

The Comparison of Bond Strength between Geopolymer Concrete and OPC Concrete for Plain Reinforcing Bars

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Abstract. This paper describes the research on bond behavior of plain reinforcing bars in geopolymer and normal concrete. The geopolymer concrete in this research was made of class F fly ash taken from Tanjung Jati Electric Steam Power Plant (PLTU) with Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) as alkaline activator, added in the mixture. The effect of bar size was studied by varying the bar diameter in range 10 mm to 19 mm. Each bar was casted in the center of concrete blocks made of geopolymer as well as normal concrete. Pull-out tests were carried out to the specimens that have reached 28 days of age. The test results show that the bond behavior of geopolymer concrete differs substantially from normal concrete, where geopolymer concrete has a higher bond strength when compared to normal concrete with identical concrete strengths.

1 Introduction

Current data shows that Portland cement concrete making material produces about seven percent of carbon dioxide (CO_2) [1]. The concentration of CO_2 in the atmosphere can dissolve in rain water to form carbonic acid (H_2CO_3) and falls to earth as acid rain. Hence, to reduce the production of CO_2 and to make environment friendly concrete, it is necessary to look for alternate materials to replace part, or all of Portland cement in concrete. In the past decade, research is focused on the study on geopolymer concrete to develop a more environmentally friendly concrete material. Geopolymer concrete is a type of alumina-silicate product and shows good bonding properties. In a fly ash-based geopolymer binder, fly ash reacts with the alkaline solution to create an alumina-silicate binder; no cement is used [2]. Numerous research showed that geopolymer can act as a binding agent in concrete [3,4]. Fly ash is one of the materials which is used to produce geopolymer concrete [5]. In the making process of geopolymer concrete, water and binding chemicals such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) are required.

As a construction material, the use of concrete is often composed with steel reinforcement, where the reinforcing bar in concrete is to resist tensile stress that cannot be carried by concrete. However, to establish the compatibility action to enable force transfer from the concrete to reinforcing bars or vice versa, a good bond between the steel bars and

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the concrete becomes mandatory. The bond between reinforcing bars and concrete has been acknowledged as a key to the proper performance of reinforced concrete structures [6].

Previous studies accessed the pull-out test to investigate the behavior of bond between reinforcing bar and geopolymer concrete with a variation in concrete compressive strength and for a range of deformed bar diameters [2]. Alternately, the study of Sarker [7] investigating the bond strength of geopolymer versus conventional concrete reported that the performance of pull-out tests on reinforced geopolymer concrete yielded in a conclusion that a higher bond strength for geopolymer concrete exist when compared to OPC concrete.

The research conducted by Kim and Park (2015) studied the bond using the pull-out tests to investigate the behavior of embedded reinforcements in geopolymer concrete for various compressive strengths and a variation in deformed reinforcement diameter [2]. This paper will elucidate the research result on the bond strength of plain reinforcing bars embedded in geopolymer concrete, compared and OPC.

2 EXPERIMENTAL STUDIES

2.1 Materials

This research employed fly ash from PLTU Tanjung Jati Jepara as a binder. The type of fly ash depends on the amount of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), and ferrite oxide (Fe_2O_3). The chemical composition of the fly ash used in this study is as shown in Table 1. It shows that the amount of SiO_2 , Al_2O_3 , and FeO in the fly ash make up to more than 83% of the total weight. Therefore, according to ASTM C618 [8], the fly ash can be classified as type F.

Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH) is used as alkaline activator. The ratio between Na_2SiO_3 and NaOH is 2:1.

Table 1. Fly Ash Composition (%)

Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	SO ₃	K ₂ O	CaO	TiO ₂	FeO	CuO
1.59	2.86	25.96	46.52	1.13	2.77	5.89	1.36	11.81	1.12

All the aggregates used as concrete-mix in this research were conditioned as saturated surface dry (SSD) before mixing to control the water content of the mix. The composition of the mixture of Geopolymer concrete can be seen in Table 2. The nominal reinforcing bars diameter were 10 mm, 12 mm, 16 mm, and 19 mm, and three specimens were prepared for every diameter category. The steel bar specimens were tested in the laboratory to determine their effective diameter, yield strength and ultimate strength as shown in Table 3.

Table 2. Mix Proportion

Material	Mass (kg/m ³)	Material	Mass (kg/m ³)
Coarse Aggregate	1008	NaOH (8M)	84
Fine Aggregate	672	Na ₂ SiO ₃	168
Fly Ash (Type F)	468		

Table 3. Properties of Reinforcement Bar

Diameter	Effective Diameter (kg/m ³)	Yield Strength (MPa)	Ultimate Strength (MPa)
10	9.6-	305.09	468.27
12	11.80	311.44	481.09
16	15.23	334.77	505.72
19	18.75	341.03	538.879

2.2 Preparation of Specimens

In this experiment, pull-out tests were conducted to determine the bond strength behavior. Each bar was embedded in a 150 x 150 x 150 mm concrete cube with a bonded length of 7D, D being the nominal diameter of the embedded steel bar. To measure the compressive strength of concrete, concrete cylinders 100 x 200 mm in size, were casted. To achieve the desired development length of 7D, the contact surface between the concrete and reinforcing bar at the top and bottom ends were separated by using PVC pipe to create a frictionless area between the steel bar and the surrounding concrete (fig. 2). The geopolymer concrete specimens were kept moist for 7 days by using wet gunny-sack covers, and were further stored in room condition until 28 days. All specimens were tested at the age of 28 days.

