

PAPER • OPEN ACCESS

Effect of Porosity and Water Absorption on Compressive Strength of Fly Ash based Geopolymer and OPC Paste

To cite this article: SitiAisyah Razak *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **957** 012035

View the [article online](#) for updates and enhancements.

You may also like

- [Fabrication, sinterability and characterization of non-colored and colored geopolymers with improved properties](#)
S E Abo Sawan, M F Zawrah, R M Khattab et al.
- [The effect of alkali activation solutions with different water glass/NaOH solution ratios on geopolymer composite materials](#)
N Doan-Salamtimur, H Öznur Öz, A Bilgil et al.
- [Development of sustainable geopolymer concrete by synergistic utilization of jarosite and GGBS](#)
Tarunkumar Pandiyan and Elavenil Solaiyan



UNITED THROUGH SCIENCE & TECHNOLOGY

 **The Electrochemical Society**
Advancing solid state & electrochemical science & technology

**248th
ECS Meeting**
Chicago, IL
October 12-16, 2025
Hilton Chicago

**Science +
Technology +
YOU!**

**Register by
September 22
to save \$\$**

REGISTER NOW

Effect of Porosity and Water Absorption on Compressive Strength of Fly Ash based Geopolymer and OPC Paste

Siti Aisyah Razak^{1,*}, Farah Farhana Zainal¹, and Shaiful Rizam Shamsudin¹

¹Center of Excellence Geopolymer Geopolymer and Green Technology (CEGeoGTech), School of Materials Engineering, University Malaysia Perlis (UniMAP) P.O. Box 77, D/A Pejabat Pos Besar, 01000 Kangar, Perlis, Malaysia.

Abstract. The fly ash based geopolymer is a promising binder by activation of fly ash with an alkaline activating solution. The fly ash based geopolymer prepared was characterized by several methods. The experimental result, studies effect of the porosity and water absorption on compressive strength of fly ash based geopolymer and Ordinary Portland Cement paste for comparison. The porosity studies were determined using the Brunauer, Emmett and Teller method included nitrogen adsorption/desorption plots. Then followed by water absorption and compressive strength tested at 7 and 28 days curing time. The result shows that the porosity of fly ash based geopolymer paste was in the lower surface area, pore volume and pore size compared to Ordinary Portland Cement paste. The small pore size of the fly ash based geopolymer had a significant proportion of a micropores whilst Ordinary Portland Cement paste pores were mostly mesopores. The highest compressive strength of fly ash-based geopolymer can be achieved up to 76.723 MPa at 28 days when less of pore size and water absorption. Therefore, the paste based on geopolymeric materials is a better durability and high resistance to aggressive environment compared Ordinary Portland Cement paste.

1 Introduction

The fly ash based geopolymer binder provides an alkaline environment that protects the steel from corrosion by forming a protective ferric oxide film. The reinforcement bar embedded in geopolymer concrete had a low corrosion rate because silicate membrane is coated strong compared to Ordinary Portland Cement (OPC) concrete [1]. But the corrosive like carbonation and chloride ions can absorb through the concrete pores to the rebar oxide layer.

The passive layer will deteriorate and leaving the rebar vulnerable to chloride attack. It is due to exposed in highly corrosive environments, thereby requiring additional help to

* Corresponding Author: ctaisyahrazak@gmail.com



prevent the corrosion occurred [2,3]. Mustafa et al. stated the primarily durability of concrete due to the deterioration corrosion of reinforced concrete, it depends on the permeability of the structure which are the damage can reduce when sealed concretes can resist the ingress of aggressive ions into the concrete [4]. Therefore, corrosion performance of geopolymer and the compressive strength of concrete were related to the porosity and water absorption percentage.

The porosity is the quantity of the total volume occupied by the pores of the sample. If the pores are disconnected and less of pore size, the percentage of water absorption is respectively low. The Brunauer, Emmett and Teller (BET) method allows measuring the pore structure of cement based materials completely and generally used this method includes nitrogen adsorption/ desorption [5]. The internal surface area of pores can be evaluated from the BET multilayer adsorption theory. Meanwhile, the pore size distribution can be obtained using Barrett–Joyner– Halenda (BJH) interpretation based on capillary condensation [6]. The pore structure of samples is characterized by the pore internal surface area, pore volume and pore size distribution. For more details into the pore size distribution, according to Tab 1, the measured pore distribution is divided into four size ranges[5].

