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The Effect of Bar Diameter on Bond Stress of Geopolymer Concrete with Pull-out Test

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Abstract

Geopolymer concrete, an eco-friendly alternative, employs silica, alumina, and alkaline activators. While wet mixing has been extensively studied, its limitations, such as impracticality, quick setting, and low workability, are overcome by the dry mixing method. Study by previous research is limited only to compressive strength, flexural strength, and shrinkage. However, research on bond strength, crucial for concrete-reinforcement adhesion, is limited. This study investigates bond strength through pull-out tests using consistent concrete materials, including Type C fly ash, 12M NaOH, and an alkali ratio of 1:1. Specimens with varying reinforcement diameters (D10, D12, D16) and additional transverse reinforcement (ϕ6-150) were tested. Bond stress averages at D10, D12, and D16 are 25.80 MPa, 25.36 MPa, and 24.25 MPa. Reinforcement diameter directly influences bond strength, with larger diameters yielding greater bond stress.

Keywords

Pull-out, geopolymer, dry mixing, fly ash type C

INTRODUCTION

Geopolymer concrete is an alternate substance that uses silica and alumina (fly ash) as a source of material and an alkaline activator [1]. This geopolymer concrete is created by a chemical reaction called hydration [2]Additionally, the use of fly ash-based geopolymer concrete has several benefits, including resistance to fire [3], [4], high compressive strength, minimal shrinkage, and good durability [5]–[7], which makes geopolymer resistant to sulfate and chloride environments [8]–[13].

Previous research used fly ash Type F with low calcium fly ash to create geopolymer concrete [14]–[17]. This geopolymer cement employs the wet mixing technique by combining pozzolanic ingredients and an alkaline activator [11]. High calcium fly ash in geopolymer concrete has decreased compressive strength because of the quick setting time and poor workability [18]. Alkaline activator solids with pozzolanic components have a longer setting time than the wet technique, which makes up for this drawback [12]. Studies on Type C fly ash-based geopolymer concrete characteristics [19]–[22] show that fly ash-based geopolymer concrete has beneficial properties and potential when used as a construction material. To further investigate geopolymer concrete as a construction material, it is necessary to understand the bond between geopolymer concrete and steel reinforcement. The bond between steel reinforcement and geopolymer concrete is important in determining the length development of the bar into the geopolymer concrete.

The bonding behavior of steel and concrete significantly impacts the mechanical properties of reinforced concrete elements, including cracking, deflection, load capacity, and hysterical behavior under seismic excitation [23] Structures made of reinforced concrete are significantly stiffer and more deformable due to local bond-slip behavior. The strength of the concrete, the thickness of the concrete around the reinforcement, the confinement of the concrete by the transverse reinforcement, and the geometry of the bars are some of the variables that determine bond strength. According to the pull-out test, geopolymer concrete has higher bond stress than ordinary concrete material [24]–[26] The pull-out test is one of the most straightforward techniques for determining the concrete bond strength. Previous studies have demonstrated that geopolymer concrete has a higher tensile strength than ordinary concrete. Geopolymer concrete has a better adhesive strength than Portland cement-based concrete because the consequent tensile strength contributes to the bond strength [27].

Previous researchers have investigated the performance of dry system geopolymers, such as compressive strength, flexural strength, and shrinkage, but there was limited research on bond strength. Understanding the relationship between concrete and reinforcement depends heavily on bond strength. This research will discuss the bond stress of geopolymer concrete using the dry method.

RESEARCH SIGNIFICANCE

This study investigates the bond-stress behavior of the steel reinforcement embedded inside the geopolymer concrete. An extensive pull-out experimental test setup was carried out considering the variation in the diameter of the rebar, pitch spacing of the confining bar, and varying the depth of rebar development into the geopolymer concrete.

