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Durability Performance of Geopolymer Concrete of Various Strength

Clarence Meripa Meechang[1], Jayakumar Muthuramalingam[1], Nicholas Tam[2]*

[1]Department of Civil and Construction Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT250, Miri 98009, Malaysia.

[2]Faculty of of Civil and Environmental Engineering, Warsaw University of Life Sciences, Nowoursynowska 166, 02-787, Warsaw, Poland.

*Correspondence: tamnfy@gmail.com

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ABSTRACT: Geopolymers, primarily composed of fly ash, have proved an excellent substitute for ordinary portland cement (OPC) in terms of sustainability and productivity. In order to determine the geopolymer concrete's (GPC) resistance to chemical assaults and water permeability, it is necessary to obtain geopolymer concrete (GPC) of varying strengths after normal curing. The objectives of the research was to test the durability performances of the GPC of various strength under normal curing and investigating the optimum strength based on durability testing of the GPC. For this research, different type of cement-to-fly ash ratio was used for various strength data. The appropriate mixture was conducted by using the trial mix method in order to obtain better accuracy of the results data during the mixing design process. To satisfy the varied strength designs, a small proportion of OPC is added to the GPC mixture as part of the mix design. After 28 days of curing, this durability testing is undertaken after the concrete has reached its maximum strength. The compressive strength test and weights were performed and compared to the GPC mix design at 60 °C after heat curing. The 8% OPC replacement has greater resistance to sulfate attack, saltwater exposure, and water permeability compared to the 6% and 7% OPC alternatives. Consequently, the experiment reveals that the GPC's durability and strength increase as the percentage of OPC increases.

KEYWORDS: Durability performance; fly ash; various strength; geopolymer concrete; ordinary portland cement.

1. Introduction

The fast expansion of the global building sector has made concrete the most in-demand material in the business. Since ancient times, this concrete, comprised of materials like as OPC, has been of enormous use to humanity in the construction of homes, bridges, tunnels, and many other structures. This obviously does not speak well for the sustainability of the ecosystem. According to research, 1 tonne of OPC emits approximately 1 tonne of Carbon Dioxide (CO_2) into the atmosphere, accounting for 6% of worldwide CO_2 emissions today. The durability performance of GPC concretes was greater than that of OPC concretes [1–3]. Global OPC use was the primary contributor to the excessive CO_2 emissions in the environment. According to earlier research, the global rate of OPC production is similar to the rate of CO_2 emissions. This study indicates that each tonne of OPC produced is comparable to approximately one tonne of CO_2 emissions. Therefore, extra materials that serve as binders to replace OPC are introduced in order to mitigate environmental consequences [4, 5]. Fly ash is one of the industrial byproducts produced and found in all coal-fired power plants. Simply by substituting OPC concrete with GPC, a 9 percent reduction in carbon footprint was obtained. GPC had also been shown to have good effects on both the economy and the environment as a result of the sale of byproduct materials such as fly ash as binders in the concrete industry for commercial benefit rather than disposal [6–8].

Geopolymer is an inorganic polymeric binder derived from the reaction of alkaline liquids with aluminium (Al) and silicon (Si) derived from geological or industrial byproducts. For the investigation, fly ash was used as a by-product material. As alkaline activation solution, liquids such as sodium hydroxide and sodium silicate are combined with fly ash to generate geopolymer paste that acts as a binder. The ratio of ingredients in the mix design could affect the compressive strength of the concrete; therefore, a suitable mix is necessary. The two types of geopolymer foundations comprise of the source material for the concrete and the alkaline activator solution for the chemical reaction that forms geopolymer. In order to satisfy geopolymerisation, the source materials must include a high concentration of silicon (Si) and aluminium (Al). Source materials include byproducts such as fly ash, silica fumes, rice husk ash, and ground granulated blast furnace slag (GGBS). Mixing alkaline liquids such as Sodium Silicate (KOH) and sodium hydroxide produced the alkaline activator liquid (NaOH). To examine the differences in durability performance, multiple samples of varying strength are necessary. Numerous durability tests were conducted by researchers in the past, but there is no recent data on the performance of durability under varying strengths [9, 10]. The aims of the research were to evaluate the durability performances of GPCs of varying strengths during normal curing and to determine the optimal strength of GPCs based on durability testing, which can be of considerable assistance to the construction industry.

