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Research Article

The effect of permeability and mechanical properties of low-calcium fly ash based geopolymer concrete

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Abstract

Preserving the environment by reducing carbon dioxide emissions from cement production is one of the most significant current sustainability requires. This can be achieved by identifying an alternative that has characteristics similar to those of cement, by suggesting geopolymer concrete as a substitute for normal concrete. This article presents the findings of an experiment conducted to examine the effects of permeability and mechanical properties of geopolymer concrete based on low-calcium fly ash. Also, investigate possible relationship between permeability and strength properties. The experiments were conducted by varying the curing condition (24, 70°C), alkali activator to fly ash ratio (0.45, 0.5. 0.55) and dosage of superplasticizer (1.5%, 2%, 2.5%). It was found curing samples at higher temperatures (70°C) has been shown to increase strength properties. Whereas the improvement was 32%, 15% and 23% for each of the compressive strength test, modulus of elasticity and flexural strength respectively. While the improvement value for absorption was 2.6%, and 19% for the sorptivity. It was discovered that samples with an alkali to fly ash ratio (0.45) had better strength characteristics. Where the compressive strength was improved by 36%, and 27% for the absorption. Also, greater strength loss is observed in samples that contain higher superplasticizer dosages (1.5%) than in samples with lower comparable values. With a 30% improvement for both compressive strength and absorption tests. Correspondingly, more strength was lost by samples with higher water absorption and sorptivity than by samples with lower comparable values. The experimental program's results show that the sorptivity and water absorption of the samples influence the mechanical characteristics of geopolymer concrete.

1. Introduction

An innovative and eco-friendly alternative to conventional concrete is geopolymer concrete. The aluminosilicate binder material (fly ash, silica fume, metakaolin, blast furnace slag, waste glass, iron slag, copper mine tailings, and red mud) is polymerized with an alkaline activator (potassium hydroxide, sodium hydroxide, or sodium silicate/carbonates soluble in water) to produce geopolymer concrete, which is a substitute cementitious material [1]. Since geopolymer concrete can be used entirely in a zero-cement composite by using industrial waste and metakaolin such fly ash, silica fume and slag to create new binders it has attracted a lot of attention recently [2]. The same as to Portland cement, geopolymer concrete offers excellent mechanical, durability, and thermal stability properties. Furthermore, throughout the manufacturing process, it uses less energy and releases less carbon dioxide (CO_2) [3-5]. In contrast with normal concrete which utilizes raw materials, the geopolymer concrete uses industrial waste materials as a source material that making it an ideal choice as well as to its status as sustainable material [4]. Subsequently, the geopolymer concrete has a lower calcium concentration than normal concrete and the durability

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problems are greatly reduced. This contributes to the production of geopolymer concrete from polymeric sodium aluminosilicate hydrate gel (N-A-S-H), compared to conventional concrete that made from calcium silicate hydrate gel (C-S-H) [5].

Arunkumar et al. [6] stated that the low-calcium fly ash is used as a binder for creating geopolymer concrete. To achieve the strength characteristics, the fly ash-based geopolymer concrete needs a high concentration of alkaline solution and a 24 hrs heat curing time at 60˚C. Additionally, Ameri et al. [7] study the optimal curing temperature and alkali activator/binder ratio. The results demonstrated that the alkali activator/binder ratio was 0.55 and the compressive and flexural strengths were strong when heat curing at about 90˚C. Therefore, temperature curing is required to produce geopolymer concrete with the appropriate strength characteristics. Nevertheless, since the temperature promotes the geopolymerization process at high moderate temperatures (between 80 and 90 ˚C) the geopolymer concrete samples demonstrated greater compressive strengths [8]. According to the research by Görhan and Kürklü's [9], the compressive strength increases when heat curing (at 65 and 85°C) is increased from 5 to 24 hrs. It was obtained that curing for longer than 24 hrs had no apparent effect on strength.

The microstructure of the materials used for producing the geopolymer concrete matrix determines its strength, which also has significant effects on the matrix's permeability [5]. The porosity has a greater impact on concrete strength than the other characteristics. Consequently, porosity has been identified to be a significant factor influencing the strength of concrete [10]. The effect is also caused by the discontinuous structure of the micro and meso pores. Therefore, it is important to be aware when analyzing information collected by porosimeter because the fine gel pores of geopolymers might obscure the larger pores. A concentration of stress could result from these micros and meso pores. They typically serve as the source of microcracks, which decreases the elastic modulus and mechanical strength [11].

