PAPER • OPEN ACCESS

Study on The Geopolymer Concrete Properties Reinforced with Hooked Steel Fiber

View the article online for updates and enhancements.

Study on The Geopolymer Concrete Properties Reinforced with Hooked Steel Fiber

M M A B Abdullah[1,2,a], M F M Tahir[1,b], M A F M A Tajudin[1,c] J J Ekaputri[3,1,d], R Bayuaji[3,1,e] and N A M Khatim[1,f]

[1] Center of Excellence Geopolymer and Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
[2] Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
[3]Civil Engineering Department, Faculty of Civil Engineering and Planning, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia

E-mail: mustafa_albakri@unimap.edu.my

Abstract. In this research, Class F fly ash and a mixture of alkaline activators and different amount of hooked steel fiber were used for preparing geopolymer concrete. In order to analyses the effect of hooked steel fiber on the geopolymer concrete, the analysis such as chemical composition of fly ash, workability of fresh geopolymer, water absorption, density, compressive strength of hardened geopolymer concrete have been carried out. Mixtures were prepared with fly ash to alkaline liquid ratio of 2.0 with hooked steel fibers were added to the mix with different amounts which are 1%, 3%, 5% and 7% by the weight of the concrete. Experimental results showed that the compressive strength of geopolymer concrete increases as the hooked steel fibers increases. The optimum compressive strength obtained was up to 87.83 MPa on the 14th day. The density of geopolymer concrete are in the range between 2466 kg/m^3 to 2501 kg/m^3. In addition, the workability value of geopolymer without hooked steel fibers is 100 mm while the workability value of geopolymer with hooked steel fibers are between 60 mm to 30 mm.

1. Introduction
Concrete is the most often used material in construction besides wood. Concrete which is a main building material is broadly used in the construction of infrastructures such as buildings, bridges, highways, dams, and others facilities. The increasing of the human population leads to the increasing the demand for the building constructions. One of the materials that is usually used as a binder in the manufacture of concrete is the ordinary Portland cement (OPC) [1].

At the same time, the amount of by-products such as fly ash produced by energy and mineral industries are increasing day by day that are currently disposed as a waste material. Fly ash is one of the coal combustion products which is composed that are driven out of the boiler with the flue gases. It is generally captured with scrubbers, electrostatic precipitators, or filter fabric baghouses in power plants, then sluiced to settling basins (wet) prior to disposal or stored in silos (dry) for disposal or sale. Fortunately, many fly ash are diverted for a good purpose in order to reduce its amount. One of the

resolution to reduce the amount of fly ash and to yield more environmentally friendly concrete is to replace OPC with these by product materials. In this respect, a new type of inorganic cementless binder called geopolymer have been discovered as an OPC replacement. Generally, many researchers suggest that Class F fly ash is more suitable to be applied for geopolymer concrete [1-3]. The most significant composition in the fly ash with regards to geopolymer concrete are silicon (Si) and aluminium (Al). The major consequence on the fly ash chemical composition comes from the type of coal. Fly ash that have higher content of calcium oxide (CaO) is claimed to produce higher compressive strength due to the development of calcium-aluminate-hydrate and other calcium compounds particularly in the early ages [4].

Geopolymer is a new inorganic polymeric material that has undergone a marked development in the past years. The geopolymer term was first used by Davidovits in its research which represents the activation of sodium hydroxide produced alumina-silicate components which was found to be as an alternative binder to the OPC [5]. Geopolymer is formed from the reaction of a source material that is rich in silica and alumina with alkaline liquid [2]. Geopolymerisation involves a heterogeneous chemical reaction between alkali metal silicate solutions and solid aluminosilicate oxides at highly alkaline conditions and mild temperatures yielding amorphous to semi crystalline polymeric structures, which consist of Si–O–Si and Si–O–Al bonds [6]. If geopolymer is compared with OPC, geopolymers show many advantages. It generally consists of covalent bonds and has such advantages as being excellent in volume stability, light in weight, fire resistant, and low in density, all of which arouse much attention from researchers [7].

