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Pull-Out Strength of Hooked Steel Fiber Reinforced Geopolymer Concrete

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Abstract. Pull-out strength of fly ash steel fiber reinforced geopolymer concrete was studied. Fly ash steel fiber reinforced geopolymer concrete was produced by mixing of Class F fly ash which taken from Manjung power station, Lumut, Perak, Malaysia with alkaline activator which are combination of sodium hydroxide and sodium silicate. Steel wool fiber were added into the geopolymer concrete as reinforcement with different weight percentage vary from 0 % - 5 %. Chemical compositions of Malaysian fly ash was first analyzed by using X-ray fluorescence. All geopolymer concrete samples with inclusion of hooked steel fiber with different volume percentage which are 0 %, 0.5 %, 1.0 %, 1.5 %, and 2.0 % were tested in terms of microstructure, flexural strength, flexural toughness, and pull-out strength. Microstructure of steel fiber reinforced geopolymer concrete shows a good degree of bonding between geopolymer binder and hooked steel fibers. Flexural strength of samples increased with the addition of hooked steel fibers until at 3 % and will slightly decrease when amount of fibers addition over than 3 %. Meanwhile, addition of hooked steel fibers shows significantly improvement to the toughness of samples. However, there is no improvement of toughness with addition of fibers over than 3 %. Pull-out strength of samples shows an excellent result where maximum result of 505 N can be achieved that indicates a good degree of bonding between geopolymer matrix and fibers.

1. Introduction

Currently, there are several types of fibers such steel fibers, polymer fibers, glass fibers, and natural fibers that have been used as micro reinforcement in Ordinary Portland (OPC) cement binder for a particular purposes. Steel is one of the most widely used material as reinforcement in cement concrete especially for certain structure that need a high flexural and toughness with high flexibility as well. This kind of micro fibers helps to improve post cracking behaviour through bridging the formation of micro-crack spot if the required amount of steel fibers addition into the cement concrete is sufficient [1].

Based on previous literature, the inclusion of steel fibers in OPC concrete is proved to form a better crack control [2-5]. In addition, tensile strength of OPC concrete before and after cracking was improved as well by addition of steel fibers [3-6]. There are a lot of studies have been made related to the potential of OPC concrete to be adjusted from brittle to ductile behaviour and many of previous studies shows positive results [3, 5, 7, 8]. Currently, geopolymer is getting attention among researchers [9-12] in order to replace the using of OPC to reduce cost and carbon footprint



The addition of steel fibers in cement concrete has transformed the concrete into a reinforcement concrete called as steel fiber reinforced concrete (SFRC) and it is found to have an adequate for OPC structural [13]. However, reinforcement of fly ash geopolymer concrete by steel fibers is still questionable due to lack of collected data from previous studies. Therefore, special testing should be applied in order to measure the effectiveness of fibers addition on geopolymer. Pull-out test has been proposed by Leung & Chi where they proved the degree of bridging by fibers in OPC binder can be measured by this test [14]. This is due to the pull-out mechanism formed in SFRC is closely related to the function of fibers on a cracked surface in which the bridging effect formed. In the pull-out test, the effectiveness of fibers from randomly distributed fibers in SFRC has been tested where the force of pull out is plotted versus fibers slip [15-18].

2. Materials and Methodology

SFRGC was produced by mixing between geopolymer binder which is fly ash and alkaline activator with addition some amount of steel fibers. Fly ash used in this experiment was taken from electric power plant Manjung, Perak, Malaysia. Alkaline activator was first produced by the mixing between sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). The Na_2SiO_3 was bought from South Pacific Chemicals Industry Sdn. Bhd. (SPCI), Malaysia with ratio between SiO and Na_2O is equal to 3.2. Meanwhile, NaOH which is in the form of pallet was bought from Famosa Plastic Corporation, Taiwan. The NaOH pellets was first diluted in distilled water and concentration of 12 M was produced. Chemical composition of fly ash used in this experiment was characterized by using X-Ray Fluorescence (XRF) as in Table 1. Ratio of fly ash to alkaline activator and Na_2SiO_3 to NaOH is equal to 2.0 and 2.5 respectively.

River sand and granite were sieved to ensure maximum size of fine aggregate and coarse aggregate are equal to 4.75 mm and 20 mm respectively. Details specification of steel fibers used in the production of SFRGC was summarized as in Table 2. Total amount of steel fibers addition into the geopolymer matrix was by the percentage of total volume of geopolymer concrete which are 0 %, 0.5 %, 1.0 %, 1.5 %, and 2.0 %.