Table 1. Range of pore size distribution.

Pore distribution	Size range
Micropores	< 4.5 nm
Mesopores	4.5–50 nm
Middle capillary pores	50–100nm
Large capillary pores	> 100 nm

According to Alehyen et al. [7] the fly ash based geopolymers using The BET method obtained porosity of cement paste. The result shows average pore sizes, total pore volumes and surface area of pores was lower than OPC. The average pore size was 1.1738 nm obtained the fly ash based geopolymer is lesser than OPC was 5.252 nm means that the geopolymeric matrix is a microporous material size range distribution. Therefore, the porosity of geopolymer is smaller than OPC.

The small pores volume and surface area for the geopolymer indicates that the geopolymer matrix is dense, which means that its permeability will be low and consequently its durability will be high [8]. Fly ash based geopolymer paste showed considerably lower pore volume than OPC paste, meaning that geopolymer paste is more compacted and dense than the OPC.

Same previous study by Mustafa et al. was observed that the porosity and water absorption of fly ash-based geopolymer concrete was in the lower range compared OPC concrete [9]. Furthermore, Thokchom et al. stated decreases porosity and water absorption can increase the compressive strength [10]. According to Suresh et. al., it is because the calcium content performs in fly ash played an important role in increasing the compressive strength and the geopolymer provided faster hardening in shorter curing time due to calcium ion produced a quick reactivity [11].

The compressive strength of concrete is the most important property. It can also be affected by these pores [12]. It can be expected that the mechanical strength of the

geopolymer will be greater than that of OPC. In fact, the porosity has been shown an inverse relationship to compressive strength, with a pore size reduced, due to increases in a material strength [13]. Farah Farhana et al. reported that the less of water absorption and porosity towards the highest compressive strength of the geopolymer paste at day 90 [8, 14].

2 Methodology

2.1 Sample Preparation

2.1.1 Geopolymer paste

The 12 molar sodium hydroxide (NaOH) solutions were prepared by dissolving the NaOH pellets in distilled water. Then, an alkaline activator was prepared 24 h prior to use with the ratio of the mixture of sodium silicate (Na_2SiO_3)/NaOH is 2.5. The optimum ratio is important in order to obtain a homogeneous solution. The prepared mixtures fly ash was placed in mould and compacted. The samples were kept at ambient temperature in the mould and taken out from the mould after 24h and then cured at 60°C in the oven for 24h.

2.1.2 OPC paste

The prepared mixture OPC with the optimum ratio of water content is 0.5. Then was placed in mould and compacted. The sample was kept at ambient temperature in mould and taken out from the mould after 24h and then cured in water for 24h.

2.2 Brunauer, Emmett and Teller

The BET method used to determine the powders of surface area and porous materials [15]. Nitrogen gas is generally employed as the probe molecule and exposed to a solid under investigation at liquid nitrogen conditions [13]. Nitrogen adsorption/desorption plots 1 g of powder were carried out under continuous adsorption conditions. Then the powders of geopolymer and OPC were heated and gas adsorption analysis in the relative pressure was used to determine the total specific area. The total pore volume and micropore volume of the powders were calculated using by t-plot analysis. The BJH method was used to obtain pore size distribution curves [15].

2.3 Water absorption

The water absorption tests were conducted according to ASTM C642-13 [16]. The percent of water absorption for these samples were determined by Eq. (1).

$$\% \text{ Water Absorption} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100\% \quad (1)$$

2.4 Compressive Strength

The compressive strength test was on fly ash based geopolymer and OPC samples using mechanical testing in order to obtain the ultimate strength were measured according to BS 1881-116:1983. The samples were compressed with 50 kN load and 5 mm/min loading rate.

