Bond Behaviour Between Reinforcing Bars and Geopolymer Concrete By Using Pull-out Test

by Ahmad Saiful Haqqi

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Ratni Nurwidayati[1,*], *Januarti* Ekaputri[2], Triwulan[2], and *Priyo* Suprobo[2]

[1]Faculty of Engineering, Lambung Mangkurat University, Banjarmasin, Indonesia
[2]Faculty of Civil, Environmental and Geo Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Abstract. This paper presents the effect of the reinforcing bar diameter (d_b) and concrete cover thickness to reinforcing bar diameter ratio (c/d_b) to the bond strength between reinforcing bar and geopolymer concrete by using the experimental pull-out test. The mass ratio of sodium hydroxide (NaOH) to sodium silicate (Na_2SiO_3) was 2.5 with an 8M concentration of sodium hydroxide were used in this research. Class F fly ash from Suralaya Power Station, Banten, Indonesia was used as raw material to produce geopolymer concrete. The maximum diameter of coarse aggregate was 10mm. The result indicated that the maximum pull-out load on reinforcing bar diameter of 16mm was higher than the diameter of 13mm. The pull-out failure occurred on the ratio of c/d_b more than equal of 4.3. The bond strength increased as the ratio of c/d_b increased, up to 4.3. However, more than 4.3 was the insignificant effect.

1 Introduction

Coal has been used as an energy resource. The burning coal produces fly ash around 25-30% and bottom ash about 2-3% that is depending on the quality of coal [1]. With the high percentage of fly ash waste, it will undoubtedly cause environmental problems such as air and water pollution and the degradation of ecosystem quality, so there is an effort to utilize this waste.

On the other hand, cement production in addition to requiring high energy can also cause a greenhouse effect. One ton of carbon dioxide (CO_2) is released into the air every ton of cement production [2]. Geopolymer concrete is one solution to use the waste of the industrial output and reduce air pollution that will occur due to cement production. In geopolymer concrete, Portland cement is not used, and all are replaced with pozzolanic substitutes which have high silica (SiO_2) and alumina (Al_2O_3) content such as fly ash, and volcano mud. These silica and alumina react with alkaline solutions as activators to form geopolymer paste. The geopolymer paste binds coarse and fine aggregates to form geopolymer concrete. In the production of one ton of geopolymer concrete, only 0.18 ton of carbon dioxide is released into the air [2]. It shows that geopolymer concrete is environmentally friendly concrete.

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[*] Corresponding author: ratninurwidayat@ulm.ac.id

Currently, geopolymer concrete for structural elements has been used. The application of geopolymer concrete structures is very dependent on bond behavior between the reinforcing bar and geopolymer concrete. Bond strength behavior of reinforcing bar in geopolymer concrete has been investigated by several researchers [3-6] by using beam-end testing and pull-out tests. Recently, Albitar et al. [7] evaluate the effect the thickness concrete cover to failure mode, the influence of the geopolymer concrete strength and concrete cover to bar diameter ratio to bond strength. However, only a few research evaluate the bond strength and the failure mode by using the pull-out test. This paper will discuss bond strength and failure mode due to the influence of reinforcing bar diameter and concrete cover.

2 Experimental Program

2.1 Concrete Material and Composition

A series of 18 pull-out test was conducted to quantify the bond strength behavior between the deformed reinforcing bar and geopolymer concrete. The chemical composition of fly ash that was used in this research is listed in Table 1. The amount of SiO_2, Al_2O_3, and Fe_2O_3 are 78.72%. It indicates that fly ash is categorized as class F fly ash.

Table 1. The chemical composition of fly ash

Component	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	TiO_2	Na_2O	Cr_2O_3	P_2O_5	SO_3	MnO_2
Mass (%)	44.83	29.23	4.47	4.66	0.68	1.62	0.84	1.32	0.01	0.25	0.62	0.09

The mixing composition of this research was based on a previous study [8] as shown in Table 2. Alkaline activator used sodium silicate solution (Na_2SiO_3), and an 8M of sodium hydroxide (NaOH) were mixed with a weight ratio of 2.5. The composition of sodium silicate solution is 18% Na_2O, 36% SiO_2 and 46% H_2O. One liter of 8M NaOH was produced by mixing 320gr of NaOH flakes (98% purify) and distilled water and prepared for 24 hours before cast the geopolymer concrete. Sodium silicate and sodium hydroxide solution were mixed prior to blend with other material. The weight ratio of fly ash to the alkaline activator was 1.86. Plastiment-VZ was applied around 2% by fly ash mass to improve the workability and delay the setting time of fresh geopolymer concrete.