Besides that, the combination of sodium silicate and sodium hydroxide solution are suitable to be used for the activation of fly ash based geopolymer concrete [8]. Hardjito stated that the most frequent alkaline liquids used in geopolymerisation is a mixture of sodium hydroxide and sodium silicate solution. The addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquids will enhanced the reaction between base materials and the solution [4]. Alkaline concentration is a huge element for controlling the leaching of alumina and silica from fly ash particles, geopolymerisation process and mechanical properties of solidified geopolymer [9]. Previous researcher also affirmed that the presence of NaOH in the alkaline activators solution can make the reaction that takes place more briskly and the gel is less smooth [10]. The most common sodium hydroxide concentration used by many researchers is 12 M. Suriya proved that the suitable molarity used for mixing of NaOH is 12 M [11].

Fiber reinforced concrete (FRC) is a composite materials made with Portland cement, aggregates and incorporating discrete discontinuous fibers. Plain and unreinforced concrete is known as a brittle material with a low tensile strength and a low strain capacity [12]. The bond between the concrete and the reinforcing steel fibers is a significant mechanism for the performance of reinforced geopolymer concrete as a composite material [13]. Several experimental done by previous researchers pointed that the utilization of fibers especially steel fibers enhanced the impact resistance of the geopolymer concrete [14].

In order to improve the properties of geopolymer concrete such as durability, ductility, flexural strength and fracture toughness, the concept of using fibers as reinforcement in geopolymer concrete is introduced. Steel, glass and synthetic fibers such as polypropylene fibers were used as a reinforcement in concrete since 1960 and the research of fibers reinforced concrete continues until today [15]. In this research, geopolymer concrete was produced by Class F fly ash as the base material and reinforced with hooked steel fibers. A mixture of sodium silicate solution and sodium hydroxide solution were used to react with aluminium and silicon in the fly ash to form the paste that bound the aggregates and steel fibers in the mixture to yield the geopolymer concrete.

2. Experimental Method

2.1. Raw Materials

The fly ash used is attained from Manjung Power Plant, Lumut, Perak which is of low calcium (Class F) is used as the base material and equivalent to ASTM C618. The chemical composition of fly ash obtained from the analysis as tabulated in Table 1 showed that the calcium oxide (CaO) content is less than 20% and the most abundant oxides in this fly ash are silica oxide (SiO_2) as the main constituents with 38.80% followed by aluminium oxide (Al_2O_3) and iron (III) oxide (Fe_2O_3) with 14.70% and 19.48% respectively.

Table 1. XRF analysis data of fly ash composition

Component	SiO_2	Al_2O_3	Fe_2O_3	TiO_3	CaO	MgO	SO_3	K_2O	MnO	BaO	SrO
Percentage (%)	38.80	14.70	19.48	1.02	18.10	3.30	1.50	1.79	0.16	0.27	0.11

Based on these results, the fly ash used can be classified as Class F type according to the ASTM C618. It is mainly pozzolanic where its silicon dioxide content reacts with the calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (CSH) gel and produced cementitious compounds which is suitable to be used in the geopolymer [16]. Besides that, this fly ash has the higher CaO content which can develop the higher compressive strength in the early ages. Other researcher also claimed that fly ash that have higher CaO content can increase the compressive strength of the concrete. It is also stated that the calcium content present in fly ash played a significance role in developing the compressive strength. The presence of calcium ions produced a quick reactivity. Thus, the geopolymer will yields quickly hardening in shorter curing time [17].

2.2. Mix Design and Process

In preparation of 12 M NaOH solution, 960 g of NaOH pellets are dissolved in distilled water in a volumetric flask for getting 12 M solution. The NaOH solution is left for settling down for 24 hours. After 24 hours, 250 g of NaOH solution and 100 g of Na_2SiO_3 solution are mixed. When both are mixed and stirred gradually, an exothermic reaction takes place and extreme amount of heat is evolved. The mixture is left for settling down about 1 hour. Hence, for safety factor, hand gloves are used. For geopolymer concrete samples, the fly ash and aggregates are dry mix. Then, alkaline activators is added to the dry mix and wet mixing is done for about 3 to 4 minutes. Lastly, hooked steel fibers is added to the wet mix in different weight such as 28 g, 84 g, 140 g and 196 g. Table 2 shows the details of mix proportions of geopolymer concrete reinforced with hooked steel fibers.

