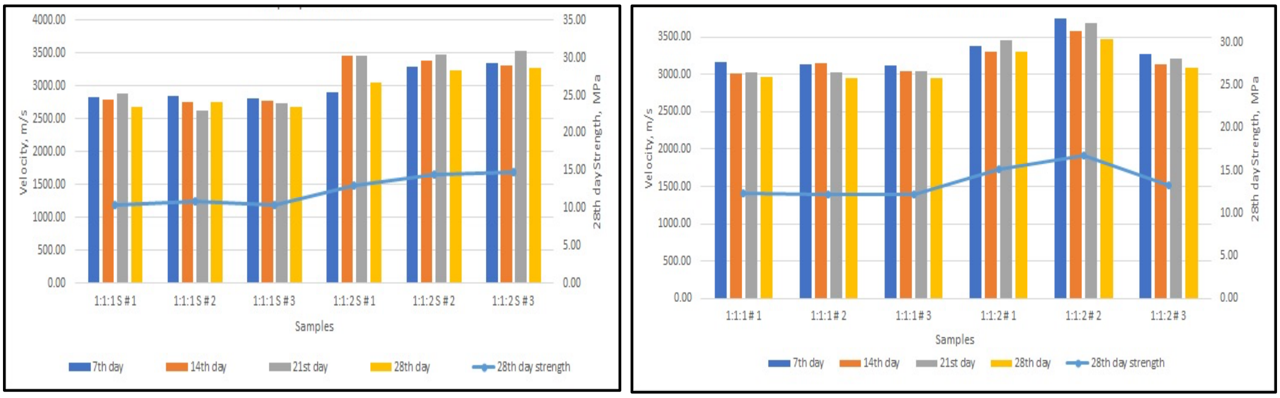
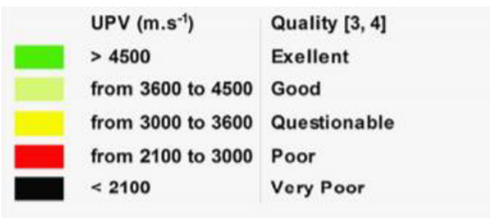


Figure 2. Strength Development of (a) Geopolymer Concrete without Superplasticizer (b) Geopolymer Concrete with Superplasticizer.



	UPV ($m.s^{-1}$)	Quality [3, 4]
	> 4500	Exellent
	from 3600 to 4500	Good
	from 3000 to 3600	Questionable
	from 2100 to 3000	Poor
	< 2100	Very Poor

Figure 3. The Concrete Quality Designation (CQD) Derived from the UPV.

Mixing of the dry and wet materials; Add the water and add the Superplasticizer. Seen in Table 2 is the design mix.

4. Results and Discussion

4.1. Effect of Superplasticizer on the Workability

Workability, described as the ease and homogeneity of concrete during mixing, was one of the properties of concrete investigated in this study. The said fresh concrete property is reliant on several factors including water-binder ratio having its relationship as directly proportional. However, the strength of concrete is negatively affected as the water in the mixture increases. In GPC, alkali activators, superplasticizer, and water present in the mixture are the factors that affect the workability [18]. A high concentration of NaOH and Na_2SiO_3 reduces the workable flow of geopolymer [19]. Superplasticizer was used in this research to improve the workability of GPC. As expected, the mixture with superplasticizer resulted to be more workable than the mixture without super-

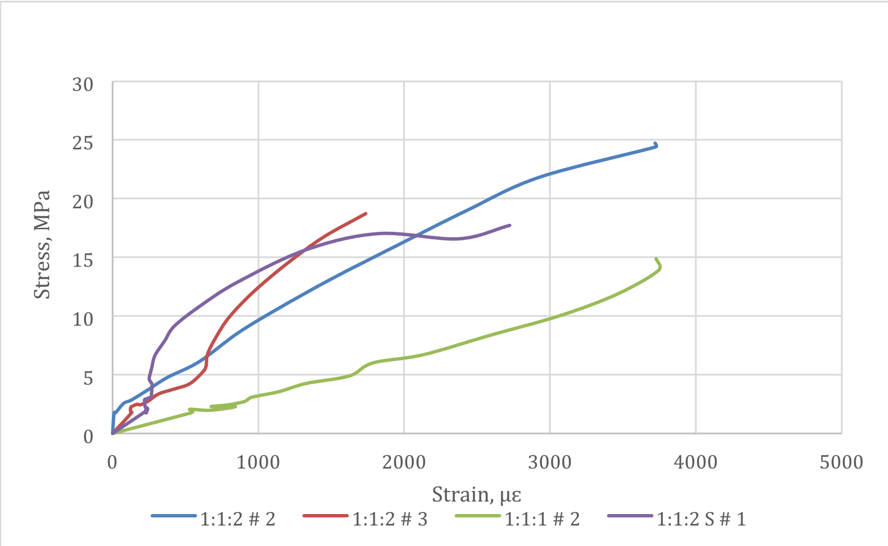


Figure 4. Stress Strain Diagram of Geopolymer Concrete.

