Effects of aging to the mechanical properties of geopolymer concrete with addition of hooked steel fibers cured at ambient temperature

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Abstract. The development of compressive and flexural strength versus aging time for steel fiber reinforced geopolymer concrete (SFRGC) cured at ambient temperature was studied. SFRGC is produced by mixing of Malaysian fly ash, alkali activator, aggregates, and hooked steel fibers. At the first stage, the addition of steel fibers in geopolymer concrete are by volume fraction which are 0 %, 0.5 %, 1.0 %, 1.5 %, and 2.0 % and cured at room temperature for 28 days. The optimum addition of steel fibers will be selected for further investigation related to the mechanical properties versus aging days. Chemical composition of Malaysia fly ash shows this fly ash is classified as class F. Result indicates 1.0 % of steel fibers addition exhibit the best performance for both compressive and flexural strength. Aging days show an improvement to mechanical properties where the compressive and flexural strength increases as the aging day increased. These mechanical properties improvement is almost similar to the mechanical growth exhibited by OPC concrete.

1. Introduction
Concrete is the most common construction material in the world and has been recorded as a second widely consumed material behind water [1]. Main material used in the production of concrete normally is Ordinary Portland Cement (OPC). However, the production of OPC conventionally brings to the green house effects due to the emission of carbon dioxide (CO$_2$). The process of producing one tons of OPC estimated to release almost one ton of CO$_2$ into the atmosphere [2-5]. The carbon footprint from OPC industry potentially causes a serious global warming issue, which indirectly attract the attention among researchers in recent years. The using of alternative binder in replacing OPC for the production of concrete is very necessary in order to protect the environment.

Recently, geopolymer has been developed as an alternative binder to OPC in the production of concrete. There are a lot of studies related to the geopolymer as an alternative binder and potentially use as aggregate [6], steel fiber reinforced concrete [7], concrete repair material [8], cutting tools [9] and etc. Production of geopolymer concrete consumed lower energy [10] hence lower the carbon footprint. However, geopolymer concrete has some drawback over OPC in terms of brittleness. The
brittleness of geopolymer concrete is higher compare to OPC concrete limiting the use of geopolymer in several applications. The inclusion of steel fibers is the best solution to settle this brittleness issue in which the flexural strength will be enhanced into a promising value [11].

Mechanical properties of OPC concrete normally increase with age [12]. OPC Concrete develops strength with continues hydration during solidification process. Normal OPC concrete gain 16 % strength in 1 day, 40 % strength in 3 days, 65 % strength in 7 days, 90 % strength in 14 days, and 99 % strength on 28th day. The geopolymer concrete normally exhibit different rate of strength development compare to OPC concrete. Generally, geopolymer concrete develop higher early strength than OPC concrete [2]. However, there are very limited study related to the development of strength for steel fiber reinforced geopolymer concrete by aging time. Thus, this paper will investigate the strength development of geopolymer concrete with the addition of steel fibers versus aging times.

2. Materials and Methodology

Steel fiber reinforced geopolymer concrete (SFRGC) was produced by mixing of fly ash with alkali activator with certain amount aggregates and hooked steel fibers. The mixing ratio between fly ash and alkali activator is equal to 2.0. Fly ash used in this experiment is from electrical power station of Manjung, Perak, Malaysia. Raw material which is fly ash was first characterized by using X-Ray Fluorescent (XRF). Meanwhile, alkali activator was prepared by mixing between sodium silicate (Na$_2$SiO$_3$) and sodium hydroxide (NaOH) with ratio of 2.5. The NaOH was bought from Farmosa Plastic Corporation, Taiwan in the form of pellets. The Na$_2$SiO$_3$ was bought from South Pacific Chemical Industry Sdn. Bhd. (SPCI), Malaysia with SiO/Na$_2$O equal to 3.2. The NaOH pellet was dissolved in specific amount of distilled water to produce concentration of 12 M.

