Lowland Technology International; Volume 24 (Issue No. 1): 20-25
International Association of Lowland Technology (IALT): ISSN 1344-9656

Research Paper

Flexural Behaviour of Reinforced Concrete Beams Repaired Using Geopolymer Fiber Mortar

Multasam[1], R. Irmawaty [2], Fakhruddin [3]

ARTICLE INFORMATION

Article history:

Received: 16 March, 2022
Received in revised form: 30 May, 2022
Accepted: 5 June, 2022
Publish on: 3 July, 2022

Keywords:
Fly Ash
PVA Fiber
Geopolymer
RC Beam

ABSTRACT

Geopolymer is an inorganic material that has brittle properties with low tensile strength. PVA fiber is one of the solutions to improve the strength of geopolymer. This research focuses on the flexural behavior of reinforced concrete beams strengthened by fly ash-based geopolymer and PVA fiber as an additive to get composited with the conventional concrete. The composite layer is applicated to repair and reinforcement of the deteriorating structure. This study was carried out with two variations of materials, named geopolymer with and without PVA fiber and normal concrete as a control beam. Also, there are two variations in the length of repaired and strengthen reinforced concrete beams, those are 1500 mm and 2700 mm in length and with 50 mm in thickness. The results show that the geopolymer mortar with fiber is more ductile compared to the control beam, in which it shows an increase into the maximum load and stiffness. On the other hand, about the failure mode, the geopolymer mortar beam without PVA fiber experienced debonding failure, while the geopolymer mortar beam with PVA fiber experienced delamination failure.

1. Introduction

Replacing several parts of cement in the process of making concrete, or replacing it with other materials that are more environmentally friendly, is one solution that can be done to reduce the negative impact on the environment. Currently, there is a shift toward the use of geopolymer mortars in various repair applications (Zhang, et al., 2010). Various studies have shown that geopolymer concrete has a higher compressive strength than conventional concrete derived from Portland cement (Van Deventer, et al., 2007). However, the weakness is that the geopolymer concrete has brittle properties. So that when applied to the structure, it will result in a sudden collapse pattern.

In this research, a geopolymer mortar material developed from a mixture of fly ash and the addition of PVA (Poly Vinyl Alcohol) fibers would be composited with conventional concrete. The composite layer is an application of repair and reinforcement of a deteriorating structure. This research will focus on the flexural behavior of reinforced concrete beams reinforced with a mixture of geopolymer mortar and PVA fiber. The results of this study are expected to be an applied innovation product for inexpensive and environmentally friendly structural repair and reinforcement materials.

[1] Master Student, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Gowa, INDONESIA
multasam180495@gmail.com
[2] Associate Professor, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Gowa, INDONESIA
rita_irmaway@yahoo.co.id
[3] Associate Professor, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Gowa, INDONESIA
fakhrudcivil05@gmail.com

2. Study Literature

In the majority of developments in the construction industry, concrete and reinforcing steel are very useful mixtures in construction components. Concrete and reinforcing steel bond to each other very well with no slippage between the two materials. The close bond between the two materials is caused by the strong adhesion force of each material, especially in the reinforcement that has a fine shape along its surface. Steel reinforcement is exposed to corrosion, but concrete materials can provide a passive film to protect the reinforcing steel surface (Mc Cormac, 2015). Where if the concrete blanket is large, the reinforced concrete will only experience damage on the surface. Thus, reinforced concrete in good condition can be used for a long time without losing strength.

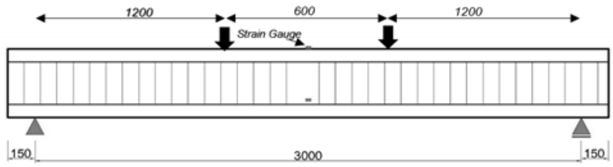
Geopolymer is an inorganic form of alumina-silica which is synthesized from materials that contain a lot of silica (Si) and alumina (Al) derived from nature or industrial by-products (Manuahe, et al., 2014). Generally, the geopolymer manufacturing step is carried out by mixing a solution of NaOH and sodium silicate solution as an alkali activator, then into fly ash and sand as an alkali activator (ACI, 2015). The physical properties of Fly Ash are specific gravity of 2.2 – 2.8 and grain size of 1 m – 1mm (passed a 200-mesh sieve = 40 – 75 m) (Hardjito, 2005).

