

Flexural Behavior of Reinforced Concrete Beams with Fly Ash Based Geopolymer Strengthening

Nazwar Furqan¹, Rita Irmawaty², Fakhruddin²

¹Magister Student of Civil Engineering Department, Hasanuddin University, Indonesia

²Civil Engineering Department, Hasanuddin University, Indonesia

email: nazwarfurqan@gmail.com

ABSTRACT

Geopolymer mortar made from fly ash waste from Steam Power Plant (PLTU) has a higher compressive strength than conventional mortar made from Portland cement. However, geopolymer mortar has a weakness that is brittle. So, it is necessary to add fiber to increase the ductility of the geopolymer mortar. PVA fiber is a synthetic fiber that can be an alternative in geopolymer mortar mixtures, because it has high tensile strength. This study aims to analyze the flexural behavior of reinforced concrete beams strengthened with geopolymer mortar with the PVA fiber addition. The research stages were divided into two, namely compressive strength test of geopolymer mortar and beam flexural test with length of reinforcement of 1500 mm. The compressive strength test of geopolymer mortar used a cube sample measuring 50x50x50 mm which was tested at the age of 3, 7 and 28 days. The beam flexural test used 10 beams with a size of 150x200x3300 mm, consisting of a control beam and the RC beam reinforced with geopolymer mortar (with and without the PVA fiber). The results showed that the addition of 0.6% PVA fiber to the geopolymer mortar increased the compressive strength by 39.23% at the age of 28 days. The application of geopolymer mortar on RC beam strengthening increased the ductility up to 71% compared to the control beam.

Keywords: RC beams, geopolymer mortar, PVA fiber, strengthening

1. INTRODUCTION

The development of construction in Indonesia is growing very rapidly along with the increase in population. In general, most of the existing facilities and infrastructure use concrete construction. So far, concrete is known as the most popular building material. Concrete is composed of the main composition of aggregate (coarse and fine), water and Portland cement or what we usually call conventional concrete. According to Malhotra [1] the consumption of concrete in the world is around 8.8 million tons every year and the need for this material will increase from year to year along with the increasing need for basic human facilities and infrastructure.

In 2016, world cement production produced around 2.2 billion tons of CO₂, equivalent to a contribution of about 8% of the world's carbon dioxide (CO₂) gas emissions [2]. For this reason, alternative materials are needed to replace cement in the preparation of mortar,

one of which is currently being studied a lot is geopolymer. Geopolymer mortar or concrete was proposed by Davidovits [3], and it is described as a non-cement material manufactured from alkali activating aluminosilicates, including industrial wastes (fly ash, blast furnace slag) or metakaolin at low calcination temperatures [4]. Studies on geopolymer mortar or concrete have revealed that its properties are comparable or superior to those of OPC mortar or concrete [5–7]. Geopolymer is made from fly ash which is rich in Alumina (Al) and Silica (Si) elements.

Fly ash is a solution to minimize the use of cement because it is an environmentally friendly material, has a high silica content, and is pozzolonic. Fly ash is one of the wastes produced from the coal combustion process in a Steam Power Plant (PLTU). The Daily Records Jakarta, Indonesia is currently the fifth largest coal producer in the world with an estimated production of 386 million tons annually. South Sulawesi Province itself has several coal-fired

power plants, namely PLTU Punagaya and PLTU Bosowa in Jeneponto, as well as PLTU Barru. PLTU produces a lot of fly ash waste every year, causing environmental problems. For this reason, it needs to be utilized so that it does not pollute the environment and is beneficial for the construction world.

Fly ash itself does not have the ability to bind like cement, but in the presence of water and its fine particle size, the silica oxide contained in fly ash will react chemically with alkaline liquids and produce substances that have the ability to bind like cement which are then known as geopolymers. The weakness of geopolymer is that it is brittle, so it is necessary to add fiber if it is applied to structural elements to increase ductility and capacity in carrying loads. The fiber used in this study is an artificial fiber, namely PVA (Poly-Vinyl Alcohol) fiber, where this fiber has a high tensile strength so that it can reduce the length and width of the crack and inhibit the rate of crack development that occurs in the beam [8-9]. Damage to reinforced concrete beams such as cracks, holes, and spalling can cause damage to the overall structure. This can be overcome by using repair materials as well as strengthening the structure on the beam such as mortar geopolymer. In this paper, will be discussed the flexural behavior of reinforced concrete beams strengthened with geopolymers with the length of the reinforcement area of 1500 mm.

2. METODOLOGY

Broadly speaking, this research was divided into two stages, namely testing the characteristics of the geopolymer, and testing the flexural strength of reinforced concrete beams. The composition of mortar geopolymer is presented in Table 1. As for concrete, ready-mix concrete is used with a target strength of 20 MPa. PVA fiber with type

NYCON-PVA RECS 15 was used to increase the ductility of the geopolymer mortar.