2. Materials and Methods

2.1. Materials.

The OPC were used as a substitute for fly ash. The applicable percentages were 6 %, 7 %, and 8%. The OPC must meet the study's target in terms of GPC diversity and strength. It is necessary to conduct trial mixing in order to determine the proper mixture ratios. Various GPC strength targets, including 45 MPa, 60 MPa, and 70 MPa, are determined by trial mixing. Mixing can be accomplished with a concrete pan mix machine. In this research experiment, multiple material compositions are used to cast cubes in order to acquire the needed amount of compressive strength test variation. Consequently, each trial mixing is accomplished by adding 6 %, 7 %, and 8 % of OPC, respectively. In addition, trial mixing involves the experimentation of various molarities of sodium hydroxide (NaOH) solutions. 8 M, 12 M, and 14 M molarity were employed for the NaOH throughout the testing mix.

2.2. Compressive strength test.

Tests of compressive strength are the most important for determining the results of GPC durability performance tests. The compressive stress of a sample can be determined by the uniaxial compressive stress attained at the time of material failure. The GPC cubes are then tested between the smooth loading surfaces of the compressive testing equipment, each of which has a capacity of 2,000 kN. The top and bottom surfaces must receive and compress the cube load until the load fails. This compressive strength values can be found by dividing the cube sample's cross-sectional area by the failure load ratio. There are two phases of testing for compression strength. Before testing for durability, the first step is to establish the GP concrete strength. This will serve as a standard against which to assess the samples tested for durability [11–13].

2.3. Durability tests.

2.3.1. Salt water exposure.

The salt water was used to test the GP concrete cubes' durability. The collected salt water was utilised to imitate salty sea water in order to increase the durability of the concrete. In laboratory testing, salt water was utilised to evaluate the seawater of the GPC used for underwater concreting. Over the course of 28 days, 100 mm × 100 mm GPC cube samples were submerged in a 3.5% salinity concentration salt water solution. The GP cube samples were then examined for any concrete damage. The materials were weighed and their compressive strength was estimated [10, 14, 15].

2.3.2. Sulphate exposure.

The durability of the GP concrete cubes was examined using sodium sulphate (Na_2SO_4)at concentrations of 5% and 10%. Samples of 100mm x 100mm GP concrete cubes were immersed in a sulphate solution for 28 days. The results of a compressive strength test and a measurement of mass losses was acquired from a sample once it has been collected on the specified day. GP cube samples are also examined for any concrete damage [10, 16, 17].

2.3.3. Water permeability tests.

Water permeability tests were conducted by measuring the amount of water GP concrete cubes absorb. The proportion of water absorbed by GP Concrete samples was determined by soaking the 100 mm x 100 mm sample cubes for 28 days in water. At the end of the requisite time, the compressive strength of the GP concrete was calculated in order to get the GP concrete durability test. The sample weight was determined and documented [10, 18].

3. Results and Discussion

3.1. Trial mixture.

Initially, 8 M, 12 M, and 14 M sodium hydroxide solutions were utilised in the GPC testing mixtures. The following tables display the properties of the trial mixture design with additions of 6%, 7%, and 8% OPC at various molarities. Due to its suitability in high strength performance tests, a water-cement ratio of 0.5 was utilised in mix design. The proposed materials are shown in the Table 1. Different Sodium Hydroxide Molarities are also presented as a test to determine the effect of NaOH concentration on GPC strength [19, 20].

Table 1. Compressive strength of GPC.

