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The Application of PVA Fiber to Improve the Mechanical Properties of Geopolymer Concrete

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Abstract. This paper presents an experimental investigation on the improvement of geopolymer concrete properties through the use of polyvinyl alcohol (PVA) fibers mixed in the fresh concrete. For the purpose of obtaining the optimum mechanical properties, the volume fraction of PVA fibers was varied at 0% ; 0.3% ; 0.5% ; ad 0.8%. All mixtures were cast by mixing fly ash, alkali activator, and aggregates. The activator used in this study was a combination of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). The mechanical properties of geopolymer concrete were obtained from the results of compressive strength, splitting strength, uniaxial tensile strength, elastic modulus, and flexural strength. It is found that the variation of 0.8% PVA fibers resulted in the highest strength for overall test. The utilization of 0.8% PVA fibers also contributed to increasing the direct tensile up to 50%. However, it is noticed that the elastic modulus was more prone to decrease as the fiber content in the mixture increased.

1 Introduction

The application of fly ash in the concrete mixture improved concrete performance. It is because the voids between particles are filled by additional hydrated products [1], in this case, fly ash has exquisite particle size. Geopolymer is formed from chemical reaction rather than hydration reaction like in Portland cement concrete based. Geopolymer concrete is well known to be brittle, several researches established by adding some fibers in geopolymer mixture is one of the solutions to improve mechanical properties and flexural strength. Bhantia and Gupta [2] found that added cellulose based fiber in the concrete mixture, can be used as repair concrete strengthening and reduced the crack width. In [3] added 0.2% kenaf fiber by volume friction, slightly improved the compressive strength as compared the bare lightweight concrete. Likewise, Manfaluthy et al [4] detected by adding abaca fiber in geopolymer mixture improved the compressive strength up to 8% from the non-fiber geopolymer concrete. Based from that reasons, the addition of fiber in the geopolymer mixture can be properly applied in geopolymer concrete. In this paper using Polyvinyl Alcohol (PVA) fiber to improve the mechanical strength varied at 0%; 0.3%; 0.5% and 0.8%

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by volume friction. Li [5] was found that the bond-strength of PVA fibers and Portland cement matrices was very high. It resulted that tensile strain-hardening with strain capacity of engineered cementitious concrete (ECC) in excess of 4%.

2 Materials and Test Specimens

2.1 Fly ash

A class F of fly ash was collected from Paiton Coal Fire Power Plant, Probolinggo, Indonesia as raw material. The density of fly ash is 2.6 gram/cm^3 and the chemical composition is provided in Table 1.

Table 1. Chemical composition of fly ash by XRF (% by weight)

Oxides	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SO_3
%	43.24	24.43	10.74	11.37	1.12	3.27	2.97	1.13

2.2 Alkali Activator

There are two types of alkali activators were used in this paper, sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH).The mass ratio of sodium silicate to sodium hydroxide was 2.5 and 14 Molar of sodium hydroxide. The silica to alumina ratio of 1.8 was applied in the binder composition.

2.3 PVA Fiber (Polyvinyl Alcohol Fiber)

PVA fiber has good properties to improve concrete strength. It has high elasticity modulus, durability, tensile strength, and bond-strength. These properties is require for increasing concrete ductility. Properties of PVA fiber are 38 μm in diameter, with eight mm in length, and density of 1.3 gram/cm^3 as shown in Fig 1.. Modulus elasticity of PVA fiber is in the range of 25 - 40 GPa, is higher than natural fiber. The elongation of PVA fiber is 6-10%, and the tensile strength of PVA fiber is in range of 880 - 1600 MPa.

Fig. 1 Properties of PVA fiber which taken with DinoLite camera.

2.4 Aggregates

Aggregates that used in this paper is commonly used in concrete production. Fine aggregate must satisfied ASTM C33 [5]. Coarse aggregate should have maximum size of 20 mm. Both fine and coarse aggregates were prepared in saturated surface dry (SSD) condition.

2.5 Test Specimens

Compressive test to acquire the strength of the specimens was conducted according to ASTM C39 [6]. Splitting test according to ASTM C496 [7]. Both compressive and splitting test specimens were conducted for cylindrical shape with 10cm in diameter and 20cm in height. Dog bone shape specimens were conducted to direct tensile test according to CRD-C 260-01 [8]. Flexural test according ASTM C348 [9] conducted by prism specimen with size 4cm in width, 4cm in height, and 16cm in length. All specimens were cure in ambient room temperature at 28 days.