3 Result and discussion

In this study, Brunauer-Emmett-Teller surface (BET) method was used to determine the pore structure of the sample. Table 2 shows parameter obtained by nitrogen absorption on fly ash based geopolymer and OPC pastes, while Fig. 1(a)(b) shows the representative pore size distribution for geopolymer and OPC pastes.

Table 2. Parameter obtained by BET method -nitrogen absorption/ desorption on fly ash based geopolymer and OPC paste.

Parameter	Geopolymer		OPC	
	7	28	7	28
Time (Days)	7	28	7	28
Surface Area (m ² /g)	2.3822	2.2719	3.5712	3.1264
Pore Volume (cm ³ /g)	0.0007	0.0006	0.0015	0.0014
Median Pore Size (nm)	1.9080	0.8235	5.3284	4.5720

According to Table 2, the fly ash based geopolymers show the data of surface area, pore volumes and median pore sizes are lower than OPC paste. The pore size 1.9080 nm and 0.8235 nm at 7 and 28 days obtained for the fly ash based geopolymer is lesser than 4.5 nm means that the geopolymer matrix is mainly a microporous material. Meanwhile, the pore size of OPC paste is 5.3284 nm and 4.5720 nm at 7 and 28 days were more than geopolymer paste. So the pore size is over than 4.5 nm, indicating that the OPC.paste is mostly composed of mesopores. Furthermore, fly ash based geopolymer paste showed lower pore volume than OPC paste, it is due to geopolymer paste is more dense and compacted than the OPC paste. The small pores volume and surface area for the geopolymer paste indicates that the geopolymer matrix is dense, which means that its permeability was low and consequently its increase the durability of paste.

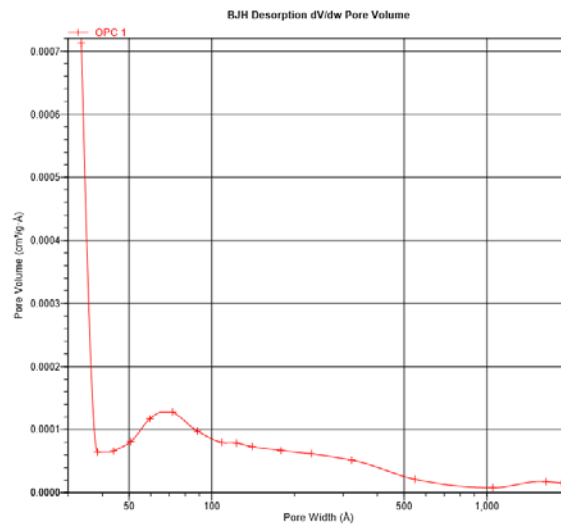


Fig. 1(a). Pore size distribution for geopolymer pastes.

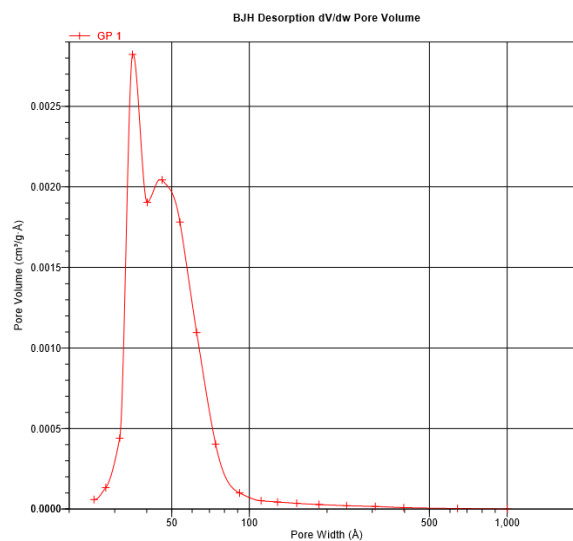


Fig. 1(b). Pore size distribution for OPC.