In research carried out by Farhana et al. [12], It was concentrated on the suitable curing conditions, such as curing at 75°C for 18–24 hrs, which produced the geopolymer concrete with low volume of permeable pores and low sorptivity coefficient. In general, increasing the porosity of the geopolymer concrete decreased the compressive strength [13]. Similar findings were noted by Mustofa & Pintowantoro [14] who found a relationship between the compressive strength of geopolymer concrete and its water absorption. When the compressive strength is higher, the more homogeneous and denser the microstructures produced, and it tends to reduce water absorption. The previous studies that are relevant to this study are shown in Table 1.

Table 1. Summary about the previous studies that related to this research study

Author /s	Binder type	Alkali Solution /Binder	Curing T. (˚C)	Properties Examined	Remarks
Josepha et al. [15]	-Low calcium fly ash	- 0.55	100˚C for 24hrs	Compressive, tensile, and flexure strength, modulus of elasticity.	- After 24 hrs of curing for the cube at 100°C, 96.4% of compressive strength for the cube was achieved in 7 days instead of 28 days. - The split and flexural strength increased by 45.5% and 30.6%, respectively
Partha et al. [16]	-Fly ash (class F) - GGBS	- 0.37 - 0.4	Amb. curing at 17–22˚C And 70±10% RH	Compressive, tensile, and flexure strength, Sorptivity and volume of permeable void.	- The compressive strength of geopolymer concrete varies from 27 to 47 MPa. - Within the increase of the slag content, the water absorption is decreased.
Ramujee et al. [17]	- Fly ash	- 0.35 - 0.4 - 0.45	60˚C for 24 hrs	Compressive and tensile strength.	- The geopolymer concrete reaches its target strength much faster when cured in an oven compared to ambient cured conditions.

Yifei Cui et al. [18]	-Fly ash (class F)	- 0.5	80˚C for 24 hrs	Compressive and tensile strength, modulus of elasticity, and microstructural properties.	- The compressive strength in 7 days varies within a range of values between 28.99 and 46.18 MPa. - The splitting strength ranged between 2.66 and 4.19 MPa. - The elastic modulus values changed between 16.74 and 24.2 GPa.
Ylmaz et al. [19]	-Low calcium fly ash	- 0.5	-Amb. curing (20±3˚C and RH 65± 10%) -Heat curried (40˚C, 60˚C , and 80˚C) for 24, 48, and 72 hrs	Compressive strength, flexure strength, water absorption, void ratio, freeze–thaw conditions, and resistance to elevated temperatures.	- The maximum value of compressive strength was achieved at 80°C after 72 hrs of curing. - The curing time and temperature significantly reduced the weight loss in geopolymer mortars subjected to high temperatures.

Through reviewing previous studies, the most of these studies focus only on mechanical properties. This research aimed to find study related to permeability characteristic, and try to cover this gap. Three parameters have been considered:

- The effect of curing condition (24, 70˚C).
- The effect of alkali activator to fly ash ratio (A/F).
- The effect of superplasticizer content (S.P).

An environmentally friendly substitute for Portland cement is geopolymer concrete. Because of its strength, durability, and lower environmental effect, the optimum mix design was utilized in this study to contribute to real-life applications in a variety of construction sectors, including infrastructure, restorations, and pavements. Thus, the aim of this study was to enhance the characteristics of geopolymer concrete in order to simultaneously decrease permeability and increase strength.

2. Experimental Program

2.1. Materials

The primary components of the materials used in this research are fly ash as a binder, fine and coarse aggregate as aggregate, water, superplasticizer as a high range water reducer, and sodium hydroxide and sodium silicate as an alkaline activator. Low calcium fly ash (class F) from the EUROBUILD company has been used in this research as a source of silicates and aluminum. Table 2 illustrates fly ash's chemical composition and Figure 1 show the low calcium fly ash (class F) that used in this research.

Fig. 1. Low calcium fly ash (class F)

Table 2. Chemical analysis of fly ash

Com.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	MnO	Fe_2O_3
Mass %	0.08	1.27	25.39	47.69	0.16	0.37	1.56	7.93	0.14	11.72

The fine aggregate that has been used in this research was natural river sand. River sand has a fineness modulus of 2.96 and a specific gravity of 2.67. The sand sieve analysis is shown in Table 3, while the grading of the used fine aggregate is shown in Figure 2-a. Crushed gravel with a maximum particle size of 14 mm was used as the coarse aggregate in geopolymer concrete mixes. The physical properties of coarse aggregate are explained in Table 3, and the grading of the used coarse aggregate is shown in Figure 2-b. The fine and coarse aggregate that has been used in this research are shown in Figure 3 (a and b).

