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Experimental Investigation on Bond Behavior between Geopolymer Concrete and Steel Rebar

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Abstract

This study presents the bond behavior between the geopolymer concrete and steel bar. A total of thirty-six cube samples were performed with the direct pullout test. Three variables are considered in this study including the type of steel bars (round bar and deformed bar), the embedment lengths (5, 7, and 9 times the bar diameter), and the type of concrete (normal concrete with compressive strength of 30 MPa and geopolymer concrete with compressive strength of 30 and 40 MPa). The effects of these variables on the bond strength and maximum shearing stress are discussed as well as the failure mechanism. Based on the test results, the bond strength of deformed bar specimens is higher compared to those of round bar specimens. The compressive strength of geopolymer concrete has no significant effect on bond strength. However, pull-out failures are found in all specimens.

Discipline: Civil Engineering & Technology.

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1 Introduction

Nowadays, there are a lot of construction projects currently underway, and they will probably continue to expand. Concrete is utilized as the primary construction material. Therefore, concrete production pollutes the environment by releasing a substantial amount of carbon dioxide. According to Benhelal et al. [1], the rapid expansion of the cement industry has resulted in large increases in carbon dioxide emissions. Currently, geopolymers are utilized as a replacement for cement material. These materials are mostly made of fly ash and alkaline solutions such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions. With the advancement of physical and chemical properties such as rapid hardening, perfect high strength, and excellent acid and sulfate resistance, respectively. Shi et al. [2] suggested that in comparison to Portland cement-based materials, applying a geopolymer alternative in steads of Portland cement in concrete mixes can reduce emissions by up to 80%. Consequently, there are several factors to take into account since changing from cement to geopolymer which is composed of fly ash and high concentration alkali solutions. In other words, the fact that the material composition had changed prompted a trial unless the concrete geopolymer and steel rebar could be substituted for one another such that the concrete structure can achieve the optimum capacity. Since the concrete structure is loaded, the shear stress is exerted through the concrete and reinforcing steel's contact surface. The resultant force will be transferred from reinforcing steel to the concrete by three different types of bonding which consist of chemical adhesion, friction, and mechanical adhesion [3, 11].

2 Literature Review

Tekle et al. [4] investigated the failure mechanism of geopolymer concrete (GPC) and normal concrete by reinforcing with glass-fiber reinforced polymer (GFRP) bars with a diameter of 16 mm. The embedded lengths of glass fiber-reinforced polymer in concrete and geopolymer concrete are 3, 6, and 9 times the diameter with the amount of 18 specimens. There is evidence of splitting (cracking at concrete) and pullout failure. Note that the pullout failure is found since the covering length is sufficient. In addition, the inadequate embedded length and the minimum diameter of the rebar sample will lead to this type of failure. Huang et al. [5] conducted experimental testing of GFRP with a diameter of 14 mm and a steel bar with a diameter of 16 mm embedded in concrete with 5 times the bar diameter. This experiment is performed with a total of 45 specimens, the pullout failure mechanism is found in 41 out of 45 specimens. As the embedded length is greater, the average bond strength will be reduced, which will minimize the bond stress [6]. Zhang et al. [7] examined the geopolymer concrete with basalt fiber reinforced polymer bar (FRP) with diameters of 6, 8, and 10 mm embedded in the geopolymer concrete at 5, 10, and 15 times the bar diameter. Based on the experimental results, it can be inferred that the diameter of the FRP bar and the embedded length have a major influence on the bond behavior. The bonding strength decreased as the diameter of the FRP bar increased. In general, the resulting trend also indicates that as the embedded length increases lead to a decrease in average bond strength. Moreover, Achillides and Pilakoutas [8] performed an experimental test on GFRP with a diameter of 8 or 8.5 mm. 10.5 and 13.5 mm embedded in concrete with average compressive strengths in the range of 15.5-49.5 MPa at 2 3 4 5 6 8 and 10 times the bar diameter to examine the failure mechanism. The results of this experiment indicated that the compressive strength of concrete directly affected the failure mechanism. For the cases of concrete with a compressive strength greater than 30 MPa, the bond failure occurs on the surface of the FRP bar. Thus, the FRP bond strength is unrelated to the concrete strength. On the other hand, for lower concrete strength (15 MPa) the failure mechanism shift from the FRP bar and contact surface to the concrete mass. However, this paper presents the experimental results of bond behavior between the geopolymer concrete and steel bar. A total of 36 samples of normal concrete and geopolymer concrete with reinforcing bars with diameters of 9 and

