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The Effect of Binder Types of Strengthening Panel for Shear Strengthening Reinforced Concrete Beams

To cite this article: R Irmawaty *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1117** 012017

The Effect of Binder Types of Strengthening Panel for Shear Strengthening Reinforced Concrete Beams

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Abstrac. This paper presents the shear behavior, crack patterns, and failure modes of reinforced concrete beams strengthened with geopolymer and Portland cement mortar panels. The specimens were prepared in the form of geopolymer and Portland cement mortar panels with a size of 300 mm x 700 mm, each consisting of 4 pieces. The reinforced concrete beams specimen were produced with dimension of 150 mm x 300 mm x 2300 mm and static monotonic loading test was carried out. To ensure the strength of the geopolymer and concrete used is in based on the target, a compressive strength test is carried out at the age of 28 days, with 3 samples each. According to the results of the loading test of reinforced concrete beams, the maximum load on the beam strengthed with geopolymer and Portland cement mortar panels increased by 34.98% and 29.54%, respectively, compared to the control beam. The addition of panels to reinforced concrete beams causes it's behavior to change, becoming more ductile. This also has an impact on the crack patterns and failure modes. CB beams experience shear failure, which is indicated by the appearance of diagonal cracks along the shear area to the point of loading, whereas mortar panel reinforced beams experience flexural failure.

Keywords: Strengthening, Mortar Panels, Geopolymer.

1. Introduction

In civil engineering, the term strengthening is known as a method of increasing the capacity of structural elements for loads. Strengthening of the structured elements are used in both new and old structures. Strengthening in new structures, was applied when a design failure occurs, or quality is not achieved during construction. While in the old structure, strengthening was applied to structural elements that were affected by environmental conditions, the age of the building, changes in building function, and changes in standardization. Strengthening was needed if there is damage that causes degradation, resulting in non-fulfillment of technical requirements such as strength, stiffness, ductility, stability and resistance to certain performances [1].

There are several strengthening methods commonly used, such as Fiber Reinforced Polymer (FRP),Concrete Jacketing, and External Steel Plates. Each of these methods has its advantages and disadvantages [2]. Strengthening using mortar panels mounted on the sides of reinforced concrete beams using the Near Surface Mounted Technique, can cover the drawbacks of other reinforcement methods.

In general, cement is used as the main binder on mortar. However, the use of cement has a negativeimpact on the environm 7 t. Industrial cement can produce CO_2 gas which is known as greenhouse gas emissions [3]. The production of one ton of cement is about one ton of CO_2 into the atmosphere. In2016, world cement production produced around 2.2 billion tons of CO_2, or equal to the contributionof about 8% of the world's carbon dioxide (CO_2) gas emissions [4]. Therefore, another alternative is needed that can be used as a binder material.

Concrete without cement or geopolymer concrete is a geosynthetic concrete whose bonding reaction occurs through a polymerization reaction and not through a hydration reaction as in conventional concrete [5]. Geopolymer itself was first introduced by Davitdovits, and described as a non-cement material made of aluminosilicate as an alkali activator, including industrial waste (fly ash, blast furnace slag) or metakaolin at low calcination temperatures. One type of geopolymer comes from the main material of fly ash industrial waste which is rich in Alumina (Al) and Silica (Si) elements. Fly ash is one of the wastes generated from the coal combustion process at the Steam Power Plant (PLTU).

Studies on the use of geopolymers have been extended to various applications in structural elements, including reinforced concrete, columns, concrete-filled steel tube (CFT) columns, reinforcedconcrete wall panels, slabs, and precast railroad sleepers. Therefore, this research was conducted by exploring the use of geopolymer mortar as a shear reinforcement technique in beams using anchored geopolymer mortar (GM) panels with the addition of PVA (Poly-Vinyl Alcohol) fibers.

The study aimed to compare the shear capacity, crack patterns, and failure modes of beams reinforced with geopolymer mortar panels (GM) and Portland cement mortar panels (PC).

2. Materials and Methods

Ready mix concrete with compressive strength design of 20 MPa. Fly Ash obtained from PLTU Bosowa Jeneponto, South Sulawesi based on ASTM C618 [6]. NYCON-PVA RECS 15 type of PVA fiber with 8 mm in length, was used to increase the ductility of the Geopolymer mortar [7].