2.3 Test Setup

The test was conducted in the Material and Construction Laboratory, Diponegoro University in Semarang. The incremental load was subjected to the specimen by a tensile force, while the base plate was restrained against movement as shown in figure 2.

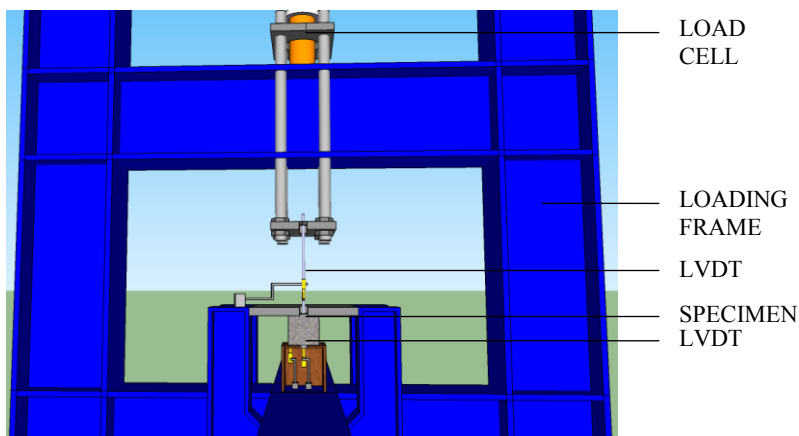


Fig. 1. Experimental Set Up

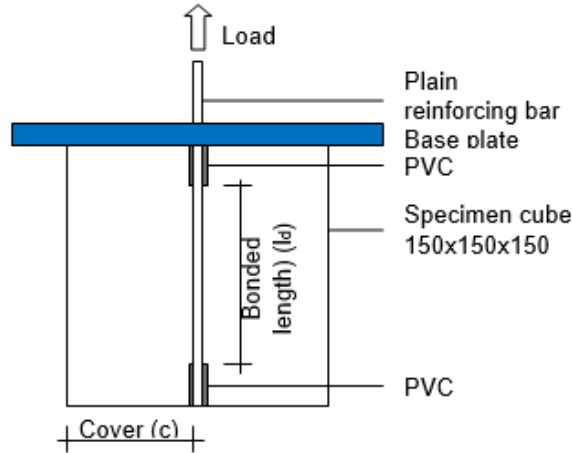


Fig. 2. Pull Out Test Scheme

3 RESULT AND DISCUSSION

The bond strength was derived from the maximum load recorded during the test, the average bond strength can then be calculated by dividing the maximum load by the area of contact surface between the reinforcement and the concrete as shown in equation 1.

$$\tau = \frac{F}{\pi d_b L_d} \quad (1)$$

Where F, d_b and L_b are force, diameter and bonded length of the bar, respectively. The test results and the calculation of average bond strength are given in **Table 4**.

Table 4. Bond Test Result

Specimen	f_c' (MPa)	Bar diameter (mm)	c/d_b	$L_d = 7 d_b$ (mm)	Bond Area (mm ²)	Avg. Max. Load (kN)	Avg. Bond Strength (MPa)
GEO-10	32.45	9.60	7.31	67.20	2026.70	18.66	9.21
GEO-12	32.45	11.80	5.86	82.60	3062.05	27.11	8.86
GEO-16	32.45	15.23	4.42	106.61	5100.91	61.63	12.12
GEO-19	32.45	18.75	3.50	131.25	7731.26	77.30	10.00
OPC-10	30.56	9.60	7.31	67.20	2026.70	9.02	4.45
OPC-12	30.56	11.80	5.86	82.60	3062.05	11.64	3.80
OPC-16	30.56	15.23	4.42	106.61	5100.91	30.78	6.03
OPC-19	30.56	18.75	3.50	131.25	7731.26	35.86	4.64

It can be clearly seen in Table 4 that even though the compressive strength of geopolymer concrete is slightly higher than the OPC concrete, but the average bond strength of geopolymer concrete is twice higher compared to the bond strength of OPC concrete.