12 mm, embedded in a normal concrete with compressive strength of 30 MPa and geopolymer concrete with a compressive strength of 30 MPa and 40 MPa respectively. The embedded lengths utilized in this study are 5, 7, and 9 times the bar diameter. The failure mechanisms are also examined and discussed.

2.1 Materials, Equipment, and Research Methodology

This research presents an experimental study to determine the affected factors on bonding behavior. This experiment is conducted with an embedded steel bar with a diameter of 9 and 12 mm. in normal concrete with compressive strength of 30 MPa and a geopolymer concrete with compressive strength of 30 and 40 MPa respectively. The dimension of the concrete cube is 150x150x150 mm. The embedded length is 5, 7, and 9 times the bar diameter with a total of 36 specimens to be tested by the direct pull-out method. The material properties are listed as follows.

2.1.1 Concrete and Geopolymer Concrete

The compressive test was performed using concrete with a compressive strength of 30 MPa and geopolymer concrete with a compressive strength of 30 and 40 MPa. The mixture proportion details and the test results are shown in Table 1 and Table 2, respectively.

Table 1: Mixture proportion of concrete and geopolymers concrete

Type of material	Cement (kg)	Fly ash (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (kg)	NaOH (kg)	Na_2SiO_3 (kg)
CN	1.52	-	3.08	4.54	0.83	-	-
G30	-	1.82	2.03	4.66	-	0.55	0.55
G40	-	1.82	2.03	4.66	-	0.5	0.5

Table 2: Mechanical properties of concrete and geopolymers concrete

Type of material	Compressive strength (MPa)	Shear strength (MPa)
CN	25.53	3.61
G30	27.28	4.77
G40	45.03	4.66

Note: CN denotes Portland cement concrete with a compressive strength 30MPa, G30 denote as geopolymers concrete with compressive strength of 30 MPa and G40 denotes geopolymers concrete with compressive strength of 40 MPa.

2.1.2 Steel Bar

The properties of the steel rebar utilized in this study are described in Table 3.

Table 3: Properties of steel rebars

Type of material	Diameter (mm)	Yield stress (MPa)	Ultimate stress	E (GPa)
Round bar (RB9)	9	2550	4300	201
Deformed bar (DB12)	12	5330	6320	235

3 Experimental Program

3.1 Test Specimen

The prepared test sample is a concrete cube with a dimension of 150×150×150 millimeters. The embedded lengths (L_b) are determined as 5, 7, and 9 times the rebar diameter (d_b), and the concrete covering is considered as 150 – ($d_b/2$). By measuring from the top of the concrete surface downward which also known as an unbonded length and the rest is considered as the bond length as shown in Figures 1 and 2. Consequently, the other related equipment installation is carried out including Data Logger and Linear Variable Differential Transformer (LVDT) to evaluate the sample subsidence. Since all the equipment is set up and prepared, the samples are then tested with the Universal Testing Machine as shown in Figure 3. This procedure in controlled by the applied load with the displacement rate of 1.3mm/mins until failure according to ACI440.3R [9].

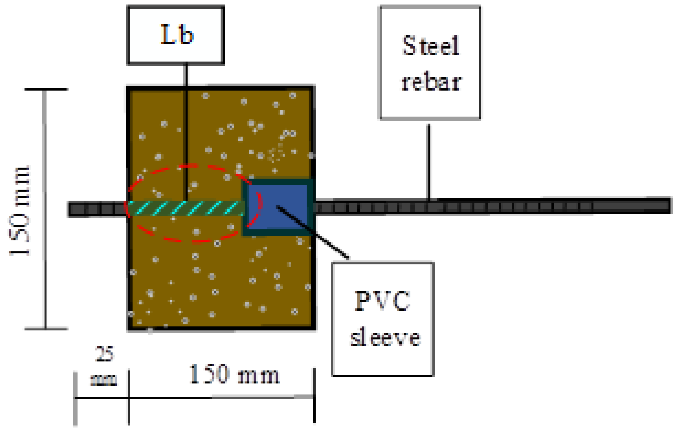

Figure 1: Details of the test sample

Figure 2: Specimens (photo)

Figure 3: Specimens setting test.