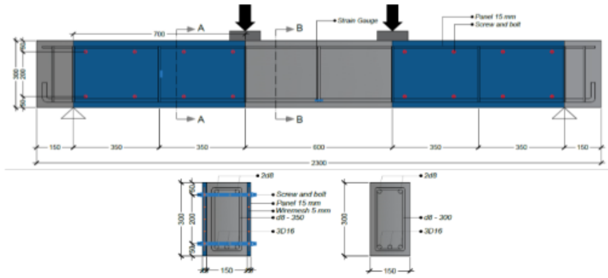
Table 1. Composition of Geopolymer and Portland Cement Mortar (kg/m^3)

Kode	kg per m3							PVA
	NaOH	Na_2SiO_3	Boraks	Pasir	Semen	*Fly Ash*	*plasticizer*	(%)
GM-0.6	156	234	10	780	-	390	7.8	0.6
PC-0.6	-	-	-	1360	636	-	-	0.6

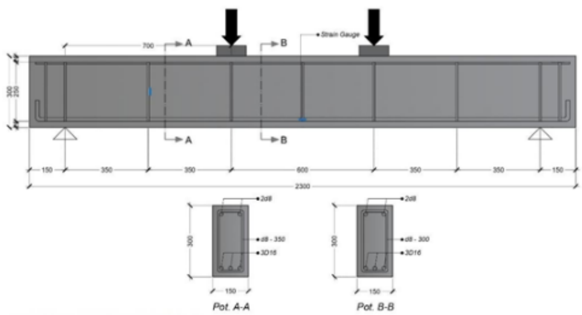
The specimens in this study consisted of three types of beams with dimensions of 150 x 300 x 2300mm with compressive strength of f'c = 20 MPa, as shown in Figure 1. Normal beams as control beams are named with the code CB, beams with panel reinforcement geopolymer mortar is named with the code GM-W-200.

Table 2. Variation of specimens

No	Code	Strengthened materials	Number of the specimens
1	CB	-	1
2	GM-W-200	Geopolymer mortar + PVA Fiber	1
3	PC-W-200	Portland cement mortar + PVA Fiber	1
		Total Specimens	**3**



(a). Longitudinal and transverse section of GM-W-200 and PC-W-200



(b). Longitudinal and transverse section of CB

Figure 1. Specimens detail

3. Fabrication and Testing of specimens

This research was conducted in the Structure and Materials Laboratory, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University. This type of research is an experimental laboratory study in the form of shear testing of reinforced concrete beams strengthened with geopolymer mortar panels and Portland cement mortar.

The fabrication of the specimens begins with the manufacture of geopolymer mortar and portland cement mortar panels. The manufacture of mortar panel test specimens begins with the manufacture of test specimen molds. After the preparation of the material (table 1), the mixing process is carried out using a mixer. At this stage, a sample of cubes measuring 50mm x 50mm x 50mm was also taken for testing the compressive strength of the mortar panel. After that, the panels are preserved by moist curing method.

During the panel maintenance process, the specimens of reinforced concrete beams were made, preceded by the manufacture of concrete and reinforcement. The manufacture of reinforced concrete beam molds is carried out simultaneously with the manufacture of panel mortar moulds. On the right and left sides of the reinforced concrete beam mold, holes are provided for the installation of anchor bolts.After that, the casting is done using ready mix concrete. Reinforced concrete beam specimens were also cured using the moist curing method. After the reinforced concrete panels and beams reach the age of 28 days, the panels are installed on the reinforced beams. Installation of mortar panels is done using an adjustable spanner (wrench) adjusted to the dimensions of the bolts used. After the reinforcement panel is inserted into the anchor of the test object, it is locked until the geopolymer mortar reinforcement panel is homogeneous with the reinforced concrete beam to be tested.

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The specimen was loaded with a two-point load monotonically using a static test device with a capacity of 1500 kN. Loading uses deflection control with a loading speed of 0.2 mm/second. The instrumentation used is a strain gauge to measure the strain in concrete and steel, a Linear Variable Displacement Transducer (LVDT) to measure the deflection of the specimen, a load cell with a capacity of 200 KN to read the load that occurs, and a data logger to store all the data measured by instrument.