Table 3. Physical Properties for fine aggregate and coarse Aggregate

Physical properties	Fine Aggregate	Coarse Aggregate
Specific gravity	2.67	2.65
Absorption	0.48	0.4
Sulphate content	0.072	0.065
Fineness modulus	2.96	2.96

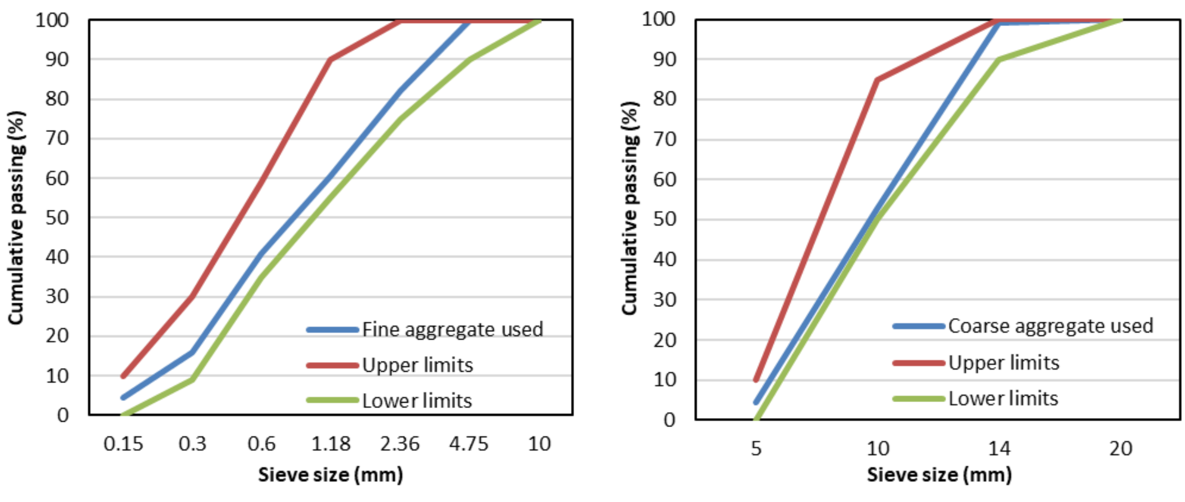

Fig. 2. Sieve analysis of (a) fine aggregate, (b) coarse aggregate

(a) (b)

Fig. 3. The aggregate (a) fine aggregate, (b) coarse aggregate

The fly ash-based geopolymer concrete has been generated more workability by adding a high rang water reducer (Type GS). This type of superplasticizer is based on modified sulfonated naphthalene formaldehyde condensate and conforms to (ASTM C494–2005, Type F) as shown in Figure 4-a.

In this research the Pure water has been used to produce various concrete mixtures, the preparation of the alkaline activator that uses in the mixture by a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions as shown in Figure 4-b. Table 4 shows the properties of sodium hydroxide and sodium silicate solutions, respectively.

Table 4. Properties of sodium silicate and sodium hydroxide.

Sodium silicate		Sodium hydroxide	
Properties	Value	Properties	Value
Ratio of SiO_2/Na_2O	2.4	Chemical formula	NaOH
Na_2O% by weight	13.4	Molecular mass	40
SiO_2% by weight	32.5	Sodium hydroxide NaOH%	99.3
Density-20°Baume	51	Sodium carbonate Na_2CO_3%	0.6
Specific Gravity (g/cm³)	1.54	Sodium chloride NaCL	0.01
Appearance	Hazy	Sodium sulphate Na_2SO_4(ppm)	50
-	-	Iron oxides	0.002

(a) (b)

Fig. 4. (a) Superplasticizer (b) The alkaline activator

2.2 Casting and Curing of Samples

A sodium hydroxide solution was prepared by dissolving a pellet of sodium hydroxide in distilled water. The NaOH solution's 8 M concentration was maintained for all mixture. The solution left to complete the interaction for at least 24 hrs before using it. For improving the workability, superplasticizer added to the alkaline liquid to obtain in the end final alkaline liquid. One day after the prepared alkaline liquid, the casting process begins by combining the dry material (fly ash and aggregate) in a pan mixer for three minutes, as shown in Figure 5.

The next step, fresh concrete was produced by mixing the dry materials with the alkaline liquid in a pan mixer for more than four minutes. Subsequently, the preparation of the wet mixture was immediately put into molds. A compaction done by manual strokes and then by applying vibrating table for 15-20 second as shown in Figure 6.

After casting the samples were wrapped in nylon to prevent excessive evaporation. The samples were placed in an oven set at 70°C for 24 hrs after casting (this is the specific rest period for this work). This procedure was performed according to the common degree from previous studies, which was taken into consideration in this study. The samples were taken out of the oven and stored in the laboratory until the day of the test. These steps are illustrated in Figure 7, while the mix design of all geopolymer concrete mixtures produced in this study is presented in Table 5.