4 Result and Discussions

4.1 Bond Strength

Based on the test result, the average bond stress related to slippage can be calculated as shown in Equation (1) according to CAN/CSA-S806-02 [10] as follows:

$$\tau = \frac{P_{max}}{\pi d_b L_b} \quad (1),$$

where: P_{max} denotes the maximum tensile strength, d_b denotes the rebar diameter, L_b denotes the embedded length which can be calculated from $L_b = L_e d_b$ in which L_e denote as an embedded length of 5, 7, and 9 times of bar diameter. Table 4 summarizes the experimental results.

Table 4: Summary of the experimental results

Specimens	d_b (mm)	L_b (mm)	P_{max} (kN)	τ_{max} (MPa)	Mode of failure
CN-ST9-5Lb-1	9	45	9.58	7.53	Pull-out
CN-ST9-5Lb-2	9	45	10.29	8.09	Pull-out
CN-ST9-7Lb-1	9	63	9.01	5.06	Pull-out
CN-ST9-7Lb-2	9	63	10.63	5.97	Pull-out
CN-ST9-9Lb-1	9	81	16.76	7.32	Pull-out
CN-ST9-9Lb-2	9	81	15.27	6.67	Pull-out
CN-ST12-5Lb-1	12	60	46.04	20.35	Pull-out
CN-ST12-5Lb-2	12	60	42.04	18.59	Pull-out
CN-ST12-7Lb-1	12	84	47.03	14.85	Pull-out
CN-ST12-7Lb-2	12	84	48.53	15.32	Pull-out
CN-ST12-9Lb-1	12	108	59.31	14.57	Pull-out
CN-ST12-9Lb-2	12	108	58.12	14.27	Pull-out
G30-ST9-5Lb-1	9	45	18.55	14.58	Pull-out
G30-ST9-5Lb-2	9	45	22.21	17.46	Pull-out
G30-ST9-7Lb-1	9	63	23.75	13.33	Pull-out
G30-ST9-7Lb-2	9	63	26.17	14.69	Pull-out
G30-ST9-9Lb-1	9	81	26.21	11.45	Pull-out
G30-ST9-9Lb-2	9	81	31.27	13.65	Pull-out
G30-ST12-5Lb-1	12	60	66.31	29.32	Pull-out
G30-ST12-5Lb-2	12	60	62.53	27.65	Pull-out
G30-ST12-7Lb-1	12	84	62.76	19.82	Pull-out
G30-ST12-7Lb-2	12	84	66.01	20.84	Pull-out
G30-ST12-9Lb-1	12	108	66.84	16.42	Pull-out
G30-ST12-9Lb-2	12	108	68.50	16.82	Pull-out
G40-ST9-5Lb-1	9	45	21.79	17.12	Pull-out
G40-ST9-5Lb-2	9	45	26.40	20.75	Pull-out
G40-ST9-7Lb-1	9	63	28.22	15.84	Pull-out
G40-ST9-7Lb-2	9	63	29.59	16.61	Pull-out
G40-ST9-9Lb-1	9	81	31.25	13.64	Pull-out
G40-ST9-9Lb-2	9	81	30.50	13.32	Pull-out
G40-ST12-5Lb-1	12	60	60.67	26.82	Pull-out
G40-ST12-5Lb-2	12	60	65.65	29.02	Pull-out
G40-ST12-7Lb-1	12	84	66.66	21.05	Pull-out
G40-ST12-7Lb-2	12	84	65.14	20.57	Pull-out
G40-ST12-9Lb-1	12	108	65.26	16.03	Pull-out
G40-ST12-9Lb-2	12	108	67.53	16.58	Pull-out

4.2 *Mode of Failure*

Pull-out failures of all samples are found in this study. The failure mechanisms are shown in Figures 4 and 5.

