Properties of slag-based geopolymer pervious concrete for ambient curing condition

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Abstract Cement consumption is increasing day by day due to the enormous expansion in the infrastructure system. Geopolymer concrete has been used to reduce the use of Portland cement. The purpose of the present work is to study some parameters related to the geopolymer binder material and could influence on the properties of ambient cured Geopolymer Pervious Concrete (GPPC). The parameters studied are: The amount of slag, concentration of NaOH, ratio of Na₂SiO₃/NaOH, and alkaline activator solution to slag ratio. The amount of slag investigated was (300, 325 and 350). Concentration or the molarity (M) of NaOH ranged between 8 M to 14 M with increment of 2 M, ratio of sodium silicate to sodium hydroxide varied from 1 to 3.5 with increase of 0.5, and alkaline solution to slag ratio was (0.25, 0.30 and 0.35). The experimental investigations were performed to measure the percentage of the flow of fresh GPPC, total void content, density, and compressive strength at the age of 3 days. The results have shown that slag-based GPPC ambient cured have gained high compressive strength at early age that could be sufficient for practical applications in road construction.

1. Introduction
The production of cement has a significant impact on environmental pollution; this is the major problem that the world is facing today. Portland cement is the most commonly used binding material for making the concrete. However, the production of cement is the main contributor to CO₂ emissions.

A new generation of cementing material such as geopolymer concrete (GPC) has been developed to reduce the use of Portland cement. It is another type of sustainable cementing material [1]. It has been used in the concrete industry as an alternative to Portland cement, [2]. The effect of Slag on the workability and compressive strength of fly ash-based geopolymer concrete under ambient curing condition was studied [3]. It has been concluded that slag increases both the workability and compressive strength. Maximum compressive, split tensile, and flexural strength resulted when 75% of fly ash replaced by slag.

Past studies on geopolymer concrete technology were presented by Tabassum and Khadwal [4], they concluded that a higher concentration of sodium hydroxide solution would increase the compressive
strength of the geopolymer concrete. They also found that the strength of geopolymer concrete could be better by decreasing the water/ binder ratio. Compressive strength of past research studies ranged between 20-60 N/ mm² and Split tensile strength was in the range of 3-4.9 N/mm². Ultra- high performance geopolymer concrete under the ambient condition was developed by Ambily et al. [5], they made geopolymer concrete by mixing 80% fly ash with 20% slag and liquid to the binding material ratio of 0.6. Excellent workability based on slump test ranged between 225-250 mm, and compressive strength ranged between 30 to 44 M at the age of 28 days of casting have resulted. Nath and Sarkar [6] studied the effect of a small quantity of slag on setting time, workability and strength of fly ash based geopolymer concrete, their results have indicated that using slag enabled curing at ambient condition. They found that blending slag with fly ash would enhance the engineering properties and durability of geopolymer concrete.

Mathew et, al. [7] studied the feasibility of using coarse bottom ash for the production of fly ash-slag geopolymer concrete. They concluded that Coal Ash and Slag based geopolymer concrete could be formed at ambient curing condition with a comparable cost to OPC based concrete. It has been found [8, 9] that the strength of geopolymer concrete increases with the increase of molarity of sodium hydroxide, and the minimum 9% replacement of fly ash by slag is sufficient for curing under the sunlight condition [9]. The behavior of geopolymer concrete containing equal proportion of fly ash and slag and subjected to elevated temperature up to 500°C was investigated [10]. It has been established that curing at high temperature is not required in all cases of geopolymer concrete and reported that sunlight can be used for curing of geopolymer concrete in tropical countries. Quasrawi et al. [11] used unprocessed steel slag as partial replacement material of fine aggregate in their mixes of GPC. Results have shown that maximum compressive strength could be achieved with a replacement ratio of 15-30% and for tensile strength with a replacement ratio of 30-50%. Al-Shather et al. [12] investigated the effect of different curing system on the compressive strength of Metakaolin based geopolymer concrete, they concluded that optimum curing temperature for geopolymer concrete is within the range of 32 to 48°C while moist curing is not suitable for this type of concrete.

Up to present, most of the works have been conducted on fly ash based geopolymers, and some works carried out to consider the effect of slag for ambient curing condition, the results have gained some achievements. However, almost all of this literature focused on the effects of some parameters on the compressive strength of fly ash based geopolymers concrete and very limited researches have emphasized on porous or pervious concrete. High void content and good strength of ambient cured geopolymer pervious concrete will permit the water to drain naturally, reduce runoff surface water, and to feed the groundwater. It can be used as a precast paving unit in pedestrian walkways, park areas, and even areas with traffic; Typically, geopolymer pervious concrete consists of coarse aggregate, binder, and admixture. The binding material would be geopolymer cement instead of portland cement, an investigation on the use of geopolymer binders in pervious concrete is needed.