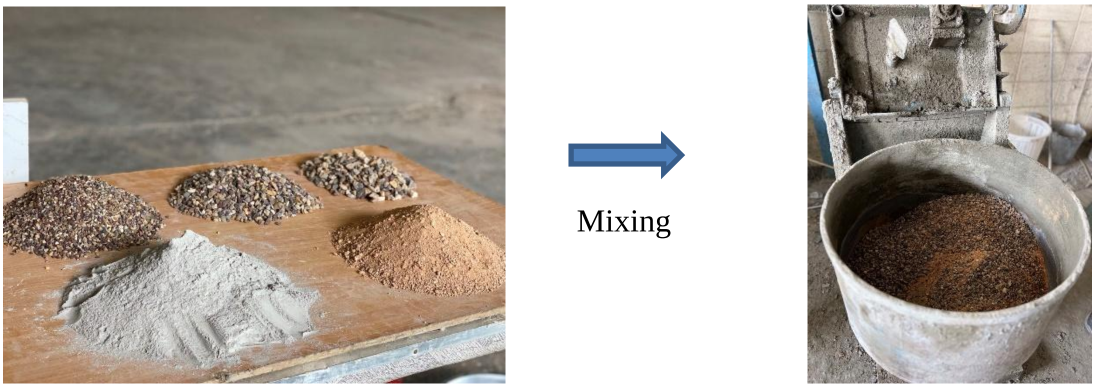

Fig. 5. Dry material (fly ash and aggregate) before and after mixing

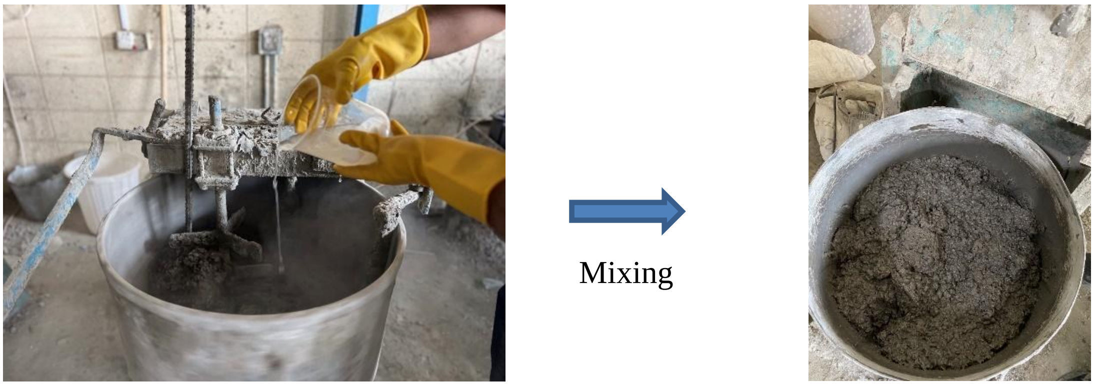

Fig. 6. Preparation the wet mixture

Fig. 7. The steps of curing geopolymer concrete mixes

Table 5. The mix design of geopolymer concrete

Details	Mixes	Coarse (kg/m^3) 12.5 mm	Coarse (kg/m^3) 10 mm	Coarse (kg/m^3) 5 mm	Sand (kg/m^3)	Fly ash (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	S.P	A/F	Curing T.
GM-1	GM11	300	400	495	670	400	51	129	1.5%	0.45	Amb.
	GM12	300	400	495	670	400	51	129	1.5%	0.45	70°C
GM-2	GM21	300	400	495	670	400	51	129	1.5%	0.5	70°C
	GM22	300	400	495	670	400	51	129	1.5%	0.55	70°C
GM-3	GM31	300	400	495	670	400	51	129	2%	0.45	70°C
	GM32	300	400	495	670	400	51	129	2.5%	0.45	70°C

2.3 Testing Program

The geopolymer concrete was filled in layers of slump cone and compacted with a tamping rod in three layers. Slump test was done immediately after mixing according to ASTM specifications (ASTM C143-03), and the fresh density for geopolymer concrete was done according to (ASTM C138-01a). According to (ASTM C642-2004), cubes of 100 mm were used for the water absorption test. The water absorption is usually measured by drying the samples in an oven at 105°C until its weight remains constant. After the cubes getting dried, the samples were submerged in water for 7 days until their weight remained constant. The water absorption test for the geopolymer concrete is shown in Figure 8-a. Oven dried samples of 100 mm were placed in a pan and submerged in water level about 5 mm above the bases of the samples. The bottom sections of the samples sides that flanked the inflow face were covered with waterproof adhesive to stop water absorption. Figure 8-b shows the sorptivity measurement for geopolymer concrete.