Table 1. Composition of mortar geopolymer [8]

NaOH	Na ₂ SiO ₃	PVA Fiber	Fine Aggregate	Fly Ash	Sp
156	234	6.5	780	390	7.8

Testing the compressive strength of geopolymer mortar with cubes measuring 50 mm x 50 mm x 50 mm after moist curing for 3, 7, and 28 days based on ASTM C39 [10]. While the RC beam bending test consisted of the control beam (CB), RC beam strengthened with geopolymer mortar with a length of 1500 mm (GP-1500), and RC beam strengthened with geopolymer mortar and PVA fiber with the length of the reinforcement area is 1500 mm (GP-F-1500) each as many as 2 pieces as described in Table 2. Beam specimens with dimensions of 150 mm x 250 mm x 3300 mm were made with 3 variations as shown in Figure 1.

Table 2. Specimen variety

No	Code	Reinforcement materials	Quantity
1	CB	-	2
2	GP-1500	Geopolymer mortar	2
3	GP-F-1500	Geopolymer mortar + PVA fiber	2

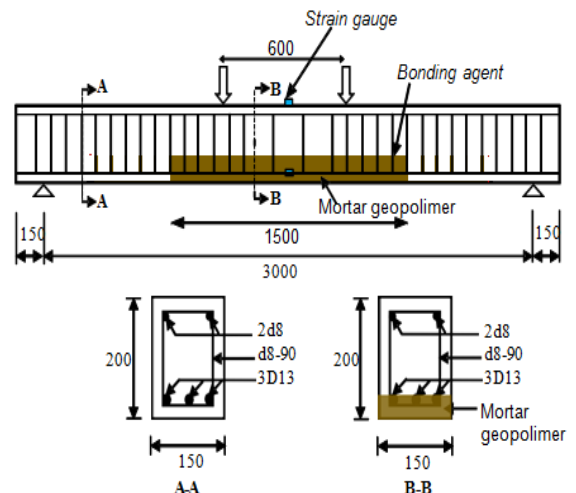


Figure 1. Configuration of beams

3. RESULT AND DISCUSSION

A. Geopolymer Mortar

The compressive strength of geopolymer mortar without PVA fiber and with PVA fiber 0.6% at the test ages of 3, 7, and 28 days is shown

in Figure 2. Based on SNI 6882:2014 [11] regarding Mortar Specifications for Paired Unit Work, it was found that the compressive strength at 28 days of geopolymer without PVA fiber (PVA 0%) was included in the S type mortar with a minimum compressive strength of 12.4 MPa. The geopolymer with PVA fiber (PVA 0.6%) is included in the type M mortar with a minimum compressive strength of 17.2 MPa. Type S mortar is recommended for structures on or below ground, foundations, retaining walls, pavements, sewers and main hole. Type M mortar is recommended for both reinforced and non-reinforced pairs that will carry large compressive loads. Based on these specifications, the geopolymer with 0.6% PVA fiber which is moist cured is included in the type M mortar and meets the specifications as a reinforced concrete repair material and will be applied to the RC beam test specimen.

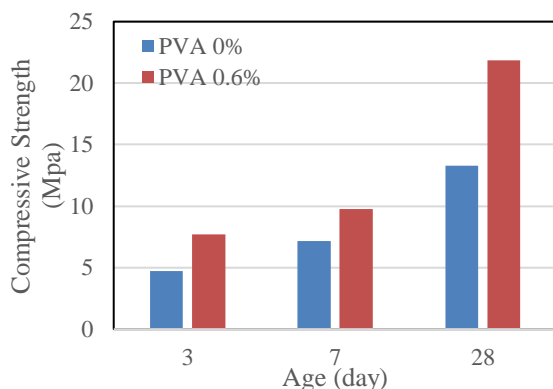


Figure 2. Compressive strength

The addition of PVA fiber as much as 0.6% had a significant effect on the compressive strength of geopolymer mortar, where there was an increase of 39.23% at the age of 28 days. The addition of fiber to the geopolymer mortar can increase the compressive strength due to the interaction between the fiber and the geopolymer matrix. This is because when a crack occurs, the fiber can provide a bridging effect on the crack so that the propagation rate and crack width can be reduced.

From the compressive strength test of the geopolymer mortar, the compressive strength

value was 21.87 MPa while the concrete compressive strength value was 21.10 MPa. This shows that the compressive strength value is the same between geopolymer mortar and normal concrete, so that geopolymer mortar can be used as a reinforced concrete repair material.