Coarse and fine aggregates were collected from a local quarry. The aggregate was in saturated surface dry (SSD) condition before mixing with other materials. The weight ratio of aggregate to the binder and coarse aggregate to fine aggregate were 75 to 25 and 60 to 40 respectively.

Table 2. The mixing composition

Material	weight (kg)
Coarse aggregate	1080
Fine aggregate	720
Fly ash	390
Na_2SiO_3	150
NaOH 8M	60
Superplasticizer	7.8

2.2 Preparation of Specimens

The prism specimens prepared for pull-out tests were 100×100, 150×150, 180×180mm in cross-section and 200mm length. The diameter of the deformed reinforcing bar in this experiment was 13mm and 16mm with a total length of 900mm. The average of the effective diameter, yield strength and ultimate strength of three reinforcing bars are listed in Table 3. It should be noted that the effective diameter will be used in the calculation, but d_b=13mm and d_b=16mm were used for labeling.

The reinforcing bar was extended from the surface of geopolymer concrete prism around 50mm on the unloaded-end reinforcing bar and 650mm on the loaded-end bar for grip the pull-out machine as shown in Figure 1. The lead length was fixed at 60mm to prevent the effect of lead length on bond strength. The reinforcing bar that was outside of the geopolymer concrete prism was painted to avoid the effect of corrosion during the curing process.

Table 3. Properties of reinforcing bar

Diameter (mm)	Effective diameter (mm)	Yield strength (MPa)	Ultimate strength (MPa)
13	12.73	503.8	641.7
16	15.71	497.0	637.6

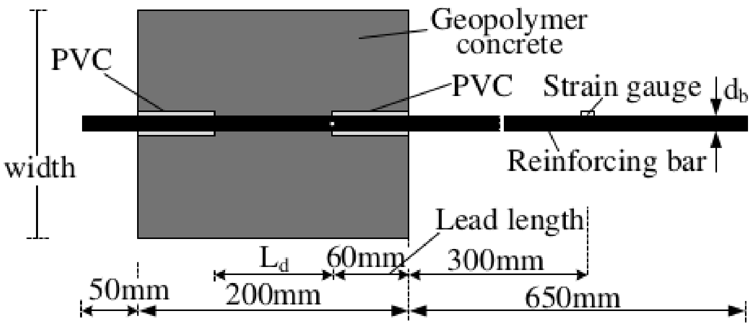

Fig. 1. Detail of Pull-out Test Specimen

The bond length (L_d) in this experiment was conducted to be $5d_b$ where d_b was the effective diameter of the reinforcing bar as listed in Table 4. PVC tube was applied to achieve bonding between geopolymer concrete and reinforcing bar on the specific bond length only. The thickness of concrete cover varied as shown in Table 4. The strain gauge type FLA-2-11 with gauge length 2mm was placed on a loaded-end reinforcing bar of 300mm from concrete prism surface to evaluate the behavior of reinforcing bar.

Table 4. Bond Length and Cover Specimens

Effective diameter (mm)	100×100		150×150		180×180		Bond Length ($5d_b$)	Bond Area (mm^2)
	cover (c)	c/d_b	cover (c)	c/d_b	cover (c)	c/d_b		
12.73	43.6	3.4	68.6	5.4	83.6	6.6	63.7	2545.5
15.71	42.1	2.7	67.1	4.3	82.1	5.2	78.6	3876.8

The reinforcing bars were embedded horizontally at the center of the prism specimens during poured the geopolymer concrete into the pull-out mold. The concrete cylinder of 100×200 was also cast to determine the compressive strength on the day of testing of the pull-out test. All samples removed from the mold one day after cast and cured. Moist curing was conducted for 28 days by using wet gunny-sack and covered with plastic as shown in Figure 2.