Table 2. Mix proportions of geopolymer concrete reinforced with hooked steel fibers

| Ingredients	Fly ash	Fine aggregates	Coarse aggregates	Hooked steel fibers	NaOH	Na_2SiO_3
Quantity (g)	700	700	1050	28	250	100
				84		
				140		
				196		

2.3. Curing and Moulding Process

Fresh geopolymer with or without hooked steel fibers are poured into (100x100x100) mm size cubes and (100x100x500) mm size beams steel moulds. The samples are left for 24 hours in room temperature and then they are demoulded. After that, the samples are then left in the laboratory ambient conditions until the day of testing. After 14 days, weight of samples were taken to determine density, water absorption and tested in compressive strength testing machine.

3. Results and Discussion
3.1. Workability
Figure 1 shows the slump test result of fresh geopolymer mix with and without hooked steel fibers. For geopolymer mix without hooked steel fibers (GPC 0), the workability value is 100 mm. For geopolymer mix with 1% hooked steel fibers (GPC 1), the workability value is 60 mm. The workability value for geopolymer mix with 3% hooked steel fibers (GPC 3) is 49 mm. While the workability value for geopolymer mix with 5% hooked steel fibers (GPC 5) and geopolymer mix with 7% hooked steel fibers (GPC 7) are 39.5 mm and 30 mm respectively. The trend of workability in Figure 1 shows the workability values are gradually decreased as the increasing amount of hooked steel fibers from GPC 0 to GPC 7. This may be cause by the hindrance which is provided by the hooked steel fibers to the free flow. As stated by Sunilkumar, the slump value are between 65 mm and 100 mm for the fresh geopolymer concrete while for geopolymer concrete with steel fibers, the slump value are between 28.2 mm and 27.5 mm [3]. To be conclude, as the amount of hooked steel fibers increases, the workability will be decreases.
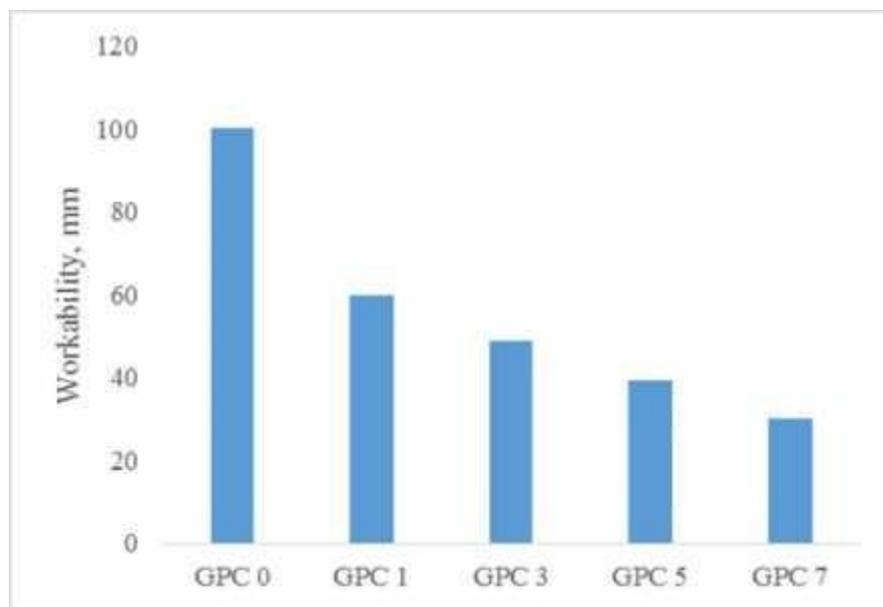
Figure 1. Workability graph for different mix of geopolymer concrete