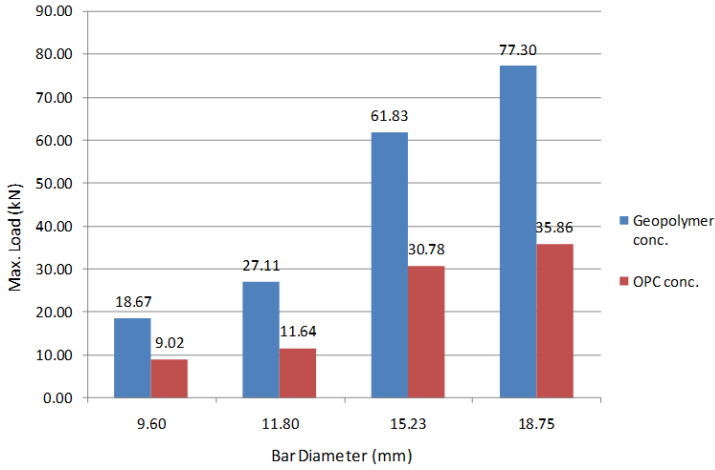


Fig. 3. Maximum load vs bar diameter of geopolymer and OPC concrete

Figure 3 shows the relationship between the maximum load and bar diameter for geopolymer concrete as well as OPC concrete. The relationship shows that the larger the bar diameter, the higher the maximum load to pull of the bars were. This phenomenon was observed for both the geopolymer concrete and OPC concrete. This behavior could be explained due to the fact that the large bar diameter has a larger contact area, when compared to the bars with a smaller diameter, the force transfer through the interface from the steel bar to concrete increases, with the increase of bar diameter. However, the relationship between the maximum load and bar diameter as can be seen in figure 3 approaches a linear pattern, although the interface area is not linear to the bar diameter, where in this research the interface area is determined to be $\pi d_b (7 d_b)$. It can be concluded that the maximum load is not only affected by bar diameter, but also influenced by other parameters. The area of interface between steel bar and concrete and passive confinement of concrete play an important role in bond mechanism.

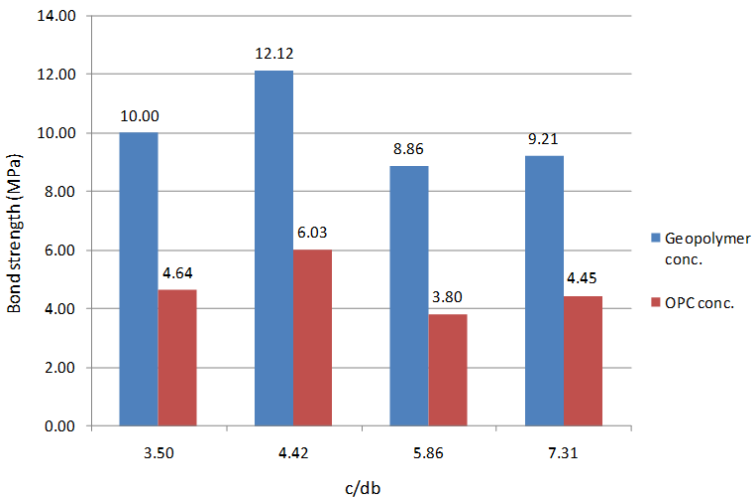


Fig. 4. Bond strength vs cover bar diameter ratio for geopolymer and OPC concrete

Figure 4 shows the relationship between the bond strength and concrete cover-to-bar-diameter ratio (c/d_b) for geopolymer concrete and OPC concrete. Where c being the length

of the concrete cover, measured from the most out bar diameter to the boundaries of the concrete specimen, and d_b being the bar diameter. The bond strength of the geopolymer specimen with a c/d_b ratio of 7.31 is slightly higher than that for the specimens with the c/d_b ratio of 5.86. Further, the specimen with the c/d_b ratio of 4.42 has higher bond strength than that of the specimens with a ratio c/d_b equal 3.50. The phenomenon is almost the same with the OPC concrete specimen. The observation to the specimens show that the failure mechanism of all specimens is characterized by shear failure, no concrete splitting or radial cracks occur for both geopolymer concrete and OPC concrete.

4. CONCLUSIONS

The bond strength between plain steel bar for both geopolymer and OPC concrete was investigated in this research. The following conclusions can be drawn from the result:

1. The bond strength of geopolymer concrete is two times higher than the bond strength for OPC concrete, even though the both compressive strengths are relatively being almost identical.
2. The bond strength increase as a function of an increases in concrete cover-to-diameter ratio (c/d_b) from 3.50 to 4.42. But the higher the ratio, the lower the strength. The bond area and thickness of concrete cover are the major contributing factors to this behavior.
3. The increase in bonded length (l_d) from 67.2 mm to 106.61 mm enhances the bond strength. However, the increases in bonded length (l_d) from 106.61 mm to 131.25 mm yields in a lower bond strength, caused by the absence of passive confining provided by the concrete.
4. Failure mechanism of all specimens are characterized by shear failure, for both the geopolymer and OPC concrete.

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