Fig. 2. (a) Pull-out specimens after demolding; (b) Curing pull-out specimens

2.3 Test Setup

All pull-out test specimens were constructed and tested at Laboratorium of Concrete and Building Material Institut Teknologi Sepuluh Nopember, Surabaya. A universal testing machine (UTM) with a maximum capacity of 2,000kN was used. The pull-out test specimen placed turn upside down on 3cm thickness of steel plate on the top of the universal testing machine as shown in Figure 3. The steel plate has a hole slightly larger than the diameter of the PVC tube and the bar diameter on the center of the plate so that the reinforcing bar can pass through. The geopolymer concrete was restrained by steel plate while the loaded-end bar was gripped by machine and pulled down on with displacement control of 1mm/min until the specimen failed.

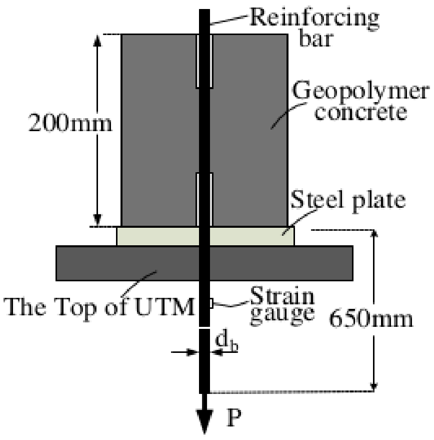

Fig. 3. Pull-out Testing Set up

3 Result and Discussion

3.1 Pull-out Load

The maximum pull-out were between 67.13kN and 114.14 kN. The average maximum pull-out load, bond strength, and failure mode of the three specimens are summarized in Table 5. Referring to Figure 4 and Table 5, the peak load increases as the bar diameter increases. The same result has been reported by Hadi [9] and Prince and Singh [10]. The maximum load of 16mm bar diameter slightly higher than that of 13mm bar diameter on prism specimen cross-section of 100×100. It was just around 11%. While on 150×150 and 180×180 prism specimens, the peak load of 16 bar diameter significantly higher about 50% than that of 13mm bar diameter. This behavior was caused by the greater bond area of 16mm bar diameter compared to of 13mm bar diameter as given in Table 4. A higher load was required to pull-out the reinforcing bar from the surrounding geopolymer concrete with the larger bond area.

The percentage of increasing maximum load on the specimen of 100×100 lower than others specimens in consequence of splitting failure took place on the samples of 100×100 on both bar diameters. Based on collected data from strain gauge, all of the reinforcing bars reached the yield strength at the peak pull-out load excepted for two of three reinforcing bars on a GP16-100 still elastic.

Table 5. Maximum pull-out load and bond strength

Specimens	Bar diameter (mm)	Bar effective diameter (mm)	c/d_b	Maximum Load, Pmax (kN)	Bond Strength (MPa)	Mode of failure
GP13-100	13	12.73	3.4	67.13	26.37	Splitting
GP13-150	13	12.73	5.4	73.89	29.12	Pull-out
GP13-180	13	12.73	6.6	76.21	29.94	Pull-out
GP16-100	16	15.71	2.7	74.28	19.16	Splitting
GP16-150	16	15.71	4.3	112.68	29.07	Pull-out
GP16-180	16	15.71	5.2	114.14	29.44	Pull-out

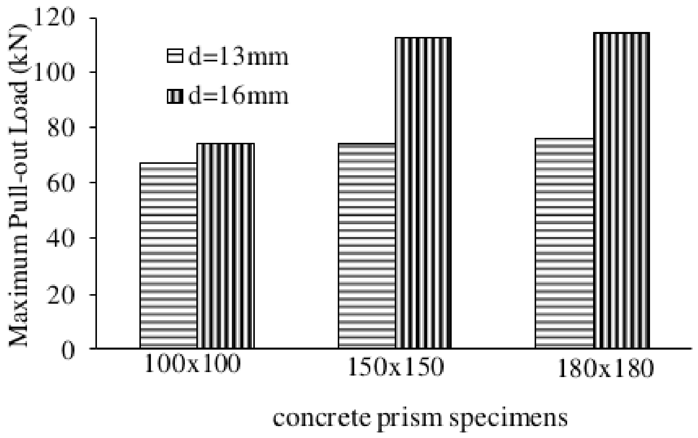

Fig. 4. The effect of bar diameter to maximum load

3.2 Bond Strength

The bond stress is assumed uniform along the bond length. The maximum pull-out load is divided by the bond area of reinforcing bar to determine the average of bond strength in megapascals as:

$$\tau = \frac{P_{max}}{\pi d_b L_d} \tag{1}$$

Where P_{max} is the maximum pull-out load (N), d_b is the effective diameter (mm), and L_d is the bond length that is five times effective bar diameter (mm).