Figure .4 Specimen failure mechanism

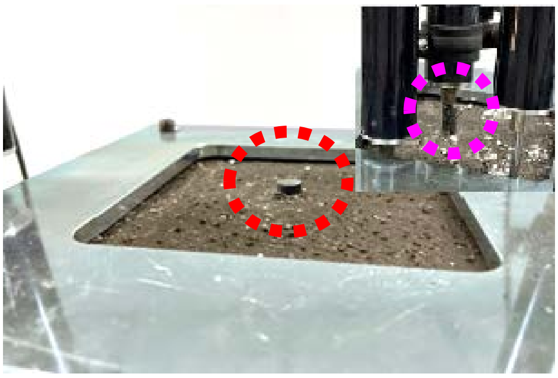

Figure 5: Pull-out failure.

4.3 Effect of Bar Diameter

Based on the test results, it was found that the diameter and the quality class of the rebar have a significant impact on the bond behavior. Since the test sample diameter is small (RB9), the tensile strength is also small nevertheless, as the diameter increased (DB12), the tensile strength increased, as illustrated in Figures 6 to 8. This happens due to the cross-section area of the rebar and the quality class of the reinforcing bars, as well as the surface of the reinforcing bars, in which RB9 is smooth round steel while DB12 is deformed steel.

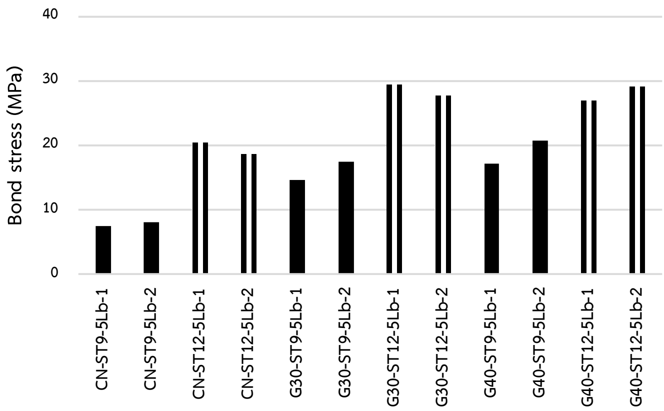

Figure 6: Bond stress of RB9 vs. DB12 specimens (embedded length of 5 times the diameter)

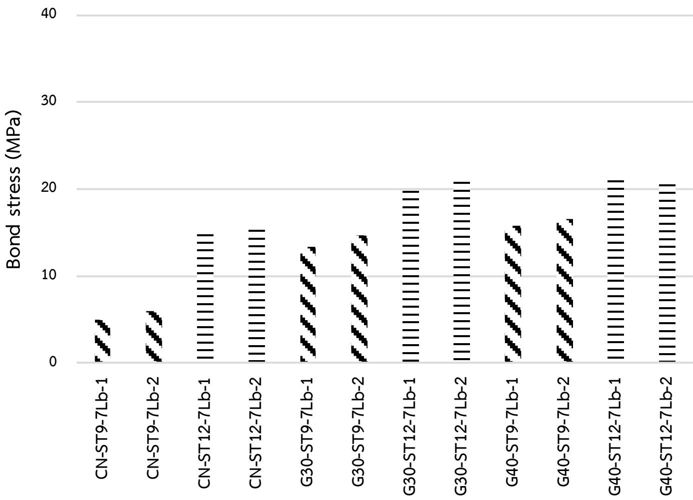

Figure 7: Bond stress of RB9 vs. DB12 specimens (embedded length of 7 times the diameter)

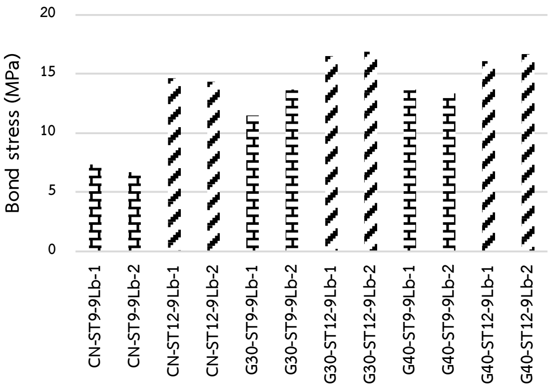

Figure 8: Bond stress of RB9 vs. DB12 specimens (embedded length of 9 times the diameter).