Strain gauges are installed in 4 locations, one on the top side of the concrete, one on the wiremesh, one on the shear reinforcement, and one on the flexural reinforcement. The strain gauge on the top side is used to measure the strain on the maximum compression side, while the strain gauge on the wiremesh is used to determine the maximum strain on the wiremesh panels and for the strain gauge on the shear reinforcement and flexural reinforcement to determine the maximum strain on the shear and flexural reinforcement.

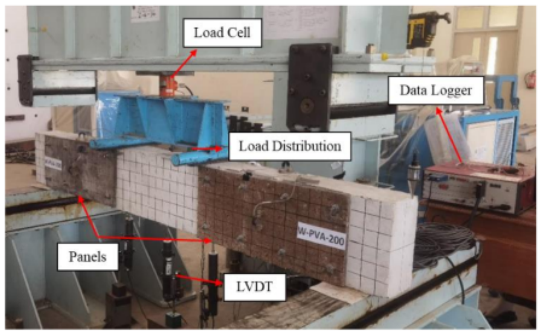

Figure 2. Set Up Specimen

4. Results and Discussion

4.1 Mechanical Properties

According to Table 4, the compressive and splitting tensile strengths of geopolymer mortar with PVA fibers at 28 days was 21.5 MPa and 2.1 MPa, respectively. Meanwhile, that of Portland cement mortar with PVA fibers for the same number of days was 23.2 MPa and 2.5 MPa. The results showed that the compressive and splitting tensile strengths of geopolymer mortar insignificantly different from that of PC. It needs to be noted that both binding materials applied the moist curing method.

Table 3. Compressive and splitting tensile strength at 28 days

Binding materials	Compressive strength (MPa)	Splitting tensile strength (MPa)
Geopolymer mortar + PVA	21.5	2.1
Portland cement mortar + PVA	23.2	2.5

4.2 Load – Deflection Relationship

In general, the behavior of the load-deflection relationship can be idealized into a trilinear form. However, the graph of the load and deflection relationship of the specimen in Figure 3 shows two forms of load-deflection relationship behavior, which is bilinear and trilinear. In the CB beam, the load-deflection relationship graph is bilinear which only consists of two phases. The first phase is the condition where the concrete has not cracked. The second phase is when the concrete begins to crack until it reaches its maximum load. Meanwhile, for the specimen with a strengthened panel, it consists of three phases. In the first phase, the concrete is still in an elastic condition (not cracked). The second is the phase where the concrete begins to crack and the third is the plastic phase where the steel reinforcement yields to the maximum load.

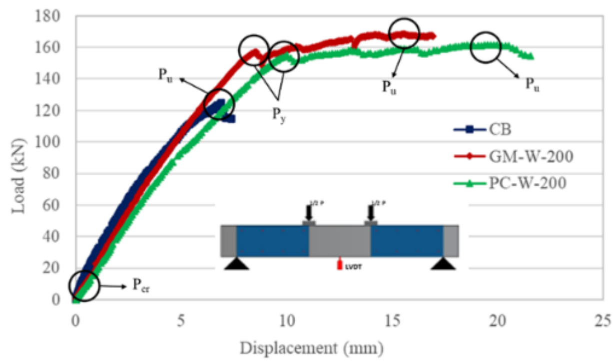

Figure 3. Load-deflection relationship

Figure 3 shows the load-deflection relationship of CB, GM-W-200 and PC-W-200 beams at mid- span. The effect of using geopolymer material on the reinforcement panels can be observed by comparing the load-deflection behavior of CB and GM-W-200 beams. Meanwhile, the effect of using Portland cement on the reinforcement panels can be observed by comparing the load-deflectionbehavior of GM-W-200 and PC-W-200 beams.

Based on Figure 3, the stiffness of the three beams had the same behavior at the initial crack. However, after the initial crack conditions reached a certain load, the CB beam experienced a decreasein stiffness until the beam was destroyed. The CB beam graph shows that after reaching the maximum load, the graph decreases suddenly, this indicates that the CB beam has shear failure.

However, in beams with strengthened panels, the loads are still increasing until it reaches the yield load, up to the maximum load. The PC-W-200 beam exhibits less rigidity than the GM-W-200 beam, this shows that both specimens suffer from flexural failure. The recapitulation of specimens is presented in Table 4, which consists of loads and deflections at initial crack conditions, yielding and maximum load.