Sample of SFRGC were cast in a mold size of 100 mm x 100 mm x 100 mm and 100 mm x 100 mm x 500 mm for pull out test and flexural test respectively. Samples were taken out from the mold after 24 hours and cured at room temperature.

After 28 days cured at room temperature, samples were tested for microstructure test, flexural test, and pull-out test. In microstructure test, samples were cutting into two pieces and cross-section image were captured. Flexural test were done by using universal testing machine (UTM) followed ASTM C1018 where 4 point bending were applied. Single fiber pull-out were set-up where 1 hooked steel fiber was embedded inside the geopolymer with depth of embedment equal to 6 mm, 10 mm, 20 mm, and 30 mm.

Table 1. Chemical composition of Malaysia fly ash characterized by using XRF

Element	Percentage (%)
Al ₂ O ₃	14.70
SiO ₂	38.80
CaO	18.10
Fe ₂ O ₃	19.48
TiO ₂	1.02
MgO	3.30
K ₂ O	1.79
SO ₃	1.50

Table 2. Specifications of hooked steel fibers

Items	Specifications
Fiber type	Hooked
Diameter (mm)	0.60
Length (mm)	0.75
Aspect ratio	80
Young modulus (N/mm ²)	210
Tensile strength (N/mm ²)	1.225

3. Results and Discussions

Bonding of hooked steel fiber in geopolymer concrete can be observed under ordinary light microscope (OM). Hooked steel fibre and aggregates were seen having a good bonding with geopolymer binder as seen in Figure 1 where there is no gap between them. Meanwhile, surface roughness of steel fibers clearly seen has high degree of roughness where it helps to increase the bonding strength between steel fiber and geopolymer binder. This happened due to the increase of contact area between steel fiber and geopolymer binder where geopolymer binder filled the empty space from the surface roughness of steel fiber.

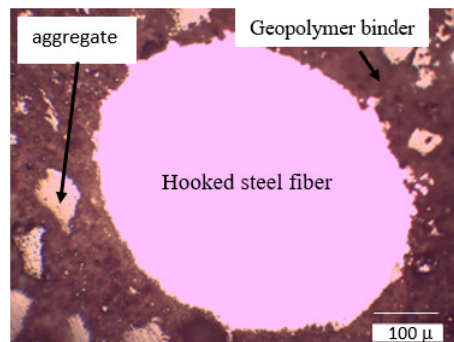


Figure 1. Cross-section image of SFRGC.

Flexural strength of geopolymer concrete with addition of hooked steel fibers is illustrated as in Figure 2. Result shows flexural of geopolymer concrete will increase with the increase of steel fibers addition until at maximum of 1.0 %. However, there is a reduction of flexural strength when steel fibers addition exceed 1.5 %. The increase of flexural strength by steel fibers addition is due to the hooked steel fibers helps to stop the crack propagation by create a bridge at the crack spot. The presence of hooked steel fibers may transform the behavior of geopolymer concrete from brittle to ductile.

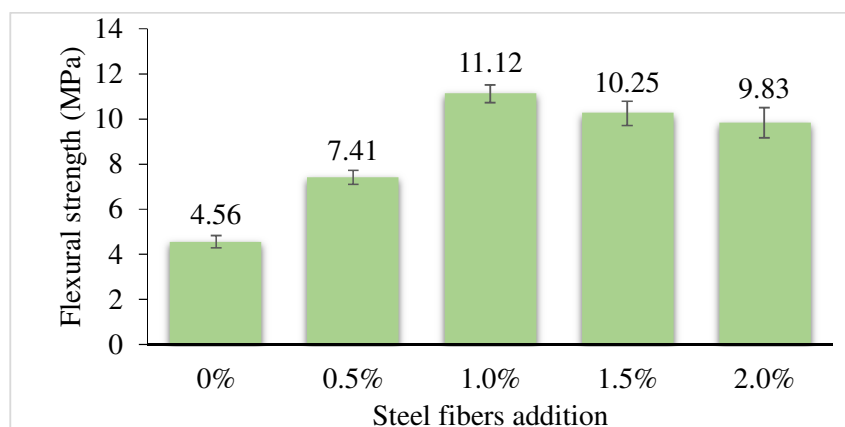


Figure 2. Flexural strength of hooked steel fibers.