B. RC Beam Testing

The beam flexural test was conducted to analyze the effect of using geopolymer mortar and the addition of PVA fiber on the flexural behavior of reinforced concrete beams. Flexural behavior is discussed on the basis of load-deflection behavior.

In general, the behavior of the load-deflection relationship is divided into 3 phases. The first phase is the phase where the concrete is still in an elastic condition. The second phase is the post-crack phase, and the third phase is the phase where the reinforcement yields. The transition of each phase is indicated by a change in the stiffness of the load-deflection relationship graph. The first transition point is used to identify the initial crack and the second transition point is used to identify yielding in the reinforcement.

Figure 3 shows the load-deflection relationship of the CB, GP-1500, and GP-F-1500 beams. The deflection shown occurs in the mid span. The effect of the repair material (geopolymer mortar) can be observed by comparing the load-deflection behavior of CB and GP beams. Meanwhile, the effect of adding PVA fiber can be observed by comparing the load-deflection behavior of GP and GP-F beams.

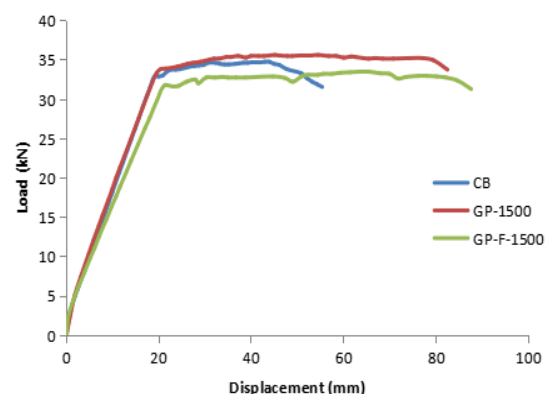


Figure 3. Load-deflection relationship

In the control beam (CB), the reinforcing steel is fully elastic until the beam experiences initial cracks where the load value is 4.93 kN with a deflection of 1.87 mm. After the initial cracking, the beam then shows the elastoplastic properties of the steel until the reinforcement yields where the load value is 32.92 kN with a deflection of 19.88 mm. The relationship curve becomes much flatter than before, this happens until the beam fails at an ultimate load of 34.78 kN with a deflection of 45.79 mm.

In the beam with reinforced geopolymer mortar without fiber (GP-1500), the beam experienced initial cracks where the load value was 5.26 kN with a deflection of 1.89 mm. After the initial crack, the beam then shows the elastoplastic properties of the steel until the reinforcement experiences yielding where the load value is 32.12 kN with a deflection of 18.57 mm. The relationship curve becomes much flatter than before, this happens until the beam fails at an ultimate load of 35.65 kN with a deflection of 79.38 mm. GP-1500 beams have higher ductility than CB beams. This can be seen from the deflection at the maximum load of the GP beam which increased by 71% compared to the CB beam. The same behavior is also shown by the GP-F-1500 beam.

Table 3 presented the of loads and deflections under initial cracking, yielding and maximum load conditions. The deflection shown in the table shows the deflection that occurs in the mid span.

Table 2. Loads and displacements

Code	Load (kN)			Deflection (mm)		
	P_{cr}	P_y	P_u	δ_r	δ_y	δ_u
CB	4.93	32.92	34.78	1.87	19.88	45.79
GP-1500	5.26	32.12	35.65	1.89	18.57	79.38
GP-F-1500	4.46	29.86	35.50	1.52	19.59	65.40

The fiber used in this study is PVA fiber with type NYCON-PVA RECS 15 with a

percentage of 0.6% of the total volume of the mixture. As a comparison, RC beams reinforced with geopolymer mortar were made without the addition of PVA fibers. The effect of the fiber can be observed by comparing the load-deflection behavior of the beam as shown in Figure 3.

From Figure 3 and Table 2 it is clear that the RC beam strengthened with geopolymer mortar with and without the addition of PVA fiber has much better ductility than the control beam (CB), although the ultimate load capacity is slightly decreased in the GP-F-1500 beam.

In beams with a length of 1500 mm reinforcement area, the addition of 0.6% PVA fiber can reduce the maximum load. This can be seen from the maximum load of the GP-F-1500 which decreased by 6.03% compared to the GP-1500.

4. CONCLUSIONS

From the experimental and analysis, the following conclusions were drawn:

- The addition of PVA fiber has a significant effect on compressive strength of geopolymer mortar. The addition of 0.6% PVA fiber increased the compressive strength by 39.23% at the age of 28 days.
- The RC beam strengthened with geopolymer mortar with and without the addition of PVA fiber has much better ductility than the control beam (CB), although the ultimate load capacity is slightly decreased in the GP-F-1500 beam.

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