METHODOLOGY

A. MATERIAL AND MIX PROPORTIONS

The use of materials in the study, such as cement substitutes, fine and coarse aggregates, and admixtures, will be discussed in this section. The fly ash used in this study belongs to high calcium fly ash or Type C fly ash, with the result of Silicon Dioxide (SiO_2) + Aluminum Oxide ($Al2O_3$) + Iron Oxide (Fe_2O_3) is 66.8%. The chemical content requirement of Type C fly ash is at least 50% by ASTM C618. The specific gravity of fly ash is 2.453 g/cm^3. The coarse aggregate is crushed stone with a maximum particle size of 20 mm. The fine aggregate in this study has an SSD specific gravity of 2.74 g/cm^3. The reinforcement used in this study is diameter 10, 12, and 16mm with 6mm diameter transversal reinforcement, reinforcement details as in Table 1.

Table 1 Detail of bar diameter geometry and material properties

Diameter	Rib Height	Modulus of Elasticity	Yield Strength
mm	mm	MPa	MPa
6	6	194,000	386
10	1	194,000	476
12	1.26	194,000	477

The mix-design was carried out using the wet method [28]. After that, the mix design was converted using the dry method [29]. To study the effect of concrete strength on bonding-slip performance, a designed compressive strength of 28 days: 35 MPa. The concrete mix proportions are given in Table 2.

Table 2 Mix-design composition for geopolymer concrete

Materials		
Fly Ash	636.83	kg/m^3
Fine Aggregate	437.73	kg/m^3
Coarse Aggregate	1020.2	kg/m^3
NaOH	48.72	kg/m^3
Na2SiO3.5H2O	62.97	kg/m^3
Water Content	158.96	kg/m3

The dry mix method thoroughly mixes the cement geopolymer, fine aggregate, and coarse aggregate into the mixing drum of the mixing machine. Then, water and superplasticizer were poured into the mixing drum and mixed until the concrete slurry was homogeneous.

A. EXPERIMENTAL METHODS

Pull-out testing was performed using specimen dimensions of 150 × 150 × 200 mm, as shown in Figure 1. The single bar was vertically anchored along the center axis for the cube specimen. The embedded length in the pull-out specimen was 140 mm. The unbonded part of the bar is 60 mm and is lined with PVC pipe. The addition of a strain gauge to measure the strain in the reinforcement.

Figure 2 shows the test setup, and LVDTs were used to measure the relative bond slip between steel and concrete. The pull-out force was measured by a dynamometer installed in the testing machine. The test progress was monitored on a computer screen. In addition, all load and displacement data were captured and stored on a USB stick through a data logger. The displacement-controlled loading was supposed to capture the behavior of the bond in the post-peak regime (softening phase). The crosshead displacement rate was set to 0.25 mm/min, and the test was stopped when bond stress was lower than 10% of its maximum value.

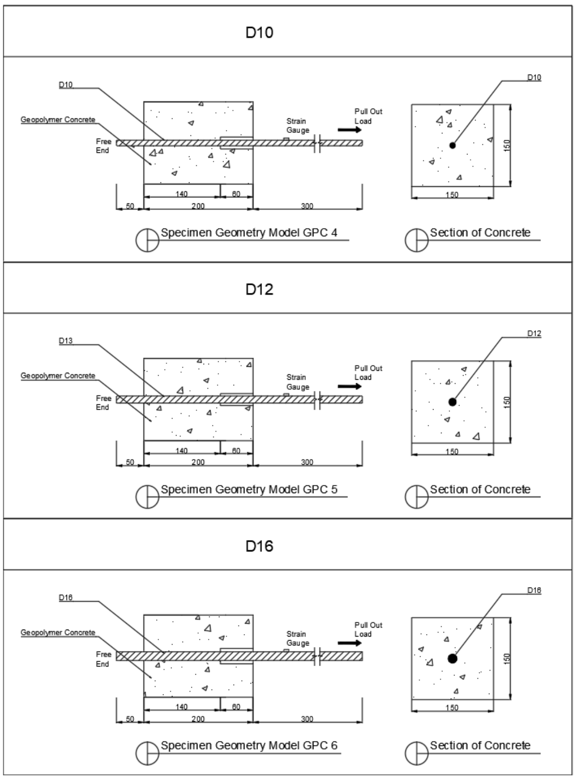

Figure 1 Typical pull-out test specimen

Figure 2 Set Up Pull–Out Test

The bond stress could be calculated by dividing the applied load by the contact area between the steel bar and the concrete, as shown in the following.

$$\tau = \frac{P}{l_d \cdot \pi \cdot d_b}$$

Where τ is the bond stress (MPa), P is the applied load (N), d_b represents the bar diameter (mm), and l_d is the embedded length (mm).