3 Mix proportions

Specimen mixing proportion is provided in Table 2. All the materials were prepared one day before mixing process. Alkali activator was separated. First, mixed fly ash, sand and gravel. Second,it added 14 M of sodium hydroxide until well-mixed. Third, added sodium silicate in the mixture. Then spread PVA fiber at the end of stage until homogeneously.

Table 2. Mixing proportion (% by volume)

Code	Fly ash	Na_2SiO_3	NaOH (14M)	Sand	Gravel	PVA fiber (by volume fraction)
GC	22%	5.7%	2.3%	28%	42%	-
FGP3	22%	5.7%	2.3%	28%	42%	0.3%
FGP5	22%	5.7%	2.3%	28%	42%	0.5%
FGP8	22%	5.7%	2.3%	28%	42%	0.8%

4 Results and Discussions

4.1 Compressive Strength Test

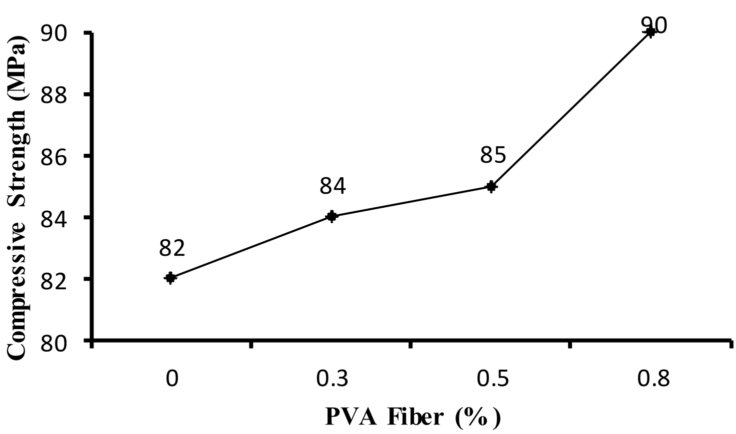

Fig. 2. Contribution of fiber variations to compressive strength.

Fig. 2. shows the addition of PVA fiber in geopolymer concrete increases slightly the compressive strength. It has a good agreement with some previous research [3, 4, 11]. It was found that natural fibers in cementitious material slightly increased the compressive strength. The maximum compressive strength was obtained 90 MPa, by 0.8% of the PVA fiber specimens. Accordingly, Ekaputri [12] found that the addition of PVA fiber in meta kaolin-geopolymer mixture increased the compressive strength. Opposite with Borges et al [13] that the adding of PVA fiber in geopolymer mixture unaffected significantly on the compressive strength. From Ekaputri [12] reported that the addition of PVA fibers as much as 1% on geopolymer paste has a tendency increased the compressive strength. Li et al [14] stated that the optimum of PVA fibers for concrete ECC at 2% when analyzed from the viscosity of the mixture and the distribution of PVA fiber. Generally, the addition of PVA fiber in geopolymer mixture is not significantly contributed in the compressive strength, it caused the properties of PVA fiber was un-resist the compressive load.

4.2 Splitting Test

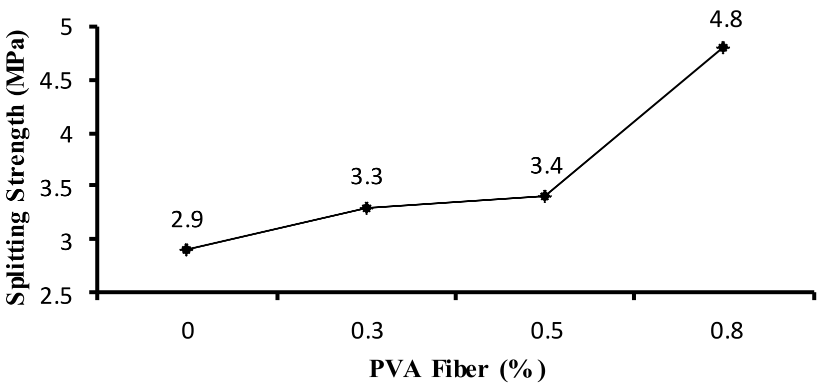

Fig. 3. Splitting strength caused PVA fiber variations.