Fig. 1(a)(b) shows that the pore size distribution of the fly ash based geopolymer and OPC are unimodally distributed. Both of samples present an optimum pore size at 3.5710 nm and 7.0000 nm respectively meaning that the fly ash based geopolymer largely on microporosity material while mesoporosity is mostly in the OPC. More the creation of mesoporosity in OPC will be increasing the surface area and reducing the strength of cement. Besides that, the pore size also can affect the capacity of the water absorption for concrete structure. Water absorption can be used to present an open pore of concrete paste. The measurement by the difference percentage of dry weight of specimen and wet weight for fully saturated conditions.

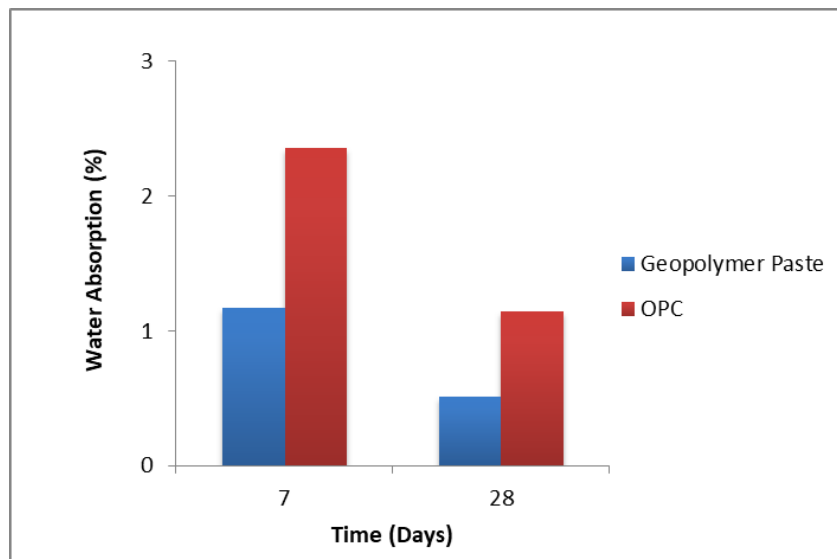


Fig. 2. The water absorption percentage of geopolymer and OPC pastes.

Fig. 2 shown that geopolymer paste has smaller water absorption percentage than OPC paste. The water absorption percentage of fly ash-based geopolymer was 1.1720 % compared to OPC was 2.3570% at day 7 and reduced respectively 0.5130% and 1.1460 % at 28 days. It has concluded, that the percent geopolymer paste of water absorption was reduced more with duration time. This show, the inclusion of less of pore size will be decreasing of water absorption capacity. The different percentage of water absorption for both samples at 7 days was 1.1850% and reduced was 0.6330% at 28 days, means that the OPC paste is more porous than geopolymer and durability can affect at early ages.

There are relationship between porosity and water absorption towards mechanical strength. The compressive strength tests of both samples were performed at 7 and 28 days and the results produced are shown in Fig. 3.

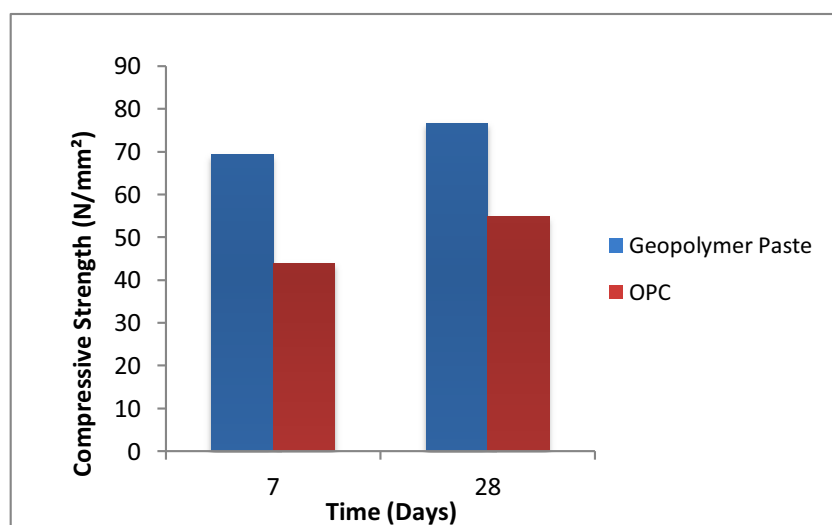


Fig. 3. Compressive strength of geopolymer and OPC pastes.