RESULTS AND DISCUSSIONS

A. FRESH AND MECHANICAL PROPERTIES OF CONCRETE

The slump test is conducted to determine the workability of concrete. The slump in value indicates the viscosity of fresh concrete. The amount of slump value can determine the level of dilution of the mixture in the process of working in the field. Table 3 shows the results of the geopolymer concrete slump test, 12 Molar NaOH with an alkali activator ratio of 1:1 and 2% superplasticizer. Uniaxial testing produces compressive strength, modulus of elasticity, and Poisson's ratio, carried out on day 28, with a target compressive strength of 35 MPa, as shown in Table 3.

Table 3 Slump test results

No	Mix	Slump (mm)
1	Mixing 1	220
2	Mixing 2	190
3	Mixing 3	185

The slump test results in Table 3 show that the casting with the dry mix design method ranged from 185 mm to 220 mm. According to ASTM C143, concretes with less than 150 mm slumps may need to be adequately plastic. Concretes with slumps greater than 230 may not be cohesive.

Table 6 Mechanical Properties of Concrete

Compressive Strength (MPa)	Modulus of Elasticity (GPa)	Poisson's Ratio	Tensile Strength (MPa)
41.42	232.3	0.166	3.40

B. BOND STRESS

Based on the test results for reinforcement in concrete size 150 × 150 × 200 mm, bars with diameters of 10 mm, 12 mm, and 16 mm failed first before the slip occurred (Table 5). The concrete in this study was cut into 150 × 150 × 150 mm to reduce the embedded length. However, no slips occurred, and the bar failed first (Table 6). The last experiment with the bonded area size made 2 d_b, as shown in Figure 4, produces bond-slip values (Table 7).

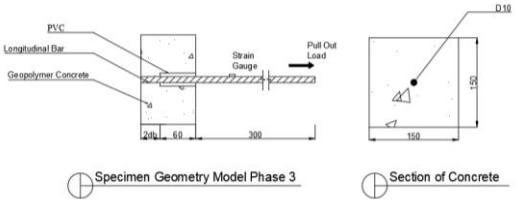

Figure 3 Specimen Geometry with Bonded Area $2d_b$

Table 4 Pull-out test result on a concrete block of 150 × 150 × 200 mm

No	Code	Dimension	c	Rebar		l_d	P_{Max}	τ	Failure Mode
				Long	Trans				
		mm	mm	mm	mm	mm	N	(MPa)	
1	D16.1	150×150×200	67	16	-	140	103,841	-	Bar Rupture
2	D12.1	150×150×200	68.5	12	-	140	71,060	-	Bar Rupture
3	D16.S1	150×150×200	67	16	Ø6-50	140	109,148	-	Bar Rupture
4	D12.S1	150×150×200	68.5	12	Ø6-50	140	74,755	-	Bar Rupture
5	D10.S1	150×150×200	70	10	Ø6-50	140	43,720	-	Bar Rupture

Table 5 Pull-out test result on a concrete block of 150 x 150 x 150 mm

No	Code	Dimension	c	Rebar		l_d	P_{Max}	τ	Failure Mode
				Long	Trans				
		mm	mm	mm	mm	mm	N	(MPa)	
1	D10.1	150×150×150	70	10	-	90	43,720	-	Bar Rupture
2	D12.2	150×150×150	68.5	12	-	90	71,060	-	Bar Rupture
3	D16.2	150×150×150	67	16	-	90	103,841	-	Bar Rupture
4	D10.S2	150×150×150	70	10	Ø6-50	90	45,937	-	Bar Rupture
5	D12.S2	150×150×150	68.5	12	Ø6-50	90	74,755	-	Bar Rupture
6	D16.S2	150×150×150	67	16	Ø6-50	90	109,148	-	Bar Rupture