Fig.3. describes PVA fiber in the mixture increases the splitting strength. The 0.8% of PVA fiber specimen generated splitting strength 4.8 MPa, which is obtained the maximum splitting test. Splitting strength results of fibrous specimens obtained up to 60% of non-fibrous specimens. It was occurred due to the mechanical properties of PVA fiber is more resisted to splitting load, because there was a strong bond between the PVA fiber and the geopolymer matrix. As known that the behavior of geopolymer concrete was very brittle. Adding some fibers in mixture increases the ability of concrete to resist the tensile loads. It aligned with Dehghan [15], due to the brittleness of Portland concrete material, fiber is required to improve the splitting strength up to 25%.

4.3 Direct Tensile Test

Fig. 4. Shows the relation stress and strain from direct tensile test, by adding fiber in geopolymer mixture increased the strength. The specimen contains high volume of fiber is illustrated in Fig. 5.. It indicates that after crack occurs, tensile stress is transferred from concrete matrices to the fiber as it has a great binding capacity with geopolymer matrices. Adding 0.3% of PVA fiber significantly rose up to two times of tensile strength resulted from non-fibrous specimens. Accordingly to Ekaputri [11], the tensile strengths of fibrous

specimens were greater than the non-fibrous specimen in a meta-kaolin geopolymer system. Tensile capacity was increased up to 52%. Hossein [16] found that, adding polypropylene carpet fiber increased tensile and flexural strength in OPC concrete. It gained 19.6% of basic OPC concrete.

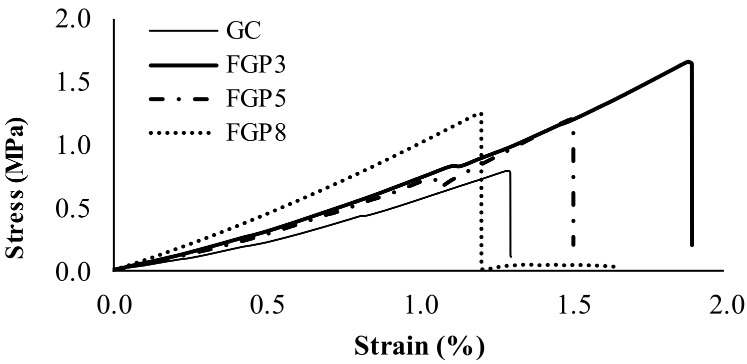

Fig. 4. Stress – strain diagram of direct tensile test.

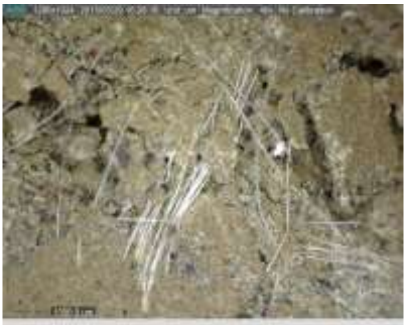

Fig. 5. Crack pattern in fibrous geopolymer concrete due to tensile load.

4.4 Flexural Test

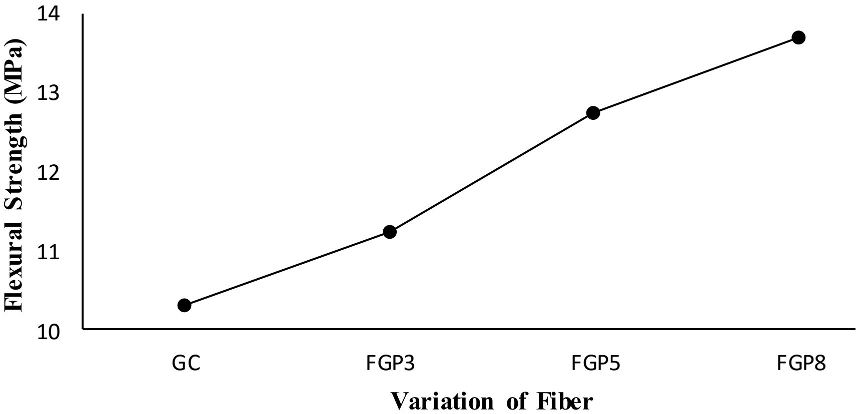

Fig. 6 The effect of fiber adding to flexural strength.