In comparison, the tensile strength of the sample G40-ST9-5Lb-1 with a diameter of 9 mm is equal to 21.79 kN while the tensile strength of the sample G40-ST12-5Lb-1 with a diameter of 12 mm is equal to 60.67. Both samples have the same embedded and concrete covering length. It can be seen tensile strength increased by 178% due to the diameter and quality class of the rebar. On the other hand, the bonding stress of the G40-ST9-5Lb-1 sample is equal to 17.2 MPa which is less than the G40-ST12-5Lb-1 sample with a value of 26.82 MPa. In this case, this condition happens due to the tensile strength development of the sample until it reaches the ultimate tensile strength.

4.4 *Effect of Embedment Length*

The embedment length has a significant impact on concrete strength as well as the failure mechanism. An increase in embedment length leads to a decrease in shearing bond stress. The low value of embedment length will cause sample strength development and pull-out failure. As the embedment length increase, the splitting failure occurs which restrain the strength development to reach the ultimate stage as shown in Figures 9-10.

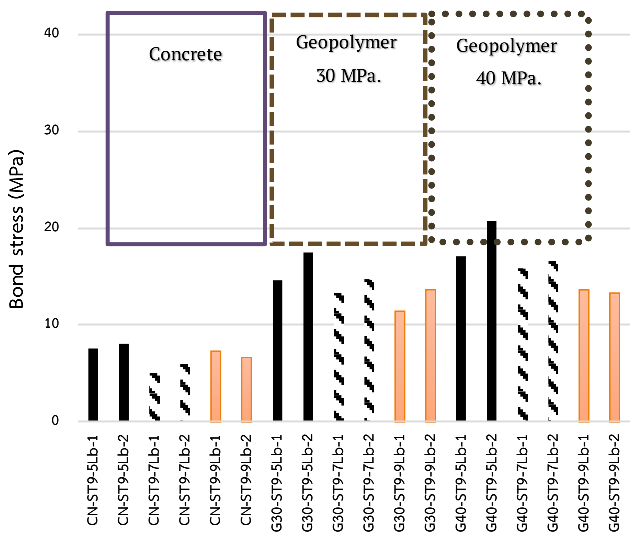

Figure 9 Bond stress of RB9 at embedded length of 5 7 and 9 times the diameter.

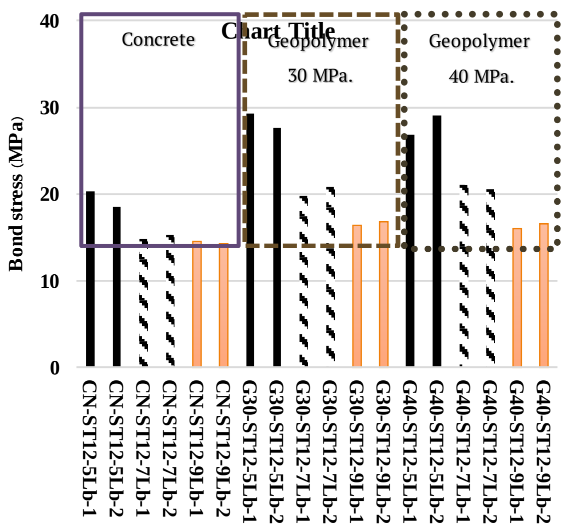

Figure 10 Bond stress of DB12 at embedded length of 5 7 and 9 times the diameter.