OPC (%)	NaOH Concentration (M)	Material Quantity (kg/m³)						Compressive strength (MPa)
		OPC	Fly ash	NaOH	Na_2Si_3	Water	Super plasticizer	
6	8	0.02448	0.38357	0.0409	0.1029	0.08	0.06	34.92
	12	0.02448	0.38357	0.0409	0.1029	0.08	0.06	62.67
	14	0.02448	0.38357	0.0409	0.1029	0.08	0.06	74.80
7	8	0.02856	0.37944	0.0410	0.103	0.08	0.06	36.92
	12	0.02856	0.37944	0.0410	0.103	0.08	0.06	68.41
	14	0.02856	0.37944	0.0410	0.103	0.08	0.06	84.63
8	8	0.03264	0.37536	0.0411	0.103	0.08	0.06	61.59
	12	0.03264	0.37536	0.0411	0.103	0.08	0.06	74.97
	14	0.03264	0.37536	0.0411	0.103	0.08	0.06	88.92

3.2. Compression strength.

The compression strength of the GPC at 14 M with sodium hydroxide is greater than the 12 M and 8 M strengths. This indicates that workability appears to decrease as molarity increases. Therefore, it is determined that 12 Molar is the optimal molarity value for sodium hydroxide. According to the literature review, the highest molarity for GPC was 14 M, while the minimum molarity is 8 M. Therefore, 12 M serves as a compromise between the two conditions and is the optimal choice in terms of achieving a balance between the workability and strength of the GPC. In addition, the preceding numbers demonstrate that each OPC % indicates a unique sample's strength. Based on the results of the trial, OPC levels of 8% have the greatest strength. The graph below depicts the strength values based on the average strength of GP Concrete with Sodium Hydroxide (NaOH) of 12 M [7, 11, 12].

3.3. Durability of GPC.

Conducting a laboratory experiment based on the concrete's resistance to sodium sulphate chemical assault, salt water attack, and water permeability is necessary for determining the GPC's durability performance under varying strengths. After casting the chosen admixture into many 100 mm x 100 mm cubes, experimentation and testing commenced. The GPC cubes were separated into two separate groups. The first group of samples is undergoing conventional curing, whereas the second group was placed at 60°C for 24 hours. In this study, the durability of GPC cubes was evaluated by soaking samples in Sodium sulphate, salt water, and distilled water. The permeability and solution attack of liquids on the samples were measured by weighing the samples, examining the surface condition of the samples, and conducting compression tests. All of the results were obtained by comparing the regular curing and heat curing groups of concrete. The results were compared hypothetically based on reviews of the relevant literature. The tests for durability were conducted by comparing the density of each GPC sample. Experiments are undertaken to establish the durability level of concrete under different types of strength, which are dependent on the proportion of OPC in GPC. The sample trial was separated into two groups, one with GPC cured at room temperature and the other with GPC cured at 60°C for 24 hours [10, 15, 20]. Figure 1 shows the weight difference between the concrete before and after hydration.