3.2. Water Absorption
Water absorption of all mixtures are measured at the age of 14 days and the results are presented in Figure 2. According to the Figure 2, the percent of water absorption are reduced where the average absorption of GPC 0, GPC 1, GPC 3, GPC 5 and GPC 7 are 3.83%, 3.81%, 3.35%, 3.33% and 2.94% respectively. The water absorption for GPC 0 until GPC 3 declined slightly while for GPC 5 and GPC 7 decreases abruptly with the increasing of hooked steel fibers.
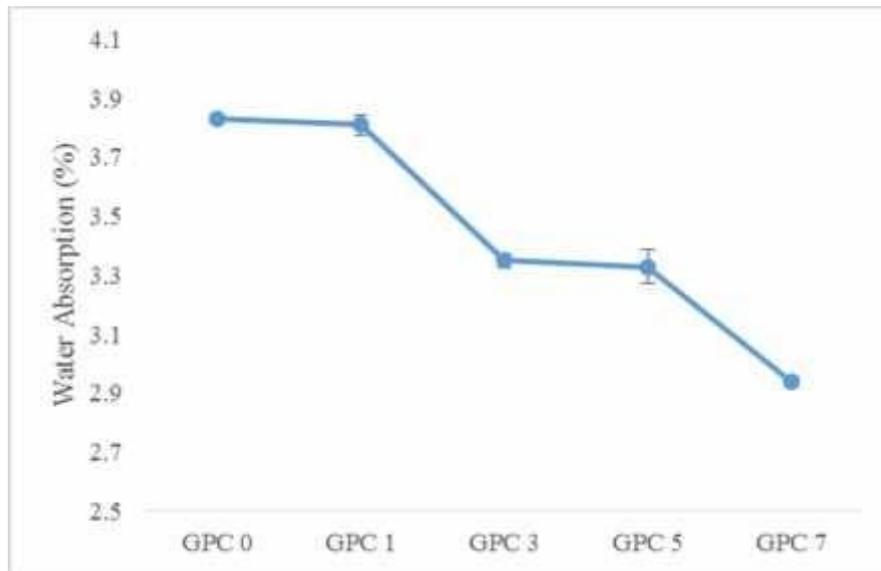
Figure 2. The relationship between water absorption and different mix of geopolymer concrete

This shows that the concrete become less permeability because the pore in the concrete have been closed by the addition of hooked steel fibers in geopolymer concrete. The geopolymer concrete with higher water absorption having the lowest compressive strength [17]. It is proved that GPC 0 have the maximum water absorption and having the minimum compressive strength. While GPC 7 have the minimum water absorption and having the maximum compressive strength.

3.3. Density
The density of geopolymer concrete after 7 days is presented in Figure 3. Density value for GPC 0 , GPC 1, GPC 3, GPC 5 and GPC 7 are 2466 kg/m^3, 2477 kg/m^3, 2487 kg/m^3, 2491 kg/m^3 and 2501 kg/m^3 respectively. The density of GPC 7 with 7% hooked steel fiber is higher than GPC 0 without hooked steel fiber. It is verified that as the loading of hooked steel fibers increased, the density also shows an increment.
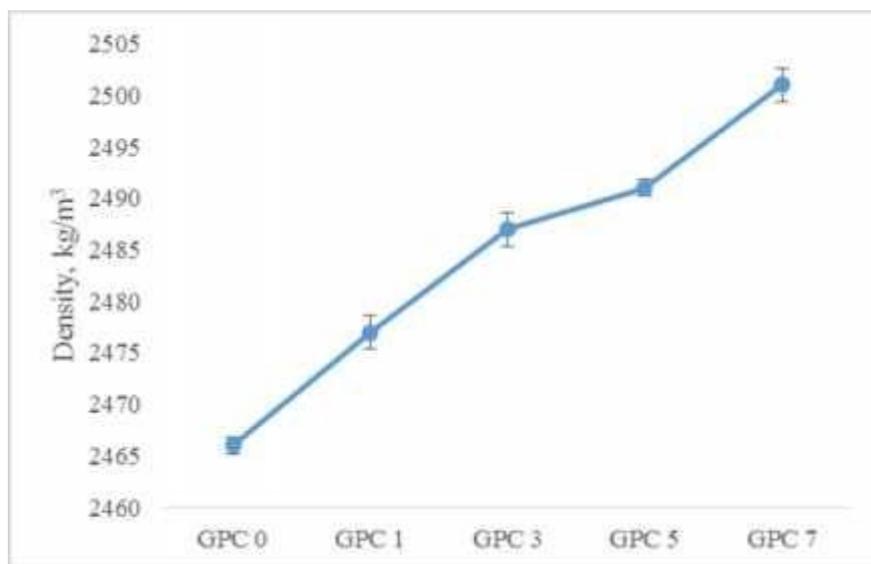