Table 4. Load-deflection relationship recapitulation

No	Code	Load (kN)				Deflection (mm)			
		Pcr	$Py_{(Shear\ Rebars)}$	$Py_{(Tensile\ Rebars)}$	Pu	δ_{cr}	$\delta_{y(Shear\ Rebars)}$	$\delta_{y(Tensile\ Rebars)}$	δ_u
1	CB	10.06	-	-	124.75	0.26	-	-	6.89
2	GM-W-200	11.06	157.00	156.27	168.40	0.52	8.54	8.38	15.46
3	PC-W-200	11.06	153.34	154.87	161.60	0.61	10.17	10.00	19.65

In the control beam (CB), the reinforcing steel is fully elastic until the beam experiences initial cracks at a load of 10.06 kN with a deflection value of 0.26 mm. After the initial cracking occurs, the load continues to increase as the deflection increases. When the load reaches 124.75 kN, the load drops suddenly. This indicates that the beam has failed.

In the beam strengthened with geopolymer mortar panels, the initial crack occurred at a load of 11.06 kN with a deflection value of 0.52 mm. After initial cracking, the beam then shows the elastoplastic properties of the steel to yield reinforcement at a load of 157 kN with a deflection value of 8.54 mm for shear reinforcement with a strain value of 1411 $\mu\varepsilon$ and 156.27 kN with a deflection of 8.38 mm for tensile reinforcement with a strain value of 2234 $\mu\varepsilon$. These results are in accordance with the tensile strength test value of steel, where the tensile reinforcement has a yield strain value of 1924 $\mu\varepsilon$ while the shear reinforcement is 1684 $\mu\varepsilon$ .After the reinforcement yielded, the load still showed an increase but was disproportionate. This can be seen from the relationship curve to be flatter than before the reinforcement yields. This happens until the beam collapses at an ultimate load of 168.4 kN with a deflection value of 15.46 mm. This shows that beams with geopolymer mortar panel reinforcement exhibit more ductile behavior than CB beams.

In the beam strengthened with Portland cement mortar panels, the initial crack occurred at a load of 11.06 kN with a deflection value of 0.61 mm. After the initial cracking, the beam then shows the elastoplastic properties of the steel to yield reinforcement at a load of 153.34 kN with a deflection of 10.17 mm for shear reinforcement with a strain value of 1905 $\mu\varepsilon$ and 154.87 kN with a deflection of 10 mm for tensile reinforcement with a strain value of 1608 $\mu\varepsilon$. These results are in accordance with the tensile strength test value of steel, where the tensile reinforcement has a yield strain value of 1924 $\mu\varepsilon$ while the shear reinforcement is 1684 $\mu\varepsilon$. Before yielding reinforcement, the load increases proportionally as happened in the GM-W-200 beam. After yield reinforcement, the beam still increased but disproportionately before the beam collapsed with a maximum load of 161.6 kN and a deflection value of 19.65 mm. This showsthat beams with geopolymer mortar strengthening panel exhibit more ductile behavior than CB beams.

The effect of Geopolymer mortar panel reinforcement can be observed by comparing the three CB beams, GM-W-200 and PC-W-200. The beams GM-W-200 and PC-W-200 show almost the same loaddeflection relationship behavior. It can be seen in the graph where the geopolymer mortar panel and portland cement mortar panel affect the behavior of the beam to be more ductile.

4.3 Maxsimum Load

Figure 4 shows the maximum load on each specimen. The maximum loads of CB, GM-W-200 and PC-W-200 beams are 124.75 kN, 168.39 kN and 161.6 kN, respectively. The maximum load of GM- W-200 and PC-W-200 beams experienced a significant increase compared to CB beams. GM-W-200 beam and PC-W-200 beam increased by 34.98% and 22.81% to the control beam

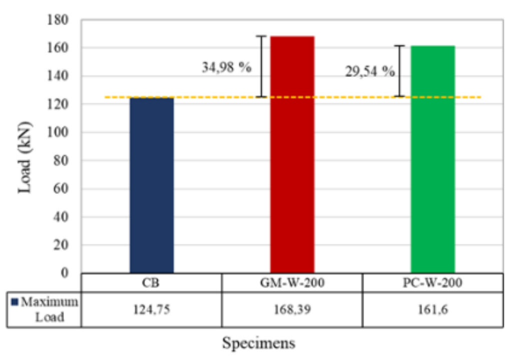

Figure 4. Maximum Load

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4.4 Crack Pattern

Figure 5 shows the control beam (CB) crack pattern. The control beam (CB) has an initial crack whichis a flexural crack at a load of 37.3 kN. The crack occurs at the bottom left of the span and increases inlength. The initial shear crack occurs when the load is 56 kN. Shear cracks are characterized by the presence of diagonal cracks in the shear area of the beam. At the time of peak load, the concrete on theshear side crumbled, indicating that the beam had shear failure.