Coarse aggregate and fine aggregate used in this experiment was granite and river sand respectively. These aggregates were sieved in order to get maximum size of granite and river sand equal to 20 mm and 4.75 respectively. Then, steel fiber was added as reinforcement in the geopolymer concrete samples. Details specifications of steel fibers used in this experiment was summarized as in Table 1. The addition of steel fibers in the geopolymer concrete was by volume fraction of 0 %, 0.5 %, 1.0 %, 1.5 %, and 2.0 %.

| Type    | Material | Length | Diameter | Specific gravity | Tensile strength |
|---------|----------|--------|----------|------------------|------------------|
| Hooked  | Steel    | 60 mm  | 0.75 mm  | 7850 kg/m$^3$   | 1225 MPa         |

After all the materials were mixed, fresh SFRGC were cast in mould of 100 mm x 100 mm x 100 mm and 100 mm x 100 mm x 500 mm for compression and flexural test respectively. Samples were carried out form the mould after left to solidify for 24 hours and cured at room temperature. Compression test has been conducted by following British Standard (BS 1881-116 (1983)) which using universal testing machine (UTM) model Automatic Max (Instron, 5569 USA). The sample of SFRGC was tested by 50 kN of compression strength with 5 mm of load speed. The load speed was adjusted to 0.1 kN/s. Meanwhile, flexural test were done by also using (UTM) which comply ASTM C1018 where 4 point bending were applied. At the first stage, compression and flexural test were done at 28th day with different amount of steel fibers addition. Then, sample of fibers addition with the highest results was chosen at the preliminary stage for further investigate mechanical properties versus time aging at 1st day, 7th day, 14th day, 28th day, and 90th day.

3. Results and Discussions

Results in Table 2 shows chemical composition of Malaysian fly ash that has been characterized by using XRF. The class of this fly ash can be identified by ASTM 618. This result certified this
Malaysian fly ash is classified as class F where amount of $\text{Al}_2\text{O}_3$, $\text{SiO}_2$, and $\text{Fe}_2\text{O}_3$ is above 70%. The CaO content in this Malaysian fly ash is quite high which is equal to 18.10%. This will help to produce a strength of geopolymer concrete with rapid setting time. Antoni et al. [13] proved the composition of CaO in fly ash shows respond to the physical properties of geopolymer concrete where higher CaO content will reduce the setting time. This happened due to the increase of CaO content lead to increase the pH value that contribute to lower the setting time of geopolymer concrete. Besides, Antoni et al. [13] also proved the increase of CaO content will increase the strength of geopolymer concrete. This happened due to the both reaction which are geopolymerization and hydration occurring simultaneously in the sample that has high CaO content.

**Table 2. Chemical composition of Malaysian fly ash**

| Element | Percentage (%) |
|---------|----------------|
| $\text{SiO}_2$ | 38.80 |
| $\text{Al}_2\text{O}_3$ | 14.70 |
| CaO | 18.10 |
| $\text{Fe}_2\text{O}_3$ | 19.48 |
| MgO | 3.30 |
| K$_2$O | 1.79 |
| TiO$_2$ | 1.02 |
| SO$_3$ | 1.50 |
| LOI | 2.41 |

Figure 1 shows the effects of fibers addition to the compressive strength of geopolymer concrete at 28th day. The highest compressive strength of geopolymer concrete at 28th day is 69.43 MPa which gained from sample with 1.0% of fibers addition. Thus, 1.0% of steel fibers addition will be considered as the optimum amount of fiber addition and selected for further investigation related to the aging time.