The purpose of this research work is to study the feasibility of using slag-based geopolymer cement as a binding material to produce geopolymer pervious concrete (GPPC) for ambient curing condition (No heat curing and No water curing). This will enlarge its use to the areas over precast concrete members. In the present work, some important parameters related to the geopolymer binder are investigated to determine their effect on the essential characteristics of GPPC, such as the compressive strength, Total permeable void content, and bulk density. The parameters investigated are; Alkaline solution-to-Slag ratio, NaOH solution concentration, and sodium silicate to sodium hydroxide solution ratio.

2. Experimental Works
2.1 Materials
2.1.1 Slag. Fine powder of slag purchased from (ALse Kimya Mineral), a Turkish company. The pozzolanic activity index was determined in accordance to EN 196-1 and chemical properties of the product were determined using the test methods of EN 196-2, values are listed in table-1. The product conformed to all the requirements of EN 15167-2:2006. It is made by grinding material made by the rapid cooling of a slag melt obtained by melting iron in a blast furnace. It consists of at least two thirds by mass of glassy slag.

2.1.2 Alkaline Activator solution (AAS). A mixture of sodium silicate solution and sodium hydroxide solution was used as an alkaline activator solution. Different proportion rates of Na$_2$SiO$_3$ to NaOH solutions are prepared. The ratios varied as (1, 1.5, 2, 2.5, 3), and mixed one day before the casting. The Sodium Hydroxide (NaOH) in the present work was available in pellets. NaOH pellets are dissolved in water to make the solution. Desired concentrations of NaOH solutions are prepared 8, 10,12, 14) M.

| Table 1. Chemical and Physical Properties of Slag used |
|-----------------------------------------------|
| **Properties** | **Conformity Requirements** | **Values** |
|----------------|----------------------------|------------|
|                | EN-15167-2                 |            |
| Mgo            | 18 % maximum               | 5.00-10.00 |
| Sulfide        | 2.0 % maximum              | 0.40-0.70  |
| Sulfate        | 2.5% maximum               | 0.30-0.60  |
| Loss on ignition corrected for oxidation of sulfide | 3.0% maximum | 0.00-2.00 |
| Chloride       | 0.10 % maximum             | 0.01-0.03  |
| Moisture Content | Less than 1.0%            | 0.10-0.30  |
| Specific surface (Blaine) cm$^2$/g               | Greater than 2750          | 5800-6100  |
| Activity index at 7days                           | Greater than 45 %          | 50-60      |
| Activity index at 28 days                          | Greater than 70 %          | 75-85      |

The Sodium Silicate Solution (Na$_2$SiO$_3$ Sol.) was brought from DCP company in bulk, the chemical analysis performed by the company showed that it composed of Na$_2$O =14.7 %, SiO$_2$ = 29.4%, and water = 55.9% by mass.

2.1.3 Superplasticizer. Naphthalene- formaldehyde condensate-based superplasticizer under the brand name of Flocrete SP33 was used to improve the workability of fresh GPPC, it complies with ASTM C494, type A and F (ASTM C494 / C494M, 2015), it was obtained from the local suppliers of Don Construction Products (DCP) Company.

2.1.4 Coarse aggregate. Naturally available coarse aggregate passing sieve 14 mm was used in the present work; the properties were tested as per the ASTM-C33. The aggregate has the specific gravity of 2.70, dry rodded bulk density measured was 1740 kg/m$^3$ and water absorption of 0.8 %.

2.2 Mix Proportions and Manufacturing process

Thirteen different mix combinations were selected to produce Geopolymer Pervious concrete (GPPC) cubic specimens. Mix variables include Alkali Activator Solution (AAS) to slag ratio, Sodium silicate
to Sodium hydroxide solution (SS/SH) ratio and the concentration of Sodium hydroxide (NaOH) solution. Previously several trial mixes were performed. As a result, the best amount of slag investigated was 325 and 350 kg/m³ that gave acceptable pervious concrete properties. The ratio of alkaline activator solution to slag varied as 0.25, 0.3, 0.35. The SS/SH ratio was changed as 1, 1.5, 2, 2.5, 3.0, 3.5, and the concentration of NaOH varied as 8, 10, 12, 14. The amount of superplasticizer approximately was 1% by weight of slag content, and no extra water was added. The geopolymer mixtures were designated with their variable constituents in the mix, for example, GPP-A25R1M12 represents a geopolymer mixture having the ratio of AAS to Slag as 0.25, Sodium silicate to sodium hydroxide ratio R as 1 and concentration of NaOH, M as 12. The alkaline activator solution was prepared in the laboratory by blending sodium hydroxide, and sodium silicate solutions and the mixture remained for 24 hrs. Before mixing with other ingredients, coarse aggregate made in SSD condition and with slag were dry mixed thoroughly in a tilting drum mixer for about 2 minutes. Premixed AAS was then added gradually in the mixer. Mixing was continued for an extra 4 minutes to manufacture fresh geopolymer pervious concrete. Details of geopolymer pervious concrete compositions are listed in table 2.