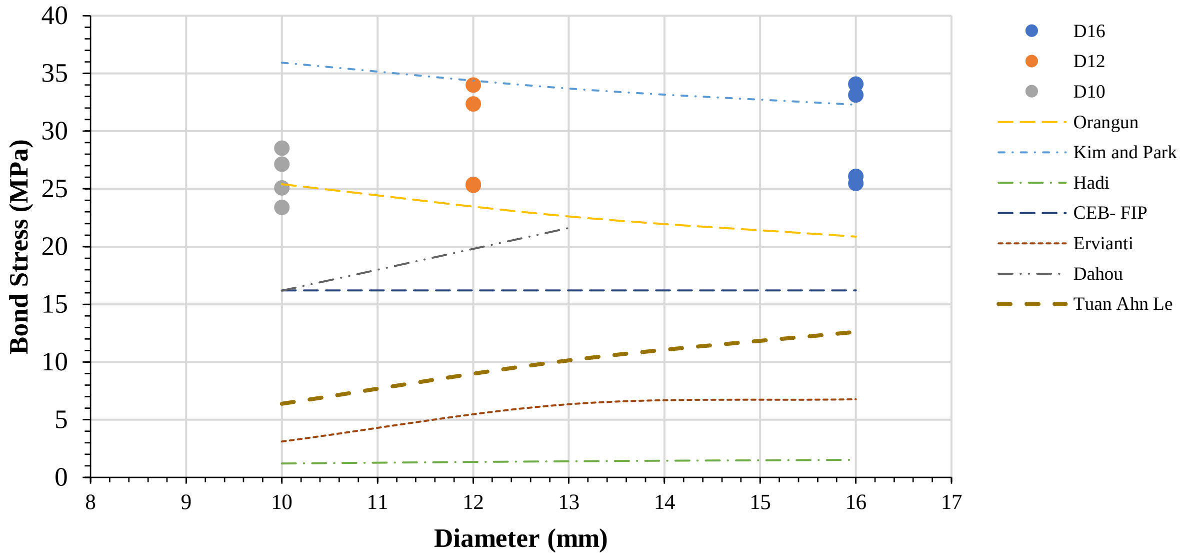

Figure 3 Comparison of Bar Diameter

EFFECT OF REBAR SIZE ON BOND STRESS

The relationship shows that the larger the diameter of the reinforcement, the higher the force required to pull by the reinforcement. In addition, it is also influenced by the contact area between steel concrete. Larger reinforcement diameters have a large contact area when compared to reinforcement with smaller diameters.

Several factors contribute to the bond strength of reinforcing steel and fly ash-based geopolymer concrete that significantly affect the ultimate strength of the bond. Chemical adhesion, friction, and mechanical interlocks are the most important factors contributing to the bond strength developed from the interaction. The force on the reinforcement is transmitted to the surrounding concrete through chemical adhesion and friction due to roughness during the interlocking of the reinforcement bars.

The research results of this thesis are to the trend of previous studies by [30]–[34]. In addition, the bond stress values obtained in this study were also compared with CEB-FIP predictions. The difference in results was 27-35%. CEB-FIP researched bond stress influenced by reinforcement diameter, concrete cover, and embedment length

Table 7 shows roundabout data for redesign condition BPKP's Intersection at Banda Aceh. Standard roundabout performance measurements, including turning movements, approach capacity, average queue length, and delay, may be calculated using data collected [23]. Table 8 shows performance measures by using the software SIDRA Intersection 8.0 at PNM's in redesign condition. The total demand flow at this leg is 310 pcu/h. Approach delay is 3.8 sec and the level on service is A. Lane 3 is the dominant lane at the roundabout approach.

CONCLUSIONS

This dry method of geopolymer concrete research includes experimental and numerical, reviewing bond strength with pull-out testing. The pull-out test was carried out using three different concrete blocks. The first concrete block has a size of 150 × 150 × 200 mm, the second 150 × 150 × 150 mm, and the third stage 150 × 150 × (60+2d_b) mm. The first and second block size results were all failures in bar rupture. However, the results for the third block size were shown to be fail in slip. The diameter of the reinforcement affects the bond strength of the concrete. The larger the diameter of the reinforcement, the greater the bond stress value. This is because large-diameter reinforcement has a larger contact area when compared to reinforcement with a smaller diameter, and therefore transfer of force through the interface from steel reinforcement to concrete increases.

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