![Figure 1](image1.png)

**Figure 1.** Compressive strength of geopolymer concrete with different fibers addition at 28th day

Figure 2 shows compressive strength of SFRGC (1% of fibers addition) versus aging time which are 1st day, 7th day, 14th day, 28th day, and 90th day. Results shows compressive strength of SFRGC increases as the aging time increase. This compressive results shows almost the same trend of compressive growth by steel fiber reinforced OPC concrete although the samples only cured at room temperature.
Produce a SFRGC at room temperature will reduce the coating in which this sample gain almost the same strength growth as standard steel fiber reinforced OPC concrete. The production of SFRGC at only room temperature is easier because it does not require high thermal energy and give advantage especially in producing SFRGC on site. Normally, geopolymer concrete consumed high curing temperature such as 60 °C to exhibit high strength with rapid setting time. Geopolymer concrete cured at high temperature will experience high early strength within 7 days then the compressive strength growth become almost stagnant. In addition, Wallah and Rangan [14] stated the geopolymer cured at 60 °C in 24 hours achieve substantially higher compressive strength at 7th day compared to samples cure at room temperature.

Compressive strength growth of geopolymer concrete samples still showing improvement even after reach 28 days. The increment of compressive strength developed from 28th day to 90th day is about 1.82 MPa. This findings are in agreement with previous study conducted by Ryu & Lee which their research involves of unreinforced geopolymer concrete.

The effects of steel fibers addition to the flexural strength of geopolymer concrete cured in 28 days has been presented as in Figure 3. Result shows the flexural strength of geopolymer concrete increases as the addition of steel fibers increased until maximum at 1.0 %. However, the flexural strength start to decrease when reach 1.5 % of fibers addition. This indicates the best steel fibers addition to enhance the flexural strength is equal to 1.0 %. The improvement of flexural strength for geopolymer concrete is much influenced by addition of steel fibers due to the fibers help to stop the crack propagation by bridging effects. Bridging effect occurred when the addition of fibers act to create a bridging at the crack spot. The steel fibers has an ability to absorb energy at the first stage and then geopolymer concrete is allowed to carry the load after the failure of steel fibers.

Figure 2. Compressive strength of geopolymer concrete with addition of 1 % of steel fibers versus aging time
Figure 3. Flexural strength of geopolymer concrete with different fibers addition at 28th day

Effects of aging time which at 1st day, 7th day, 14th day, 28th day, and 90th days versus flexural strength of SFRGC were studied and result is presented as in Figure 4. Inclusion of 1 % fibers is selected in this study due to the best flexural strength from previous result. Result shows flexural strength of samples increases as the aging time increase from 1st day to 90th day. The flexural growth of samples with respect to 28th day that obtained from 1st day to 90th day is equal to 20.41 % to 101.8 %. This development of flexural strength exhibited by geopolymer concrete is almost similar to the standard OPC concrete that has been mentioned by previous study which is from Ahmad Mallick [15].

Figure 4. Flexural strength of geopolymer concrete with addition of 1 % of steel fibers versus aging time

This results proved that SFRGC can achieve a comparable flexural strength with respect to aging time as produced by standard OPC concrete with same grade although this SFRGC samples were only cured at room temperature. Normal geopolymer concrete need to cure at high temperature to gain rapid flexural strength. Curing standard geopolymer concrete at high temperature will contribute to gain high early strength and will achieved almost 90 % of flexural strength within 7 days as reported by Vijai et al. [16]. Meanwhile development of flexural strength within 7 days exhibited by this SFRGC samples is about 53.78 % which is almost the same as OPC concrete. This is shown curing geopolymer concrete at high temperature is depending on the need. Curing at room temperature is
more preferable due to the low cost in which samples can achieve almost the same flexural strength development by the standard OPC concrete without heat up at higher temperature.

Based on the result, the development of flexural strength by SFRGC samples is continuous even after reach 28 days. There is still a slight improvement in flexural strength exhibited by SFRGC at 90th day. There is about 1.8 MPa of increment of flexural strength developed by SFRGC samples at age of 90th day.

4. Conclusions
The optimum addition of hooked steel fibers in geopolymer concrete at 28 days is equal to 1.0%. Mechanical properties which are compressive and flexural strength of SFRGC shows improvement similar with an increase of aging days. The development of SFRGC cured at room temperature is almost similar to the standard OPC concrete.

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