**Table 2. Details of geopolymer pervious concrete mixes**

| Mix designation | Na₂SiO₃/NaOH ratio | NaOH Molarity | AAS/Slag | Slag Content | Dry Density at 3 days (Kg/m³) |
|-----------------|--------------------|---------------|----------|--------------|-------------------------------|
| GPP-A25R1M18    | 1                  | 8             | 0.25     | 325          | 1760                          |
| GPP-A25R1M10    | 1                  | 10            | 0.25     | 325          | 1756                          |
| GPP-A25R1M12    | 1                  | 12            | 0.25     | 325          | 1753                          |
| GPP-A25R1M14    | 1                  | 14            | 0.25     | 325          | 1754                          |
| GPP-A25R1.5M12  | 1.5                | 12            | 0.25     | 325          | 1755                          |
| GPP-A25R2M12    | 2                  | 12            | 0.25     | 325          | 1754                          |
| GPP-A25R2.5M12  | 2.5                | 12            | 0.25     | 325          | 1753                          |
| GPP-A25R3M12    | 3                  | 12            | 0.25     | 325          | 1758                          |
| GPP-A25R3.5M12  | 3.5                | 12            | 0.25     | 325          | 1766                          |
| GP-A25R1M14S    | 1                  | 14            | 0.25     | 350          |                               |
| GP-A30R1M14S    | 1                  | 14            | 0.30     | 350          |                               |
| GP-A35R1M14S    | 1                  | 14            | 0.35     | 350          |                               |
| GP-A35R1M14S    | 1                  | 14            | 0.35     | 300          |                               |

(a) S: the amount of slag was 350 kg/m³ and S': slag content was 300 kg

Cubical molds of size 15 cm X 15 cm X 15 cm were filled with geopolymer concrete mixtures in three layers and compacted by a vibrating table until full compaction was observed. The molds were stored in a laboratory condition for 24 hrs; this period is known as the rest period fixed for all specimens. After that, the cubes were demoulded and left for curing under the ambient condition during March where the temperature of the surrounding recorded was 17/8 as a maximum/minimum for an additional 48 hrs. Before testing the specimens at the age of 3 days. In the present study this early age was considered as a basis for evaluating all specimens to develop ambient cured geopolymer pervious concrete with a sufficient strength that could be used for practical application of pavement construction. It was reported [12] that geopolymer concrete has a high rate of strength development, where, the ratio of 7 days to that of 28 days strength was more than 83%.

2.3 Testing

*Flow Test.* The workability of GPPC mixtures was determined using flow table test apparatus according to ASTM C1437 in which the increase in diameter of spread mixture over the base diameter of the molded material, calculated from the following formula.

\[ \text{Flow ()} = \frac{\text{spread dia(cm)}}{25} \times 10 \]
Compressive strength. The compressive strength was measured by BS EN 12390-3 at the age of 3 days. Specimens were placed in a direction perpendicular to the direction in which they were cast. Rate of loading was maintained at 0.3 MPa/sec, and the testing was performed by a compression machine name with a capacity of 2000 kN and precision of 0.1 kN.

Void Content. Samples of pervious concrete were dried in the oven until they achieved a constant mass. The unit weight of the specimens was tested under oven-dry conditions and the total void content was determined by ASTM C1754-2012. The percentage of permeable voids were calculated using the following equation.

\[
Void (%) = \left[ 1 - \frac{(W_2 - W_1)}{\rho \cdot V} \right] \times 100
\]

Where;
\( W_1 \): the weight of the specimen in water,
\( W_2 \): the weight of specimen in the air at the saturated condition \( \rho \): is the density of water and
\( V \): the volume of the specimen.