(a) (b)

Fig. 8. Permeability test (a) absorption, (b) sorptivity

The compressive strength of mixes was measured according to (B.S 1881:part 116 :1989) as shown in Figure 9-a. For each mix of 100 mm cubes were tested at age of 1,7, and 28 days from casting within loading rate of 0.3 MPa/s. Three cubes were tested for each mix, and the average was determined. The cylinder samples of 150 × 300 mm loaded under a testing equipment within 3000 kN capacity is used to measure the modulus of elasticity. The modulus of elasticity for the geopolymer concrete samples tested at age 28 days is calculated by averaging three samples using a digital extensometer dial gauge with an accuracy of 0.002 mm fixed around the cylinder according to (ASTM 469-02) as shown in Figure 9-b. The flexural tensile strength for the geopolymer concrete samples that shown in Figure 9-c, has been conducted on prismatic samples measuring of 100 x 100 x 400 mm under two-point loading using a hydraulic testing machine (LIYA) with a 200 kN capacity according to (ASTM C78-02). The average of three samples was used to determine the flexural strength at 28 days of age.

(a) (b) (c)

Fig. 9. Mechanical test (a) compressive strength (b) modulus of elasticity (c) flexural strength

3. Results with Discussion

3.1 Fresh properties Results

The slump values of geopolymer concrete mixtures are shown in Table 6. It shows that the slump values of the geopolymer concrete base mix (GM11 and GM12) had slump ranging values from 35 to 40 mm. The results show that the increase in A/F ratio to (0.5 and 0.55) increases the workability of (GM21 and GM22) mixes between 60-80 mm compared to the control mix (GM12). According to Ketana et al. [20] the workability will increase when increasing the alkali activator solution (AAS) to fly ash (FA) ratio (AAS/FA) in geopolymer concrete. In addition, Memon et al. [21] showed that the workability of the freshly produced geopolymer concrete was determined to be affected by the alkaline activator/fly ash ratio, and the effect increased as the ratio increased from (0.3 to 0.4). While using higher S.P dosages (2% and 2.5%) in (GM31 and GM32) mixes, it leads to increasing the workability and thus increasing the slump between 110-120 mm compared with the control mix, respectively. Superplasticizer is frequently used to enhance the fresh characteristics of concrete and obtain good flowability for the fresh mix [22]. Additionally, the workability of fresh geopolymer concrete enhanced with the commercially available superplasticizer based on naphthalene [22]. Figure 10 shows the slump test results for geopolymer concrete base mix (GM12), geopolymer concrete (GM21) mix, and geopolymer concrete (GM31) mix.

Table 6. Slump values for geopolymer concrete mixes

Mix	GM11	GM12	GM21	GM22	GM31	GM32
Slump (mm)	38	40	100	114	150	162

(a) (b) (c)

Fig. 10. Sump test: (a) geopolymer concrete base mix (GM12) (b) geopolymer concrete (GM21) mix (c) geopolymer concrete (GM31) mix

All geopolymer concrete mixes had fresh density values between 2400 and 2500 kg/m3, according to the fresh density test results. The fresh density of all geopolymer concrete mixtures is shown in Table 7.

Table 7. Fresh density of all geopolymer concrete mixes

Mix	GM11	GM12	GM21	GM22	GM31	GM32
Fresh density (kg/m^3)	2453	2493	2502	2447	2483	2461

3.2 Permeability Tests

The Permeability properties of mixes can be evaluated based on the water absorption, and sorptivity.

3.2.1 Water Absorption

By measuring water penetrability, such as sorption, permeability, and absorption, the concrete durability can be controlled. Diffusion, absorption, and permeability through porous material allow liquid penetration into concrete through it. In addition to this, pores in concrete are crucial for permitting liquid to flow through the substance [23]. Mahmoud et al. [24], show that the water absorption and permeability for the dense microstructure of geopolymer concrete reduced by 38% and 64.6%, respectively when compared to conventional concrete. The difference in water absorption between all geopolymer concrete mixes is shown in Figure 11. The results show that using ambient curing temperature leads to increasing the water absorption of the (GM11) mix by about 2% compared to the control mix (GM12). In terms of A/F ratio, the water absorption of the (GM21 and GM22) mixes increase by 25% and 30%, when A/F ratio was increase to 0.5 and 0.55, respectively. Also, it shows that the uses of the high dosage of S.P (2% and 2.5%) leading to an increase in the water absorption of the (GM31 and GM32) mixes by 55% and 58% compared with control mix. Furthermore, the results show that because of the high range water reducing admixture air entraining effect, the high range water reducing admixture will increase the porosity [25].