Geopolymer concrete is an alternative to conventional concrete. However, the weakness is that the geopolymer concrete has brittle *properties*. So that when applied to the structure, it will result in a sudden collapse. Currently, there is a shift towards the use of geopolymer mortars in various repair applications. The test results confirmed the potential use of geopolymer mortar as a protective layer for offshore concrete structures by measuring corrosion resistance, permeability, volume stability, and bond strength. The geopolymer layer was found to be able to increase the strong bond with the concrete mixture (Zhang, et al., 2010).

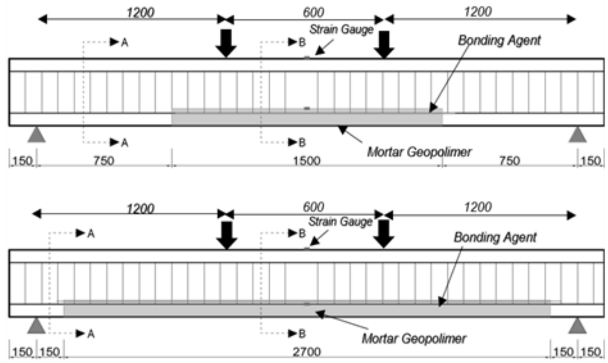
Several studies recommend the use of fiber in geopolymer concrete to increase its tensile strength, flexural strength, and ductility (Velasco, et al., 2004), one of which is the use of PVA fiber. PVA fiber has good properties to increase the strength of concrete. These fibers have a high modulus of elasticity, durability, tensile strength, and bond strength. This property is needed to increase the ductility of concrete. The physical properties of PVA fiber are Diameter of 38 m, length of 8 mm, and density of 1.3 gram/cm^3. The modulus of elasticity of PVA fibers is in the range of 25 - 40 GPa, which is higher than that of natural fibers. The elongation of PVA fiber is 6-10%, and the tensile strength of PVA fiber ranges from 880 - 1600 Mpa (Manfaluthy, 2017).

3. Experimental Program

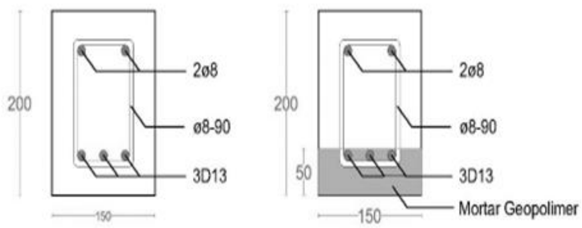
The geopolymer mortar consists of fly ash type C (50%) and alkali (50%) and the addition of PVA fiber is 0.6% of the volume of concrete (McCormac, 2015). The steps in this study were carried out by dividing 2 (two) variations of the material, namely geopolymer material without PVA fiber and with PVA fiber as a comparison material with conventional concrete and with 2 (two) variations of the length of repair and reinforcement of Reinforced Concrete (RC) beams, namely 1500 mm and 2700 mm with a layer thickness of 50 mm.



a) Control RC beam



b) Length of repair and strengthening beams 1500 mm and 2700 mm RC beam



c) RC beam details

Figure 1. RC beam specimens

Table 1. Mechanical properties of concrete

Concrete	Result
Compressive Strength *(f'_c)*	21,10 Mpa
Tensile Strength *(f'_t)*	2,17 Mpa
Flexural Strength *(f'_r)*	4,48 Mpa
Modulus of elasticity *(E_c*	23500