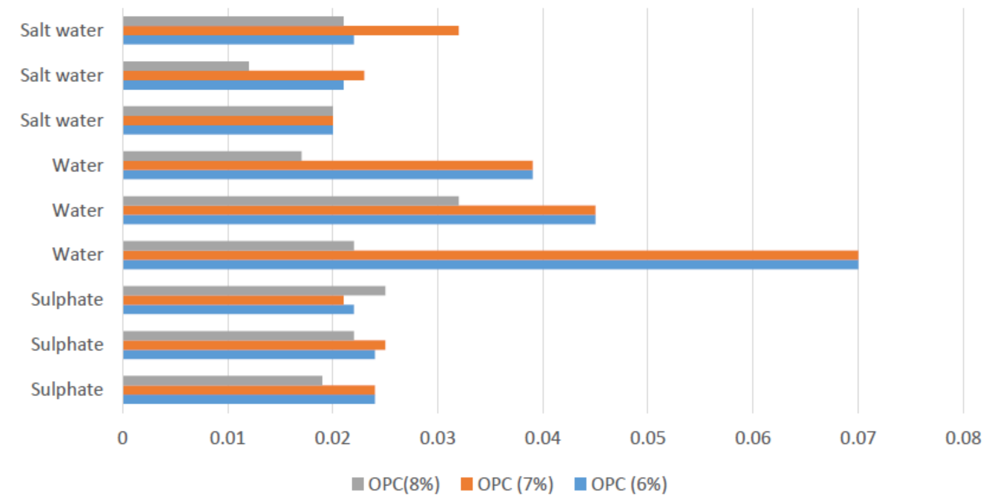

Figure 1. Weight difference for normal curing.

In terms of water permeability, the sample undergoing normal curing, which is exposed to salt water and sulphate attack, seems nearly identical to the sample undergoing salt water exposure and sulphate attack (Figure 2). In all situations, the weight difference between samples with 7% OPC and those with 6% OPC appears to be nearly identical. The samples with an OPC of 8% are typically, but not always, inferior to the other two. It has been demonstrated that when the amount of OPC added to the GP samples increases, solution penetration decreases. The OPC functions as a curing agent in the GPC mix design, hence accelerating the GP concrete's setting time. The results indicate that the greater the OPC addition, the greater the concrete's resistance to all types of chemical exposure. The following graph illustrates the durability performance of GP concrete after 24 hours of heat curing at 60°C. The difference in weight depicted in the preceding diagram indicates that the OPC values of 7% and 8% are inconsistent and that the penetration level for sulphate attack, water permeability, and salt water permeability is greater in both cases. Literature review indicates that heat curing's durability performance should be marginally superior to regular curing. This may be the result of misconduct during the casting process, particularly during oven heating. The heating time may be too long, causing some materials in the GP concrete samples to get charred or lose efficacy due to the high temperature [10, 21, 22].

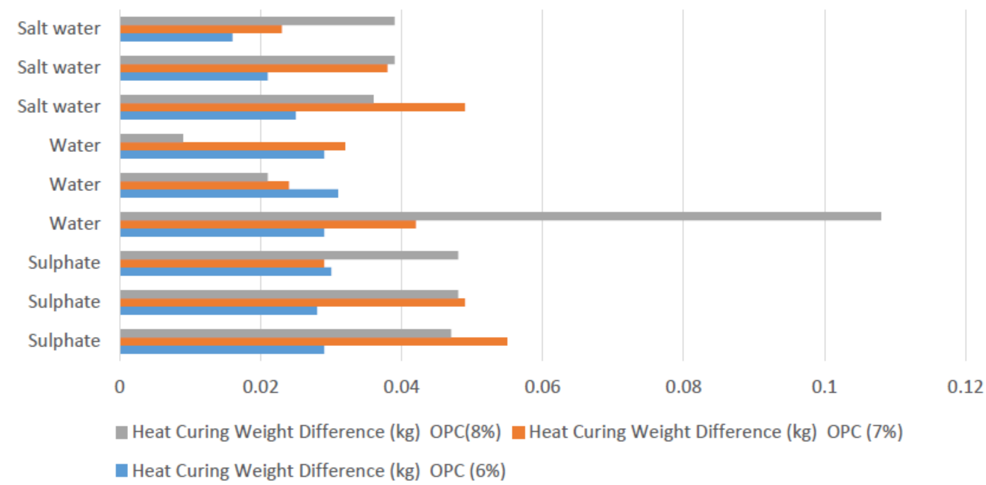

Figure 2. Weight difference graph for heat curing.