Fig. 6 shows flexural strength of the non-fibrous specimen is gained 10 MPa. The fiber contributed to higher flexural strength as compared to non-fibrous specimen. The flexural strength of fibrous specimen containing 0.3%; 0.5% and 0.8% obtained 11 MPa; 13 MPa and 14 MPa respectively. In general, the application of fibrous specimen containing 0.8% PVA increased the flexural strength up to 30%. Adding some fibers in geopolymer concrete indicated higher strength, it resulted from the compressive, tensile, and flexural strength were increased by adding fibers in the geopolymer mixture. It because after crack occurs in geopolymer matrices, the loads were transferred to PVA fiber. Therefore, fibrous geopolymer concrete accepted higher loads than non-fibrous geopolymer concrete. Bayuaji [17] was found that flexural strength affected by curing system. It suggested oven curing system at 65°C for 24 hours. In the future, combining of PVA fibers adding in the geopolymer mixture and oven curing system must be conducted to produce greater flexural strength.

4.5 Modulus of Elasticity

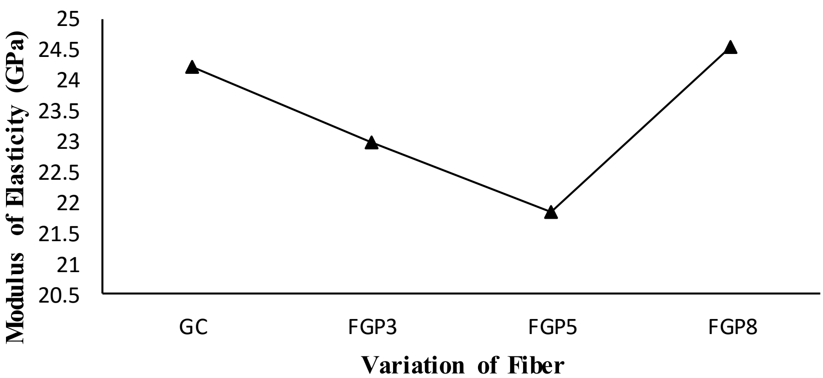

Fig. 7 Modulus of elasticity due to fiber variatons.

From Fig. 7. shows the modulus elasticity test results, it obtained varied results at 14.4 GPa through 24.54 GPa Based Fig. 7 shown that the elasticity modulus of 0.3% and 0.5% of the PVA fiber specimens decreased as compared to 0% specimen. However, addition of 0.8% PVA fiber increased the elasticity modulus. Increasing of elasticity modulus for fibrous specimens caused by the dependent of inter-fiber. It because the fiber covered the micro-cracks and subsequently improved, [18]. It was found that the elasticity modulus of specimens containing 0.4% and 0.5% of polypropylene fiber decreased as compared to non-fibrous specimen. It because the pore formation in the mixtures thus affecting the workability. This is also supported by Karahan and Atis [19], the addition of 0.5% polypropelene fibers in the concrete mixture can increase the modulus of elasticity to 13.3% from the non-fiber concrete mixture.

5 Conclusions

1. The highest strength of the specimens were conducted from 0.8% of PVA fiber specimens. These are, compressive strength increased 9.95% ; splitting strength reached 61.69% ; and direct tensile strength rose 32.78% as compared with non-fibrous specimen. Adding fiber in geopolymer mixture has important role improved the strength of geopolymer concrete.

2. The adding of fiber contributed higher splitting strength and tensile strength. Nevertheless, it showed less contribution to compressive strength. It is because the properties of PVA fiber is only to resist in tensile and flexural load.
3. It is recommended to add 0.5% PVA fiber in geopolymer concrete to improve the mechanical properties of the geopolymer concrete. Whereas, by adding 0.8% PVA fiber improve the strengths of geopolymer concrete, but it is not recommended. It caused by the workability of the mixture very low when added a lot of fiber. Particullary for the fly ash that used in this paper. It contained 10.74% of calcium oxides, which affected to rapidly setting time process for the mixtures.

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