3. Results and Discussion

3.1 Influence of NaOH Molarity
The effect of sodium hydroxide molarity on both the compressive strength and total void content of GPPC are presented in figure 1. It shows that (NaOH) molarity significantly affects the compressive strength and void content of GPPC specimens, where compressive strength increased with increase in the concentration of sodium hydroxide in the alkaline solution. Maximum compressive strength of GPPC was obtained by GPP-A25R1M12, which has molarity of 12. The rise of molarity from 12 Molar to 14 Molar resulted in 8% reduction in compressive strength. This finding agreed with previous researchers. According to Hardjito[13], NaOH molarity has an important influence on the strength attainment of the fly ash-based geopolymer material. Where the increase in molarity advance the rate of reaction due to an increase in the soluble silicate and the higher concentration of reactants. Wardhono [14] proved that the uppermost strength was achieved with 12 Molar of NaOH for fly-ash based geopolymer mortar at the age of 3 days.

Concerning the void content, to show a converse relationship with the compressive strength. While the results showed a continuing increase in the percentage of voids with an increase in NaOH concentration. The differences in the percentage of voids are not very high, most likely due to other factors that have more impact on the percentage of voids. It was reported [15] that void content in Portland cement pervious concrete is highly dependent on several factors such as aggregate gradation, maximum size, cementitious material content, w/cm, and compaction effort. Efforts spent for the compaction influence the total void content (and related unit weight) of a given pervious concrete mixture. It has been concluded that the level of compaction must be considered in the design of the pervious concrete mixtures. Generally, geopolymer concrete mixtures are sticky with a viscous nature in a fresh state that requires more compactive efforts than conventional concrete.
3.2 Influence of Sodium silicate to Sodium hydroxide (SS/SH) ratio.
The effect of Sodium silicate-to-sodium hydroxide ratio on the compressive strength and total void content of GPPC are presented in figure 2. It can be noticed that compressive strength decreased with increasing the ratio of sodium silicate-to-sodium hydroxide. Morsy et al. [16] reported that increase in Na₂SiO₃/NaOH ratio would reduce the compressive strength, as extra sodium silicate in the structure of geopolymer inhibits evacuation of water and retard the formation of geopolymer structure. It is shown that geopolymer mix of SS/SH =1, achieved the highest compressive strength of 27.65 MPa at the age of 3 days. Skvara et al, [17] from his experimental work on fly-ash based geopolymer concrete concluded that leaching of Si and Al depends on SS/SH ratio, where at low SS/SH ratio, leaching of Si was higher than of AI this probably was the cause of highest geopolymer gel formation that had a homogenous microstructure and lowest percentage of voids. For mixtures with SS/SH ranged between 1 and 3.5 the percentage of voids followed inverse relationship with the compressive strength, where this result is normal. The compressive strength decreased by 56%, and void content increased by 28%.

3.3 Influence of AAS/Slag
The effect of alkaline solution-to-Slag ratio on the compressive strength of GPPC specimens is shown in figure 3. The ratio by mass was varied as 0.25, 0.3 & 0.35; these ratios were selected approximately Similar to the typical w/cm ratios of pervious concrete made by Portland cement. According to ACI 522-10 [18], pervious concrete should be proportioned with a relatively low w/cm ratio that within the range of 0.27 to 0.43 to obtain the desired workability.

It can be seen that increase in AAS/Slag ratio increased the compressive strength. A rapid increase in the compressive strength from 22.7 to 30 MPa occurred with increasing the alkaline activator/slag ratio from 0.25 to 0.30, followed by a slight increase in compressive strength from 30.0 to 31.7 MPa. The relationship between AAS/Slag ratio and compressive strength was expected to be inversely proportional because increasing AAS increased the amount of water in the preparation of alkaline liquid and a substantial increase in the number of pores. Results revealed that the alkaline activator/Slag ratio of 0.35 has the highest amount of alkaline liquid, which shows the highest rate of geopolymerization compared to other ratios. As a result, the most upper compressive strength of 31.7 MPa was achieved at the age of 3 days cured under the ambient condition.
Figure 2. Effect of Sodium Silicate-to-Sodium hydroxide ratio (SS/SH) on both the Compressive strength and total void content of GPPC

![Graph showing the effect of Sodium Silicate-to-Sodium hydroxide ratio on compressive strength and total void content.]

Figure 3. Effect of AAS/Slag ratio on the compressive strength of GPPC

![Graph showing the effect of AAS/Slag ratio on compressive strength.]

4. Conclusions and Recommendations

From the obtained results, the following conclusions are drawn.