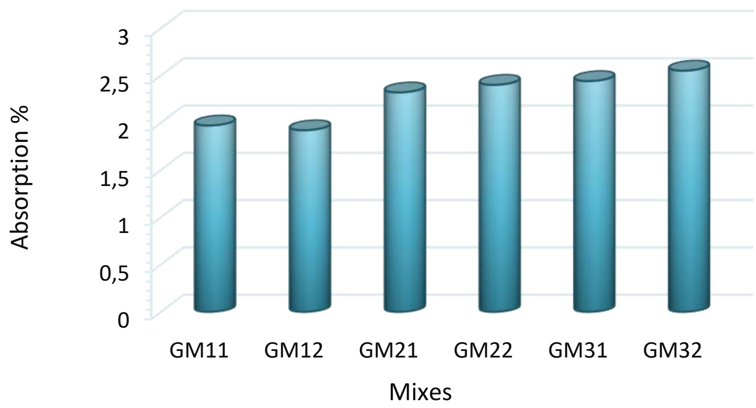

Fig. 11. Water absorption of geopolymer concrete mixes

3.2.2 Sorptivity

Concrete durability can be determined by a water sorptivity test which measures a medium's capacity to absorb or desorb liquid by capillarity (the flow of liquids in porous materials produced by the surface tension of capillaries). [26]. The geopolymer concrete mixes showed lower sorptivity in comparison to the conventional concrete mix within a water/cement ratio of 0.50 (about 40 MPa strength level) [23]. Concrete that has a lower sorptivity shows higher resistance to absorbing water. A high sorptivity value indicates a closely connected porous structure or low tortuosity of the pore network [12].

The ambient curing temperature that used in (GM11) mix leading to increasing the sorptivity by about 18% compared with control mix (GM12), while the elevated curing temperature that used helped in reducing the sorptivity of geopolymer concrete. The results show that curing at 75°C for 18 to 24 hrs produced geopolymer concrete with a low volume of permeable voids and a low sorptivity coefficient [12]. According to Gunasekara et al. [27], the geopolymer concrete shows an interconnected pore network within a variety of pores having different diameters when heat curing for the samples within 4, 8, and 12 hrs. In terms of A/F ratio, the sorptivity of the (GM21 and GM22) mixes increased when A/F ratios were increased to (0.5 and 0.55) by 16% and 18% compared with the control mix. Also, the use of the high dosage of S.P (2% and 2.5%) leads to an increase in sorptivity of the (GM31 and GM32) mixes by 27% and 40% compared with the control mix (GM12). The sorptivity test results for each geopolymer concrete mix are shown in Figure 12.

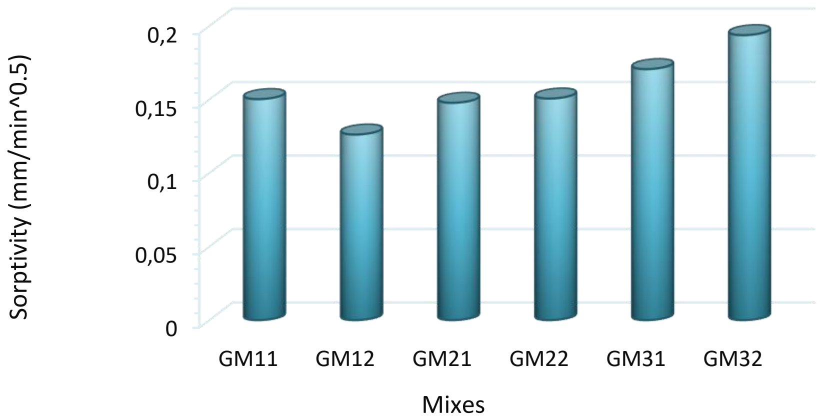

Fig. 12. Sorptivity of geopolymer concrete mixes

3.3 Mechanical Properties

The mechanical properties of mixes can be evaluated based on the compressive strength, modulus of elasticity, and flexural strength.

3.3.1 Compressive strength

In terms of curing temperature, our research results show a significant improvement by about 32% in compressive strength that was achieved by curing the concrete samples at a higher temperature (GM12) mix in 28 days. Bhavsar et al. [22] established that curing the geopolymer concrete samples at a higher temperature and longer curing period results in higher compressive strength. Gunasekara et al. [28] studied the effect of increasing the curing temperature on strength of geopolymer concrete samples, the results showed that strength increased when the curing temperature increased from 30°C to 75°C, with a maximum strength of 50.0 MPa achieved at an optimal temperature of 75°C. Also, the results in our research show that using a high A/F ratio resulted in decreasing the compressive strength of the (GM21 and GM22) mixes compared with the conventional geopolymer concrete mix (GM12) by about 24% and 30%, respectively.