In comparison, the tensile strength of the sample G40-ST12-5Lb-1 at an embedded length of 5 times diameter is equal to 60.67 kN while the tensile strength of the sample G40-ST12-9Lb-1 with an embedded length of 9 times diameter is equal to 65.29. Both samples have the same diameter and concrete covering length. The tensile strength increases by 7.56% as the embedded length vary from 5 times the diameter to 9 times the diameter. On the other hand, the bonding stress of the G40-ST12-5Lb-1 sample at the embedded length of 5 times the diameter is greater than the bonding stress of the G40-ST12-9Lb-1 sample at the embedded length of 9 times the diameter with the value of 26.82 MPa and 16.03 MPa, respectively. Figure 11 shows the relationship between the bonding stress and the embedment length of the geopolymer with compressive strength of 40 MPa and a deformed bar with a diameter of 12 mm. It can be observed that an increase in embedment length leads to a reduces in bond stress.

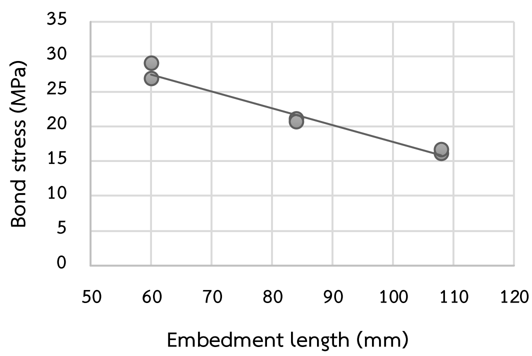

Figure 11: Influence of embedment length on bond stress (DB12 in G40 specimens)

4.5 *Effect of Concrete Strength*

The bond strength is directly influenced by the compressive strength and type of concrete. Therefore, the greater the concrete compressive strength, the greater the bond strength.

The comparison is made up of three different types of samples including CN-ST12-5Lb-1, G30-ST12-5Lb-1 and G40-ST12-5Lb-1 with a fixed embedment length of 5 times the diameter. It can be observed that the normal cement concrete with the compressive strength of 30 MPa seems to have less bond stress compared to that geopolymer concrete with compressive strengths of 30 MPa and 40 MPa with bond stress values of 20.35, 29.32 and 26.82 respectively. The bond stress rises by 44.07% and 31.79% as the material shift from normal concrete to geopolymer30 and 40 respectively, as shown in Figure 12.

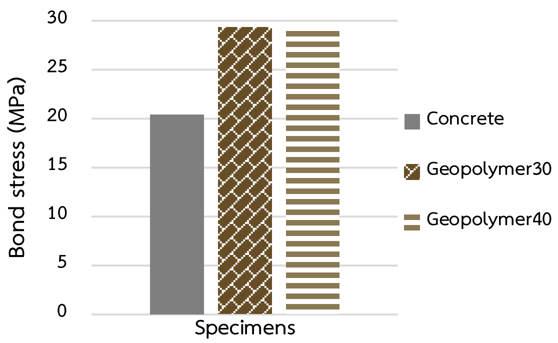

Figure 12 Comparison of bond stress for each type of concrete

5 Conclusion

An experimental investigation on the bond behavior between geopolymer concrete and steel rebar has been carried out. Test variables includes the type of steel bars (round bar and deformed bar), the embedment lengths (5, 7 and 9 times the bar diameter), and the type of concrete (normal concrete with compressive strength of 30 MPa and geopolymer concrete with compressive strength of 30 and 40 MPa). Based on the test results, the following conclusions could be drawn:

The diameter and the quality class of the reinforcing steel is directly affect the bonding behavior. The tensile strength directly depends on the diameter, the bond stress increases as diameter increased which leads to a lager contact surface.

An increase in embedding length decreases bond stress. Moreover, the embedment length also effects the failure mechanism, pull-out failure are observed for all samples due to the adequate concrete covering length.

This experimental study only examines the factors that affect the bond behavior between concrete and rebar steel by considering the effect of the rebar's diameter and quality, embedded length, and concrete compressive strength. Many other variables can affect the bond behavior such as concrete covering, type of concrete, surfaces of rebar, etc, which can be further investigated in the future.

6 Acknowledgement

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