Effect of reinforcing bar diameter on bond strength can be found in Figure 5. The graph indicates that on 100×100 cross-section prism sample, the bond strength of 13mm bar diameter is higher about 38% than that of 16mm bar diameter. The bond strength decreases for a bigger bar diameter. However, the bond strength of 13mm bar diameter as high as bond strength of 16mm bar diameter on prism specimens of 150×150 and 180×180. The increase in bar diameter from 13mm to 16mm was not followed by an increase in bond strength for both cross-section samples.

The small ratio of c/d_b causes the bond strength of 16mm bar diameter on 100×100 prism specimen lower than the bond strength of 13mm bar diameter. The influence of c/d_b is illustrated in Figure 6. Bond strength increase with increasing c/d_b from 2.7 to 4.3 after that there is no effect of c/d_b to bond strength. The same result had been reported on Albitar [7] and Hadi [9]. More experiments will be required with a larger diameter to verify the effect of diameter and c/db ratio to bond strength.

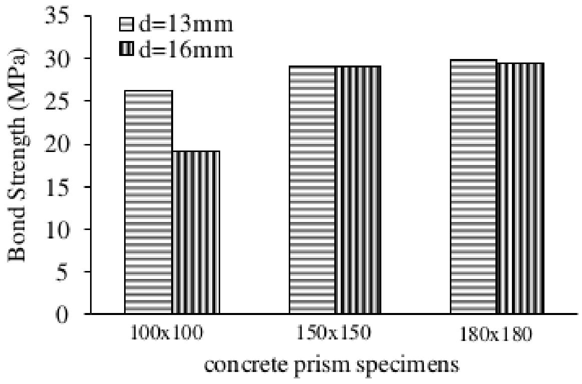

Fig. 5. The effect of bar diameter on bond strength

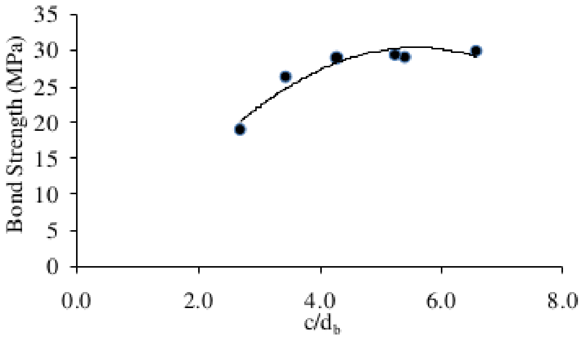

Fig. 6. Effect of c/d_b to bond strength

3.2 Failure Mode

Pull-out failure mode was occurred for all specimens in this experiment, except on small ratio of c/d_b of 2.7 and 3.4 that was demonstrated by splitting failure mode. The thickness of the cover concrete relative small that was not adequate to prevent the crack reach the concrete surface. Figure 7 shows the bond area between reinforcing bar and geopolymer concrete of pull-out specimens after failed. The pull-out failure took place when concrete between two rips of reinforcing bar detached as shown in Figure 7a. While Figure 7b represents the splitting failure occurs on the bond area.

Fig. 7. Type of failure mode on the bond area (a) pull-out failure mode; (b) splitting failure mode

4. Conclusion

The paper presented the experimental finding on the bond strength between geopolymer concrete and reinforcing bar. In this experimental pull-out test, concrete cover to bar diameter ratio varied between 2.7 to 6.6 and bar diameter of 13mm and 16mm were conducted. Based on the result from the experimental, the conclusions are expressed as follows:

1. The maximum pull-out load increased as the bar diameter increased. The maximum pull-out load on the bar diameter of 16mm were 74.28kN, 112.68kN, and 114.14kN and on bar diameter of 13mm were 67.1kN, 73.89kN, and 76.21kN when the prism concrete specimens were 100×100, 150×150, dan 180×180 respectively.
2. The bond strength on the prism-sample of 150×150, dan 180×180 were relatively the same for both bar diameters. While on 100×100 prism-sample, bond strength on 16mm bar diameter lower than 13mm bar diameter.
3. The pull-out failure occurred in the ratio of c/d_b more than 3.4. While splitting failure happened when c/d_b less than 3.4

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