Multasam et al. / Lowland Technology International 2022; 24 (1): 20-25

Table 2. Mechanical properties of rebar

Rebar	Result
Yield Stress *(f_y)* - Ø8	384,82 Mpa
Ultimate Stress *(f_u)* - Ø8	538,75 Mpa
Yield Stress *(f_y)* - D13	336,75 Mpa
Ultimate Stress *(f_u)* - D13	469,24 Mpa

Based on the compressive strength test of geopolymer mortar, as much as 21.87 MPa was obtained while the compressive strength of normal concrete was only 21.10 MPa. These results indicate that the use of geopolymer as a substitute for portland cement in concrete mixtures has good compressive strength and can be used as a repairment and reinforcement material for reinforced concrete beams.

a) Normal concrete surface cleaning

b) Bonding agent application

c) Pouring geopolymer mortar to composite with normal concrete

d) Testing tools setting with static test equipment with two-point load

Figure 2. Geopolymer mortar mixing process

4. Result and Discussion

In general, the behavior of 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 condition, and the third phase is the phase where the reinforcement yields. The transition of each phase is indicated by the change in the stiffness of load-deflection relationship chart. These transition points are used to identify the initial and yield cracks in the reinforcement (Manuahe, et al. 2014). The flexural behavior of reinforced concrete beams is based on the analysis of the load-deflection behavior, the load-strain of the concrete, the stress-strain load of steel, and the crack pattern. **Table 2** recapitulates the test results, which consist the deflection, concrete strain, and steel strain at maximum loading conditions.

Table 2. The test result of flexural behaviour reinforces concrete beams.

	PVA fiber	Max load *(kN)*	Displacement *(mm)*	Concrete strain (μ_ε)	Rebar strain (μ_ε)
CB	-	34.78	0.286	0.593	0.286
GP 1500	-	35.65	0.067	0.796	0.067
GP 2700	-	32.65	0.077	0.782	0.286
GP-F 1500	With	33.50	0.077	0.782	0.286
GP-F 2700	With	37.92	0.077	0.782	0.286

4.1 Load and displacement relationship

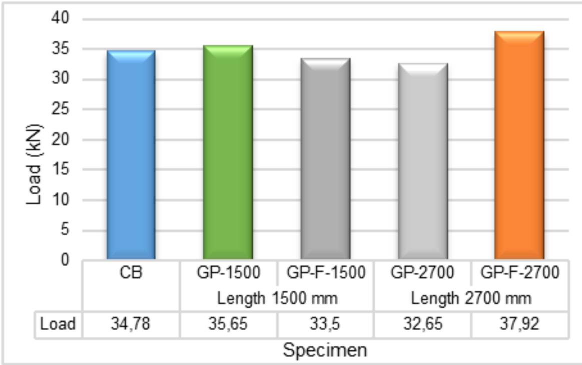


Figure 3. Maximum load of each variation

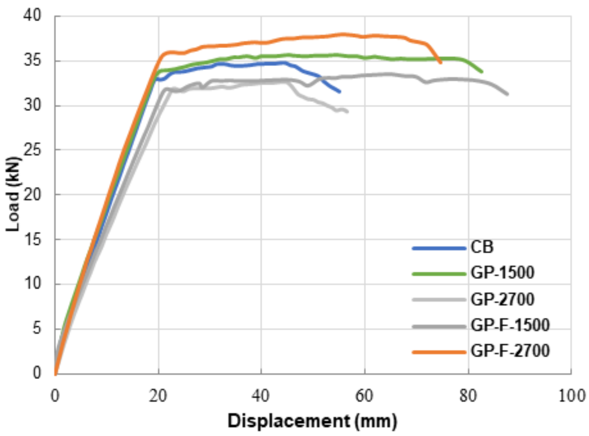


Figure 4. Chart load-deflection curve

From **Figure 3** and **Figure 4** above, it can be explained that in the beam using geopolymer mortar with a reinforcement length of 1500 mm (GP 1500), the maximum deflection and load are 8.42% higher than the GP 2700 beam. Meanwhile, in the geopolymer mortar beam using a reinforced length fiber of 2700 mm (GP-F 2700), the maximum deflection and load of beams with fiber are 13.19% higher than those of GP-F 1500 beams under maximum loading conditions.