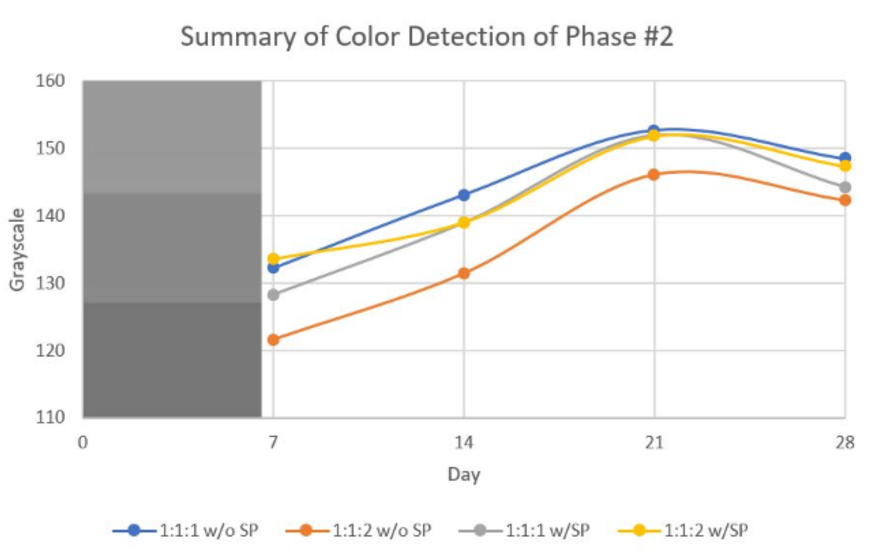


Figure 5. Average Color Detection of each Design Mix.

plasticizer. Additionally, the researchers were able to assess the workability of various mix designs since all the specimens were hand mixed. Shown in Table 3 below is the assessment of the workability of the geopolymer in this study. The assessment makes use of a rating from 1 to 5, with 1 being the least workable and 5 being the most workable.

4.2. Effect of Superplasticizer on the Compressive Strength

Shown in Figure 1 below is the comparison of the average compressive strength of geopolymer concrete without superplasticizer and that of the geopolymer containing superplasticizer. The Figure 1 shows that the superplasticizer did not positively impact the compressive strength of the specimens. Percentage differences of 17.68% and 6.87% were calculated for the design mixtures 1 : 1 : 1 and 1 : 1 : 2, respectively. The superplasticizer content of the mixtures was seen as the vital factor that affected its effect on the geopolymer concrete's strength. Increasing the content of polycarboxylate-based superplasticizer to 2% could positively impact the strength [20].

4.3. Strength Development - Ultrasonic Pulse Velocity Test

The strength development of geopolymer was monitored in this research through Ultrasonic Pulse Velocity (UPV) Test which was done every seven days until the 28th day. The velocity obtained from the UPV machine was converted into its equivalent strength in Megapascal (MPa) using Raouf's equation [21].

Observing Figure 2, it can be seen that there is a constant decrease in strength development for most of the samples. Possible factors such as varying amounts of water and the inaccuracy of the manual compaction may have influenced the outcome of the results. Based on the CQD by [22] shown in Figure 3, the quality of the geopolymer concrete cylinders without superplasticizer and geopolymer concrete cylinders with superplasticizer were good and poor to questionable, respectively.

4.4. Compressive Strength Test

Compressive strength test was done on the 28th day of the concrete cylinder samples. Strain gauges were also attached to the sample upon the application of the load to generate stress-strain diagrams. Table 4 shows the compressive strength of the geopolymer concrete samples. It can be observed that 1 : 1 : 2 without superplasticizer had the optimum compressive strength equal to 24.752 MPa.

Design Mixture (FA:S:G)	28th Day Strength (MPa)		
	1	2	3
1 : 1 : 1	18.538	14.897	13.089
1 : 1 : 2	18.373	24.752	18.729
1 : 1 : 1 w/ SP	15.954	12.032	10.988
1 : 1 : 2 w/ SP	17.711	19.646	20.384

Table 4. Assessment of the Workability of the Geopolymer Samples.

Figure 4 displays the stress strain diagram of the geopolymer concrete. It can be observed that 1 : 1 : 2 # 2 has the optimum compressive among all the specimens. The diagram also implies that the stress-strain curve of GPC is similar to a typical stress-strain curve of an ordinary portland cement concrete. Additionally, the curve dictates the geopolymer is a ductile material.

4.5. Image Processing: Color Detection

Images were taken every 7th, 14th, 21st, and 28th day, which were then manually cropped to maintain a fixed perspective of the surface of the GPC. Images were then uploaded to MATLAB so that the software can automatically convert them to grayscale, giving values between 0 (black) and 255 (white). The main factor in the change in color is due to gradual dehydration of geopolymer and oxidation of iron present in the fly ash [23]. Each sample in Figure 5 follows a pattern from a darker shade to a lighter shade, indicating gradual dehydration.

5. Conclusion

In determining the optimum strength of fly ash-based geopolymer concrete, the Compressive Strength Test was used. The optimum mix design ratio would result in a compressive strength greater than 3000 psi (21 MPa). For GPC specimens, a peak strength of 24.752 MPa was obtained in the mix design ratio of 1 : 1 : 2. Moreover, based on the previously shown stress-strain diagram, it can be stated that the geopolymer concrete followed a curved orientation until its failure point. Such orientation denotes that the material tested is ductile. Higher alkali activator concentration and proper method of mixing greatly affect the performance of geopolymer concrete. With the use of superplasticizer, the specimen had a glossier appearance when compared to a specimen without it. It was found that the superplasticizer did not increase the strength of fly ash-based geopolymer concrete. However, it improved the workability of the concrete specimens. Further investigation is recommended on the application of different types of superplasticizers and other materials in improving workability of geopolymer concrete.

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