The result shown the compressive strength of fly ash based geopolymer is higher than OPC. The compressive strength simply comparable between both of the sample which is increasing steadily compressive strength with curing time. The smaller pore size and water absorption of geopolymer can increase the compressive strength greater than OPC, which is fly ash based geopolymer was 25.4240 N/mm² higher than OPC at early ages. Meanwhile, the result obtained at 28 days of testing, the highest compressive strength 76.7230 N/mm² was produced compared to OPC was 54.7490 N/mm². It was concluded that the fly ash-based geopolymer produced higher compressive strength than OPC. This has been proved through finding in this study, which is the samples with less of porosity and water absorption of geopolymer paste produced high compressive strength than OPC.

4 Conclusions

The fly ash based geopolymer with lowest porosity and water absorption had highest compressive strength while the OPC with highest porosity and water absorption had lower compressive strength. Thus, the compressive strength is related to porosity and water absorption. It can be concluded that pastes based on geopolymer materials possess is a high resistance to aggressive environment and higher compressive strength compared to OPC.

The authors would like to thank the staffs of Centre of Excellence Geopolymer & Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis (UniMAP) for their involvement in the research. This work was supported and funded by the Fundamental Research Grant Scheme (FRGS) under a grant number of **FGRS/1/2018/TK06/UNIMAP/02/2** from the Ministry of Education Malaysia.

References

1. Farhana, Z., Kamarudin, H., Rahmat, A., Al Bakri Abdullah, M., & Norainiza, S. *Adv. Mater. Res.* **795**, 509-512 (2013)
2. Reiner, I., MCI 2022 (2003).
3. S. Razak, F. Zainal and S. Shamsudin, *IOP Conf. Ser. Mater. Sci. Eng.* **701**, 012027 (2019)
4. Al Bakri Abdullah, M., Hussin, K., Binhussain, M., Khairul Nizar, I., Abd Razak, R., & Zarina, Y. *Adv. Mater. Res.* **476-478**, 2173-2180 (2012)
5. Metha P.K., Monterio P.J.M., "*Concrete, Microstructure, Properties and Materials, McGraw-Hill, London*", (2006).
6. E. P. Barrett, L. G. Joyner, and P. P. Halenda, *J. Am. Chem. Soc.* **73**(1), 373-380 (1951)
7. S. Alehyen, M. Zerzouri, M. ELalouani, M. EL Achouri, M. Taibi *JMES*, **8 (10)**, 3676-3689 (2017).
8. Farhana, H. Kamarudin, A. Rahmat and A. Al Bakri, *Mater. Sci. Forum*, **803**, 166-172 (2014)
9. Mustafa Al Bakri, A.M., Kamarudin, H., Bnhussain, M., Khairul Nizar, I., Rafiza, A.R. and Zarina, Y. *J. Rev Adv Mater Sci*, **30**, 90-97 (2012).
10. Tokchom, Partha Ghosh and Somnath Ghosh. *J. Eng. Appl. Sci.* **4**, 28-32 (2009)
11. J. G. S. Van Jaarsveld, J.S. J. Van Deventer and G. C. Lukey. *Mater. Lett* **57**(7), 12721280 (2003)

12. Asmara, Y., Siregar, J., Tezara, C., Nurlisa, W., & Jamiluddin, Int. J. Corros. 1-5 (2015)
13. Asthana R., Kumar A., Dahotre N. Materials Processing and Manufacturing Science , First Edition. United Kingdom: Butterworth- Heinemann. 656 (2006).
14. Farhana, Z., Kamarudin, H., Rahmat, A., & Al Bakri, A. Key Eng. Mater. **594-595**, 1112-1116 (2013)
15. Adamson R.W., A.P. Gast A.P. *Physical chemistry of surfaces* Ch. 17, 6th ed., Wiley, New York, (1997).
16. ASTM C642-13, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, United States (2013).