This shows that the ability to use geopolymer mortar as a repair material is only able to work maximally at half of the beam span length, and will experience a decrease in compressive strength if it exceeds the span length.

This is because the geopolymer mortar has low tensile strength and has brittle properties that caused many cracks on the beams. In addition, geopolymer mortar with fibers is more ductile when compared to control beams without fiber. This is due to the fiber effect which can increase the tensile strength and minimize the number of cracks and microcracks that occur during the hardening process in geopolymer mortar.

4.2 Load and strain relationship

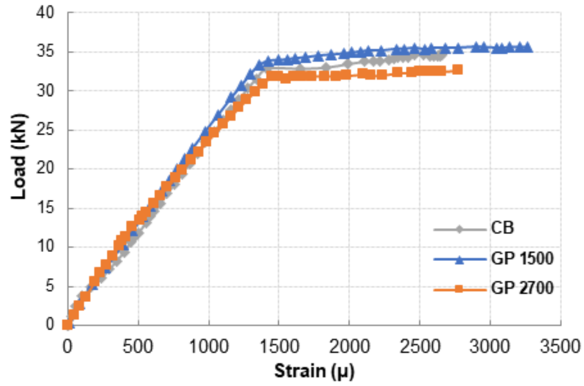


Figure 5. Chart load – concrete strain curve without PVA fiber

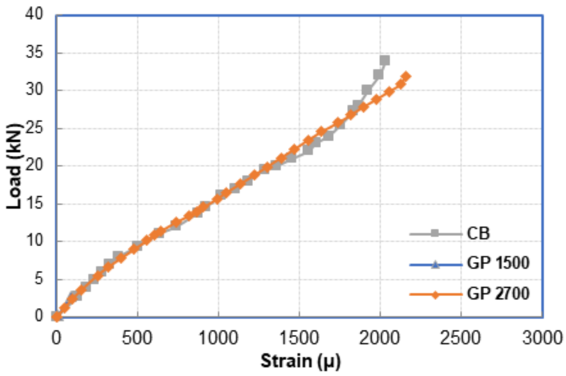


Figure 6. Chart load – rebar strain curve without PVA fiber

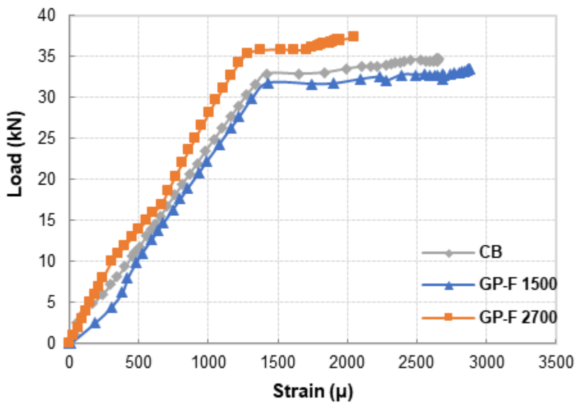


Figure 7. Chart load – concrete strain curve with PVA fiber

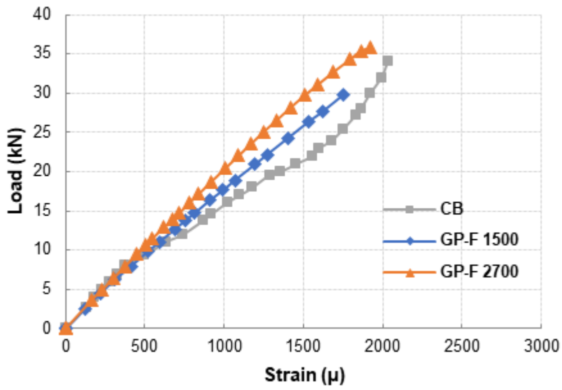


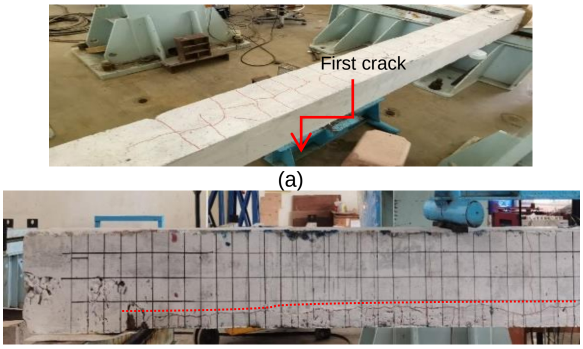
Figure 8. Chart load – rebar strain curve with PVA fiber

Figure 5 shows that the effect of using geopolymer materials with variations in the length of reinforcement influences the strain of concrete. Where the concrete strain produced from the GP 1500 beam is 17.67% greater than the GP 2700 beam. However, **Figure 6** shows that the steel strain in the GP 1500 beam is 95% lower than that of the GP 2700 beam. The steel strain in the 2700 beam has reached its ultimate strain of 2000 for concrete and 1683 for steel. Which causes the concrete in the GP 2700 beam to experience flexural or ductile failure, characterized by compression side destruction at mid-span.