- The highest compressive strength for GPPC achieved was 27.5 MPa at NaOH molarity 12 and slag content of 325 kg/m³ at the age of 3 days.
- Increase in molarity of NaOH increased total void content of GPPC specimens.
- Increase in sodium silicate-to-sodium hydroxide ratio decreased the compressive strength, where the ratio of SS/SH = 1 produced the highest compressive strength.
- Increase in sodium silicate-to-sodium hydroxide ratio increased total void content.
- Increase in alkaline solution-to-slag ratio increased the compressive strength, where the highest compressive strength achieved was 31.7 MPa at molarity 14, slag content 350 kg/m³ at the age of 3 days.
It is recommended to study the effect of different ambient curing conditions to find the best sunlight temperature convenient for the production of ambient cured geopolymer pervious concrete in addition permeability or infiltration rate and the durability under different exposure conditions are required for further investigations.

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References
[1] Davidovits J 1994 Properties of geopolymer cement, Proceedings First International Conference on Alkaline Cement and Concrete, Kiev Ukraine, pp 131-149
[2] Juenger M C G, Winnefeld F, Provis J L and Ideker J H 2010 Advances in alternative cementitious binders Cement and Concrete Research, 41: pp 1232–43
[3] Zende R and Mamatha A 2015 Study on Fly Ash and GGBS based Geopolymer Concrete under ambient curing JETER, Vol. 2, Issue 7: pp 3082–87
[4] Tabassum R K and Khadwal A 2015 A Brief Review on Geopolymer Concrete International Journal of Advanced Research in Education Technology LIJRET Vol.2, Issue 3: pp 70-73
[5] Ambily P S, Madheswaran C K, Lakshmanan N, Dattatreya J K and Sathik SA 2012 Experimental Studies on shear behaviour of reinforced Geopolymer Concrete thin webbed T-Beams with and without fibers International Journal of Civil & Structural Engineering IJCASE Vol. 3 No.1: pp 128–40
[6] Nath P and Sarkar P K 2014 Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition Construction and Building materials Journal, Vol. 66: pp 163–71
[7] Mathew B J, Sudhakar M and Natarajan C 2013 Strength, Economic and Sustainability Characteristics of Coal Ash-GGBS Based Geopolymer Concrete International Journal Of Computational Engineering Research, LICER online), Vol. 3 Issue 1: pp 207-12
[8] Supraka V and Kanta Rao M 2019 Experimental study on Geopolymer concrete incorporating GGBS International Journal of Electronics, Communication & Soft Computing Science and Engineering Volume 2, Issue 2: pp 11-15
[9] Ganapati Naidu P, Prasad A S S N, Adiseshu S and Satyanarayana P V V 2012 A Study on strength properties of Geopolymer Concrete with Addition of G.G.B.S International Journal of Engineering Research and Development (IJERD) Volume 2, Issue 4: pp 19-28
[10] Krishnarao M P 2013 Design of Geopolymer Concrete International Journal of Innovation Research in Science, Engineering and Technology (IJIRSET) Volume 2 Issue 5
[11] Quasrawi H, Shalabi F and Asi I 2009 Use of low CaO unprocessed steel slag in concrete as fine aggregate, Construction, and Building Materials, 23(2): pp 1118-1125
[12] Al-Shather B S, Al-Attar T S and Hassan Z A 2016 Effect of curing system on metakaolin based geo- polymer concrete. Journal of Babylon University, Engineering Sciences, 24, pp 569-576
[13] Hardjito D, Cheak C C and Lee I C H 2004 Strength and Setting Time of Low Calcium Fly Ash- based Geopolymer Mortar. Mod. Appl. Sci., 2(4): pp 3-11
[14] Wardhono A 2018 The Effect of Sodium Hydroxide Molarity on Strength Development of Non-Cement Class C Fly Ash Geopolymer Mortar, J. Phys.: Conf. Ser. 947 012001
[15] Meiningr R C 1988 No-fines pervious concrete for paving CI magazine ACI publications, Vol. 10 Issue: 8m pp 20-27
[16] Morsy M S, Alsayed S, Al-Salloum H Y and Almusallam T 2014 Effect of Sodium Silicate to Sodium Hydroxide Ratios on Strength and Microstructure of Fly Ash Geopolymer Binder, Arab J Sci Eng, 39: pp 4333–39
[17] Skvara F, Kopecky L, Nimeeek J and Bittnar Z 2006 Microstructure of geopolymer materials based on fly ash. *Ceramics Silikaty* **50**, pp 208–215

[18] ACI 522R, 2010, Report on Pervious concrete, American Concrete Institute, Farmington Hills, MI –USA (Reapproved 2011)