Figure 3. Density with different mix of geopolymer concrete

3.4. Compressive Strength

Figure 4 demonstrates the effect of addition of hooked steel fibers on the compressive strength with the increasing of age of concrete. From Figure 4, it can be observed that at the age of 7 days, the trend show that the strength is slightly increase from GPC 0 until GPC 7. The compressive strength of GPC 0, GPC 1, GPC 3, GPC 5 and GPC 7 for 14 days are found to be 12.45 MPa, 18.25 MPa, 20.87 MPa, 22.35 MPa and 26.55 MPa respectively. The increase in compressive strength are about 46.6%, 67.6%, 79.5% and 113.3% for GPC 1, GPC 3, GPC 5 and GPC 7 respectively with respect to GPC 0 concrete. While at the age of 14 days, the trend show that the strength is increase rapidly from GPC 0 until GPC 7. The compressive strength of GPC 0, GPC 1, GPC 3, GPC 5 and GPC 7 for 14 days are found to be 51.30 MPa, 59.47 MPa, 63.17 MPa, 70.23 MPa and 87.83 MPa respectively. The increase in compressive strength are about 15.9%, 23.1%, 36.9% and 71.2% for GPC 1, GPC 3, GPC 5 and GPC 7 respectively with respect to GPC 0 concrete.

In terms of inclusion of hooked steel fibers, the compressive strength also increased. It is proved that the compressive strength of GPC 1, GPC 3, GPC 5 and GPC 7 are increased enormously than GPC as shown in Figure 4. The optimum strength is obtained in GPC 7 which have the higher amount of hooked steel fibers. In addition, compressive strength can also increase as the age of the concrete increases. The compressive strength for 14 days showed a big increase in strength compared to 7 days. As the age of concrete increases, the compressive strength will also increases for all concrete. The longer the age of concrete improves the polymerisation process producing higher compressive strength of concrete [18]. Other researchers also claimed that geopolymer concrete with steel fibers will reach its maximum strength in less than 20 days.

There is an explicit relationship between compressive strength and density of geopolymer concrete with hooked steel fibers. For each geopolymer mix, it shows the increment of density as the compressive strength increase. Steel fibers are firstly used to control and prevent the drying shrinkage while in the concrete [19]. So, it is proved that as the density increase, the geopolymer concrete with hooked steel fibers become more durable compared to geopolymer without hooked steel fibers.
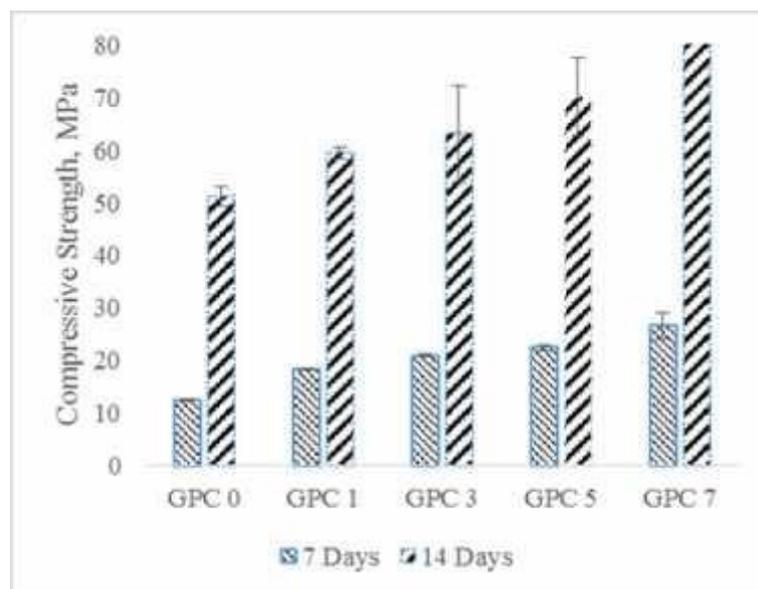
Figure 4. Effect of inclusion of hooked steel fibers on compressive strength