Figure 7 shows that the effect of adding geopolymer mortar fibers with variations in the length of reinforcement affects the concrete strain. Where the concrete strain resulting from the GP-F 1500 beam is 40.45% greater than that of the GP-F 2700 beam. Similarly, **Figure 8** shows that the steel strain in the GP-F 1500 beam is 57.86% higher than that of the beam. GP-F 2700. In addition, concrete strain and steel strain in both test specimens have reached their ultimate strains of 2000 for concrete and 1683 for steel, which causes the concrete to fail in flexural or ductile, characterized by compression side failure at mid-span. However, the effectiveness of the use of fiber is better in the GP-F 2700 beam because it can reduce some of the strain that occurs in the reinforcement. This is due to the presence of fibers that have high tensile strength so that strain in the steel is partially distributed to the fibers.

4.3 Crack patterns and failure modes

In general, all beams experience flexural cracks which are characterized by vertical cracks. Beams also experience under-reinforced compression failure which is indicated by the destruction of the concrete on the compression side when it reaches peak load.



(a)

(b)

Figure 9. Microcrack during the hardening process-before testing

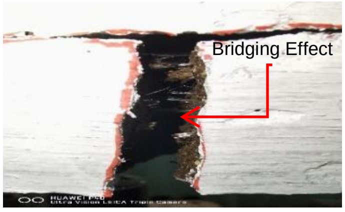


Figure 10. Crack width - first crack

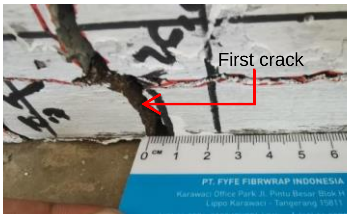


Figure 11. Crack width - maximum load

Figure 9 - figure 15 shows that In Reinforced Concrete (RC) beams GP 1500 and GP 2700 found quite a lot of microcrack on the old concrete joints and geopolymer mortar on the subsurface of the beam. These cracks occur during the hardening process because the geopolymer mortar has brittle properties and low tensile strength (Fig. 9). This microcrack also causes the beginning of crack development which spreads upwards in the middle span and forms vertical cracks in the beam axis (Fig. 10). Initial cracks in the entire beam occurred in the average range of 5 kN so it did not have a significant effect on beam stiffness and increase in length of the reinforcement area. After the peak load, the crack width was measured in the area with the maximum crack, with a crack width of 0.7 mm (fig.11).