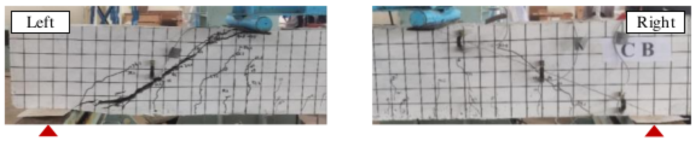

Figure 5. Crack pattern of CB

Figure 6 shows the GM-W-200 beam crack pattern. Based on observations, the initial crack which is a flexural crack in the GM-W-200 beam occurs at a load of 25.19 kN as shown in Figure 6. Meanwhile, the initial crack in the geopolymer mortar panel appears at a load of 57.38 kN. Cracks occur in the center of the panel. After the initial crack on the panel appears, other cracks start popping up randomly.

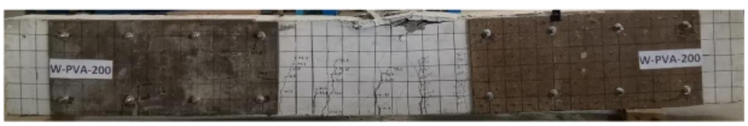

Figure 6. Crack pattern of GM-W-200

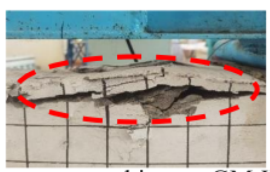

Figure 7. Concrete crushing on GM-W-200 beam

After reaching the maximum load, the concrete is destroyed on the compression side (Figure 7). This can also be seen in the graph of the load-strain relationship of concrete, where the strain of GM- W-200 beam concrete in the compression area is close to 3000 $\mu\varepsilon$.

Figure 8 shows the PC-W-200 beam crack pattern. Based on the observations, the initial crack which is a flexural crack in the PC-W-200 beam appears in the mid-span area when the load is 12.73 kN. After the initial crack appears, another flexural crack appears and then propagates towards the loading point. Initial cracks in the Portland cement mortar panel appeared at a load of 73.57 kN. Cracks occur in the upper area of the panel adjacent to the loading point After the initial crack in the panel, other cracks begin to appear randomly.

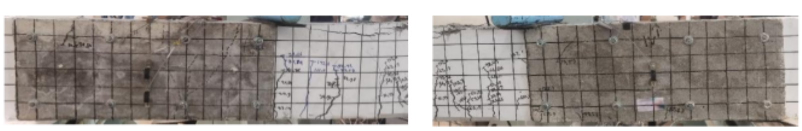

Figure 8. Crack Pattern of PC-W-200

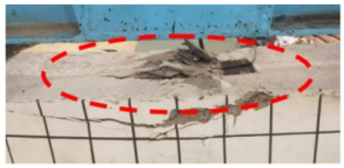
Figure 9. Concrete crushing on PC-W-200 beam

After reaching the maximum load, the concrete is destroyed on the compression side. This can also be seen in the graph of the concrete load-strain relationship, where the concrete strain for PC-W-200 in the compression area reaches a value of 4313 με.

Based on observations on crack patterns and failure models on the GM-W-200 and PC-W-200 beams, it can be seen that both of them have similarities, including the type of initial crack and the number of cracks in each specimen. In addition, both variations of the beam were destroyed on the compression side. both specimens of the test object experienced flexural failure

4 Conclusion

Based on the results of research and discussion, it can be concluded that :

1. The additional of strengthened panels with geopolymer and Portland cement materials was able toincrease the loading capacity of reinforced concrete beams, respectively by 34.98% and 29.54% to the control beam, in the form of increasing the maximum load and changing the failure pattern from shear failure to flexural failure.
2. Crack patterns and failure modes on the GM-W-200 and PC-W-200 beams show similarities,both in terms of crack patterns and the number of cracks in each specimen. Both panel's variations show a flexural failure pattern while the control beam exhibits a shear failure.

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