4. Conclusion

The purpose of this paper is to investigate the geopolymer concrete properties reinforced with hooked steel fibers. The compressive strength of the geopolymer concrete is highly influenced by the amount of CaO content in the fly ash. Besides that, the compressive strength also increases as the amount of the hooked steel fibers increases. The highest compressive strength is found to be 87.83 MPa at 14 days. Geopolymer concrete with 7% of hooked steel fibers give a higher grip strength to the concrete. Besides that, the highest density is found to be 2501 kg/m^3 at 14 days for GPC 7. While for workability and water absorption, GPC 7 have the lowest value which is 30 mm and 2.94% respectively. This can conclude that, as the amount of hooked steel fibers increases, the workability and water absorp tion will be decreased and the density will increased.

5. Acknowledgements

6. References

[1]   Izzat, A.M., Al Bakri, A.M.M., Kamarudin, H., Moga, L.M., Ruzaidi, G.C.M., Faheem, M.T.M., Sandu, A.V. 2013. *Materiale Plastice,* Volume **50**, Issue 3, September 2013, Pages 171-174.
[2]   I. Arya A. & Matthews M.P. 2014. *International Journal of Engineering Research & Technology,* Vol. **3**, pp. 825-829.
[3]   Sunilkumar S.P. & Amol A.P. 2015. *International Journal of Research in Advent Technology,* Vol. **3**, pp. 70-74.
[4]   Hardjito D. & Rangan B.V. 2005. *Research Report*, pp. 1-103.
[5]   Sivakumar A. & Srinivasan K. 2014. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering,* Vol. **8**, pp. 1275-1278.
[6]   Hardjito D., Wallah S.E., Sumajouw D.M.J. & Rangan B.V. 2004. *Invited Paper*, pp. 1-10.
[7]   Haoyang S., Jinyu X. & Weibo R. 2016. *Ceramics International,* Vol. **42**, pp. 3888–3898.
[8]   Subhash V.P., Yuwaraj M.G. & Sanjay S.J. 2015. *Advances in Structural Engineering,* pp. 1619-1634.
[9]   Ramkumar G. Sundarkumar S. & Sivakumar A. 2015. *International Journal of Advance Research in Science and Engineering*, Vol. **4**, pp. 1717-1725.
[10]   Duchesne J., Duong L., Bostrom T. & Frost R. 2010. *Waste and Biomass Valorization*, Vol. **1**, pp. 367-377.
[11]   Suriya A.P. & Senthil G.K. 2015. *International Journal of Engineering Trends and Technology,* Vol. **21**, pp. 396-399.
[12]   Nguyen V.C. 2004. *Seminar Material* Ho Chi Minh: Faculty of Civil Engineering, Ho Chi Minh City University of Technology. pp. 108-116.
[13]   Prabir K.S. 2011. *Journal of Materials and Structures*, Vol. **44**, pp. 1021-1030.
[14]   Murali G., Santhi A.S. & Ganesh G.M. 2014. *Journal of Applied Science and Engineering*, Vol. **17**, pp. 259-266.
[15]   Vijai K., Kumutha R. & Vishnuram B.G. 2010. *International Journal of the Physical Sciences,* Vol. **5**, pp. 1419-1423.
[16]   Atteshamuddin S.S. & Subhash V.P. 2013. *Indian Journal of Materials Science*, Vol. **2**, pp. 1-8.
[17]   Mustafa Al Bakri, A.M., Kamarudin, H., Bnhussain, M., Nizar, K., Rafiza, A.R., Zarina, Y. 2012. *Reviews on Advanced Materials Science*, **30** (1), pp. 90-97
[18]   Vijai K., Kumutha R., & Vishnuram B.G. 2011. *Asian Journal of Civil Engineering*, pp. 377-385.
[19]   Mustaqqim A.R., Zuhayr M.G., Azizi A.M., Fazdliel A.I., Norlia M.I. & Izzati M.N. 2015. *Applied Mechanics and Materials*, Vol. **754-755**, pp. 373-377.