3.4. GPC strength in term of durability.

Using a compressive strength testing machine, the experiment was continued by determining the concrete's strength. After 28 days of soaking in a 5% sodium sulphate solution, 3.5% salinity salt water, and water, the strength of GP concrete samples was measured. The strength was compared to samples that had not been subjected to durability testing and had undergone 28 days of heat curing at 60°C for 24 hours and normal curing. The blue line represents the original concrete strength that was utilised as a reference in the investigations of concrete's durability (Figure 3). Even throughout a range of concrete strengths, as depicted in the preceding graph, the GP concrete strengths are very similar and have a similar general form. The strength of the sample decreased after soaking in sulphate, salt water, and water, according to the results of the investigation [21, 22]. This is owing to the solutions' ability to permeate the concrete and consequently alter its characteristics. On concrete, chemical solutions such as salt water and sulphate could generate minute honeycombs and minor corrosion. This may account for the decrease in strength. The graph reveals, however, that a sample soaked in water has a significant decrease in strength. This was not intended to occur. This could be the result of a calculation error during the formulation of the mixture or inappropriate conduct during casting. The graph also demonstrates that when the OPC percentage grows (8% OPC), the final strength increases. This demonstrates that the greater the OPC percentage, the more durable the concrete [23–26].

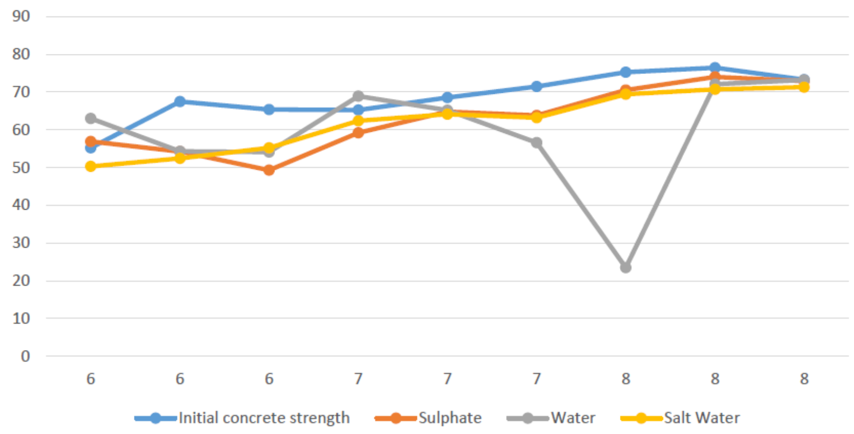

Figure 3. GP concrete strength graph under normal curing.

4. Conclusions

To fulfil the goal of the research, the trial mixture design for the GPC was created in order to examine the GPC's materials composition, workability, and concrete strength. From this trial mixture, the appropriate proportions of materials and chemicals were established and applied to the formulation of the experiment's final admixtures. The water-to-cement ratio of 0.3 has proven to be adequate, as it enhances the GPC's workability. Since the GPC requires a large number of samples to be cast in a single batch, superplasticizers are employed to further improve the workability of the concrete, making it easy to cast without having to worry about the concrete setting too quickly. In addition, depending on the design of the trial mixture, it is recommended that the water-to-cement ratio stay constant at 0.3. This is because exceeding the ratio with water could reduce the performance of the GPC. The compressive strength of the GPC was raised by the substitution of OPC for fly ash during the formulation process. As the experiment develops, this is observable in every data. To meet the varied strength needs of the target, additions of 6%, 7%, and 8% are made based on the mix design experiment. After the samples have been cast, they are separated into two unique groups: GPC under heat curing and GPC under normal curing. The objective is to compare the two sample populations. The GPC samples are then left for 28 days before durability testing, which involves another 28 days of soaking in selected solutions. High replacement of OPC can increase the GPC's durability, as demonstrated by its performance in this regard. The 8% OPC replacement has greater resistance to sulphate attack, salt water exposure, and water permeability compared to the 6% and 7% OPC alternatives. Consequently, the experiment reveals that the GPC's durability and strength increase as the percentage of OPC increases.

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Conflicts of Interest

The authors declare no conflict of interest.

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