In terms of failure mode, the GP 1500 beam experienced a debonding failure, namely loss of bond between the old concrete and the geopolymer mortar, while the GP 2700 beam experienced a delamination failure between the old concrete and the geopolymer mortar in the middle of the span expanded into the maximum moment area.

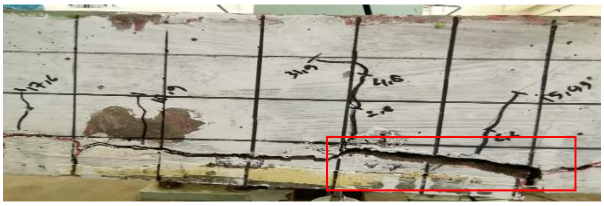


Figure 12. Delamination failure; starts from a microcrack and widens as the load increases

In RC beams GP-F 1500 and GP-F 2700 microcracks are found in beams that occur in the middle of the span, but not as much as those found in geopolymer mortar beams. This is because the addition of fiber can reduce the microcrack of the concrete hardening process, and it can reduce long-term costs by reducing repair and maintenance costs.

Almost the entire crack in the geopolymer mortar beam with the addition of fibers connections originated from normal concrete and geopolymer mortar. This is because the fiber can increase the tensile stress in the geopolymer mortar. Immediately after the peak load, the crack width was measured in the area with the maximum crack. The crack width was 0.6 mm. This is because of the fiber bridging effect which will reduce the width and rate of crack expansion. From the connection failure mode, the behavior of the beam with fiber is the same as the behavior of the geopolymer mortar beam without fiber, namely debonding and delamination failure **(fig.12)**.

5. Conclusion

- An applied innovation product for inexpensive and environmentally friendly structural repair and reinforcement materials
- The use of geopolymer mortar with fibers, increases the flexural behavior of reinforced concrete beams, which can reduce the microcracks and increase the tensile strength of the RC beams.
- Microcrack in geopolymer mortar with fiber does not affect the length of the beam undergoing repair and reinforcement.
- The span length 1500 is an effective span from the use of geopolymer mortar as a repair and reinforcement material for RC beams because it has the best ductility.

References

ACI Manual of Concrete Practice Index., 2015. Detroit, MI,USA:American Concrete Institute.

Hardjito, D., 2005. Studies on Fly Ash-Based Geopolymer Concrete. Curtin University. Retrieved from http://hdl.handle.net/20.500.11937/634.

Manfaluthy, Muhammad Lutfi and Januarti Jaya Ekaputri., 2017. The Application of PVA Fiber to Improve the Mechanical Properties of Geopolymer Concrete. Institut Teknologi Sepuluh Nopember, MATEC Web of Conferences 138, 01020 EACEF 2017.

Manuahe, R et al., 2014. Kuat Tekan Beton Geopolimer Berbahan Dasar Abu Terbang (Fly ash), Jurnal Sipil Statik Vol.2 No.6, Universitas Sam Ratulangi.

McCormac, J. C., 2015. Design of Reinforced Concrete 10th Editi.pdf (D. Fowley (ed.); 10th ed.). John Wiley & Sons, Inc.

Van Deventer, J., Provis, J., Dixson, P., & Lukey, G., 2007. Reaction mechanisms in the geopolymeric conversion of inorganic waste to useful products. Journal of Hazard Mater 139 506–13.

Velasco, R. V., Filho, T.R.D., Fairbairn, E.M.R., Lima, P.R.L., & Neuman, R., 2004. Spalling and Stress-Strain Behaviour of Polypropylene Fibre Reinforced HPC After Exposure to Higt Temperatures. Department of Civil Engineering, COPPE, Universidade Federal do Rio de Janeiro, Brazil. https://www.researchgate.net/publication/237842671

Zhang Z., Yao X., & Zhu, H., 2010 Potential application of geopolymers as protection coatings for marine concrete: I. Basic properties. Appl Clay Sci. 49 (1–2) 1–6.