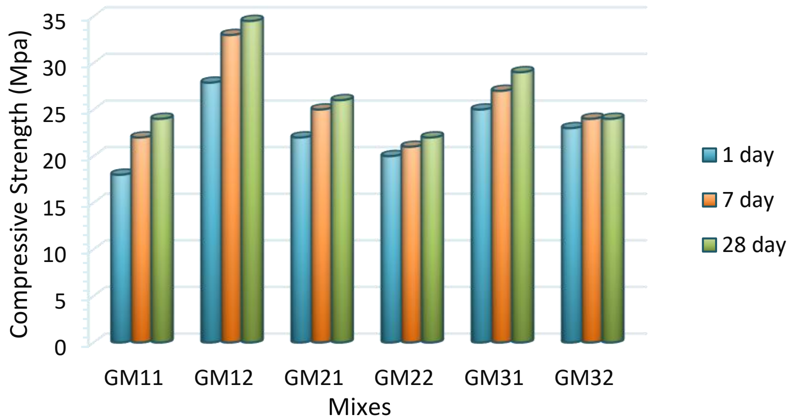

Fig. 13. Compressive strength of geopolymer concrete mixes

Mustafa et al. [29] stated that the geopolymer concrete samples that made within alkaline solution/fly ash ratios of 0.35 and 0.40 resulted in a higher compressive strength and more homogenous matrices. This illustrates how porosity of matrices influences compressive strength. Therefore, the compressive strength will increase as porosity reduces [10]. Furthermore, our research results shown that in terms of S.P, increasing dosage of S.P to (2% and 2.5% leads to a decrease in the compressive strength of the (GM31 and GM32) mixes by about 15% and 28%, respectively. Figure 13 shows the effect of using different parameters on the compressive strength of geopolymer concrete at 1, 7, and 28 days.

3.3.2 Modulus of Elasticity

In terms of curing temperature, our research results demonstrated that when using room temperature curing, it will decrease the modulus of elasticity at age 28 days for (GM11) mix by 19% compared with control mix. Noushini et al. [27] stated that the heat curing has been identified to significantly increase the temperature of the chemical reaction (alkali-fly ash) that occurs in 100% fly ash-based geopolymer concrete. The development of the microstructure and the transformation of the structure of the geopolymer concrete from amorphous to crystalline during heat curing [27]. Also, the results in our research show that in terms of A/F ratio, the modulus of elasticity of the (GM21 and GM22) mixes decrease when A/F ratio is increased to (0.5 and 0.55) by 11% and 22% compared with control mix. Aliabdo et al. [25] found that after 28 days, the modulus of elasticity of the fly ash-based geopolymer concrete was affected by the ratio of alkaline solution to fly ash. Evidently, the alkaline solution to fly ash ratio affects the 28-day modulus of elasticity similar to that of compressive and tensile strengths. Furthermore, our research results shown that in terms of S.P dosage, increasing dosage of S.P to (2% and 2.5% leads to a decrease in the modulus of elasticity of the (GM31 and GM32) mixes compared with control mix by about 23% and 25%, respectively. The decrease in fly ash-based geopolymer concrete characteristics is shown in compressive strength, splitting tensile strength, and modulus of elasticity, and there is an increase in porosity and absorption due to higher chemical admixture concentration because of the increase in microstructure pores [25]. Figure 14 shows modulus of elasticity of all geopolymer concrete mixes.