Geopolymer concrete without reinforcement will failed immediately after first cracking. Meanwhile, sample of geopolymer concrete with steel fiber reinforcement undergo post-cracking load carrying capacity. There are no further improvement of flexural strength at fibers addition starting at 1.5 % where the reading was slightly decrease. This is due to the low workability of samples at fiber addition starting at 1.5 % which will cause a poor fibers distribution. This indicates the inclusion of hooked steel fibers is optimum at 1.0 % of addition.

Steel fibers inclusion shows significant improvement to the toughness of geopolymer concrete until maximum at 1.0 % of addition as shown in Figure 3. This is due to the addition of hooked steel fibers helps to increase the post-cracking strength of geopolymer concrete samples. Test results also shows reinforced geopolymer concrete with hooked steel fibers can absorb more energy compared to unreinforced sample. Fundamentally, the toughness of sample is very important measurement that indicates the energy absorption capacity of concrete and energy consumed of concrete to be failed.

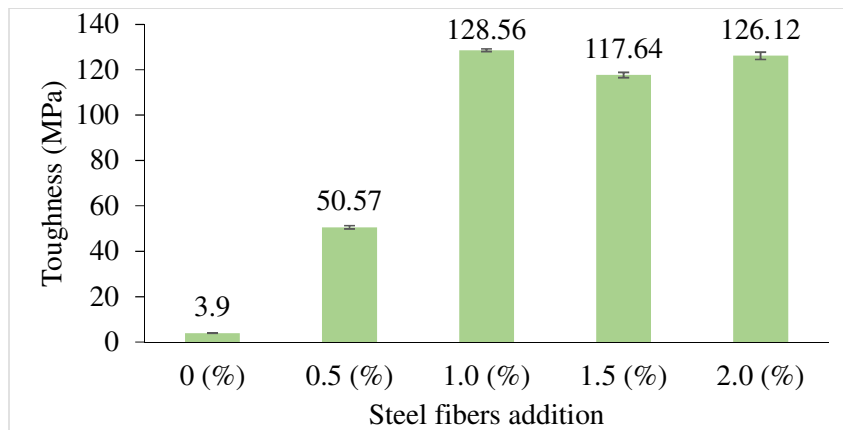


Figure 3. Toughness of hooked steel fibers.

Toughness of geopolymer concrete doesn't improve at hooked steel fibers addition exceed 1.5 % and become very slightly lower compared to the maximum toughness posted on fibers addition of 1.0 %. This also may due to the fibers distribution of hooked steel fibers starting at 1.5 % of fibers addition shows a low workability.

Pull-out strength of geopolymer concrete was measured versus embedment depth of hooked steel fiber and results is summarized as in Figure 4. Result shows the pull-out strength increase as the embedment depth was increased. The increase of pull-out strength by the increase of embedment depth is due to the contact area between the binder and the surface of hooked steel fiber getting higher. This will resulting in higher contact resistance between geopolymer binder hand the fiber when the fibers is pulled out from the geopolymer concrete by the UTM machine.

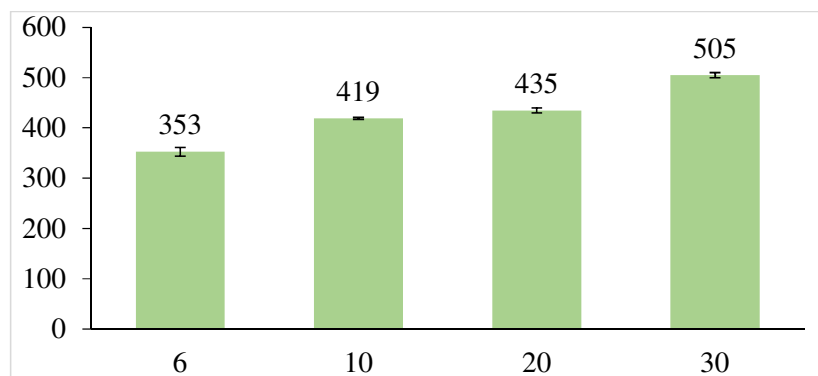


Figure 4. Pull-out strength of hooked steel fibers

Besides, the maximum pull-out of geopolymer concrete reinforced with hooked steel fibers shows an excellent reading which is 505 N compared to normal OPC concrete that have been done by previous researchers which are 400 N [17]. This is prove that interfacial bonding between steel fiber with geopolymer concrete is better than OPC concrete.

4. Conclusions

The reinforcement of geopolymer concrete by steel fibers give an improvement to the flexural strength and toughness. Plus, it is proven that hooked steel fiber and geopolymer concrete has an excellent interfacial bonding and better than OPC concrete.

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