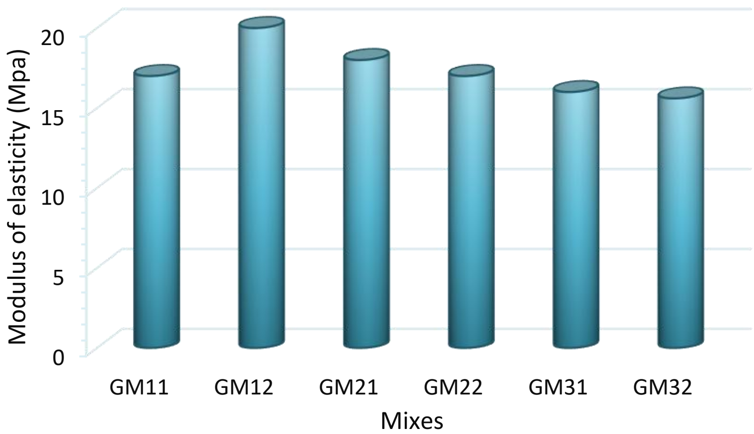

Fig. 14. Modulus of elasticity of geopolymer concrete mixes

3.3.3 Flexural Strength

The geopolymer concrete outperformed the conventional concrete in terms of flexural strength. Mustafa et al. [30] showed that after 28 days, the flexural strength of geopolymer concrete increased approximately within 13%, whereas that of conventional concrete increased only within 3%. In terms of curing temperature, our research results demonstrated that the mix (GM11) curing at room temperature shows lower flexural strength by about 6% compared with control mix (GM12) at age 28 days. Özbayrak et al. [31] show that the highest flexural strength value for geopolymer concrete was obtained after one day of oven curing at 70°C. Nath et al. [32] showed that the geopolymer concretes outperformed conventional concrete when compared in terms of flexural strength. Also, the results in our research show that in terms of A/F ratio, the flexural strength of the (GM21 and GM22) mixes decreased when A/F ratio is increased to (0.5 and 0.55) by 24% and 31% compared with the control mix. Neupane et al. [33] show that the flexural strength of the geopolymer concrete for each mixture at 28 and 90 days with different alkaline solution/binder ratios (A/B) will increase up to A/B of 4.0 and then decrease. Furthermore, our research results show that in terms of S.P dosage, increasing the dosage of S.P to (2% and 2.5% leads to a decrease in the flexural strength of the (GM31 and GM32) mixes compared with the control mix by about 7% and 9%, respectively. Figure 15 shows the flexural strength of all geopolymer concrete mixes.

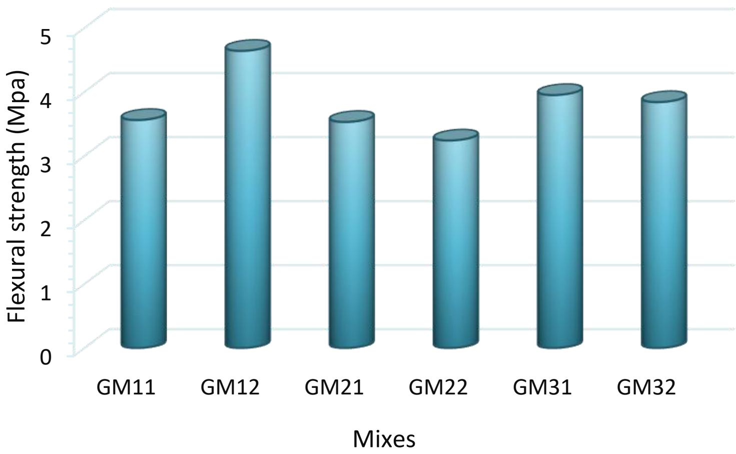

Fig. 15. Flexural strength of geopolymer concrete mixes

4. Conclusion

This study aims is to examine the consequence of the most effected parameters on permeability characteristic for the geopolymer concrete. The mechanical properties were also studied in this research and an attempt was made to link the effect of porosity to the strength properties. Three parameters were selected in this study to show the effect of: curing condition (24, 70°C), the difference in proportions of alkali activator to fly ash ratio (A/F) and the dosage superplasticizer content (S.P). The experiments were conducted on the parameters that specified in the study plan, through two experiments for each parameter. For the experiments that conducted on the first parameter (curing condition) it was found that the results of the first experiment at (24°C) was lower compared to heat temperature at (70°C) that selected in the second experiment, as there was an improvement in compressive strength by 32%, 2.6% for the absorption, and 19% for the sorptivity. When considering the experiments that conducted on the second parameter (alkali activator to fly ash ratio) it was found that the results of the first experiment for 0.45 (A/F) ratio was higher compared to 0.5, and 0.55 (A/F) ratio that used in the second experiment, as there was an improvement in compressive strength by 36%, 27% for the absorption, and 18% for the sorptivity. Finally, for the experiments that conducted on the third parameter (superplasticizer content) it was found that the results of the first experiment at 1.5% (S.P) was higher compared to 2% and 2.5% dosage superplasticizer content (S.P) that used in the second experiment, as there was an improvement within 30% in compressive strength likewise for the absorption within same ratio, and 50% for the sorptivity. The results showed that using heat curing at temperature (70°C), (A/F) at a rate of (0.45) and superplasticizer (S.P) at a dosage of (1.5%) gave the best results. Furthermore, similar trends were seen in the relationship between residual compressive strength, water absorption, and sorptivity of geopolymer concrete samples when the strength of the concrete was related to the permeability characteristic.

In further work, the researcher should focus on incorporating detailed microstructural analysis techniques such as Scanning Electron Microscopy (SEM), X-ray Computed Tomography (XCT), or Mercury Intrusion Porosimetry (MIP) to provide direct evidence of porosity, void distribution, and internal morphology of the geopolymer matrix. This will help validate the qualitative observations made in this study and offer deeper insights into the relationship between microstructure and mechanical behavior. In addition, future experimental work should include a statistically significant number of replicates for each test condition. This will enable the calculation of standard deviation, confidence intervals, and allow for statistical significance testing. Such measures are essential for improving the reliability, reproducibility, and scientific rigor of the findings.

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