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SHEAR BEHAVIOR OF FLY ASH-BASED GEOPOLYMER R/C BEAM WITH BAUXITES AS COARSE AGGREGATES: EXPERIMENTAL PROGRAM

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ABSTRACT: Some regions in Indonesia have bauxite materials but difficult to find gravel stone for coarse aggregates. Strength behavior of fly ash-based reinforced concrete beam with bauxite material as coarse aggregates was very important to investigated before applying in the real project. Two beams were tested in this study. The first beam was normal reinforced concrete beams as a reference beam. The second beam was fly ash-based geopolymer reinforced concrete beam with bauxite as coarse aggregates. The beams had the section of (120 mm × 240 mm) and simple support with span of 3000 mm. Two points loading was applied to the beam to investigate the shear behavior. The beam specimens were tested under load control. A transfer beam was used to transfer the load from the actuator to the beam. The experimental result showed that the normal reinforced concrete beam and the fly ash-based geopolymer reinforced concrete beam with bauxite as coarse aggregates were fail in shear failure. The normal reinforced concrete beam was failure in brittle manner, while the fly ash-based geopolymer reinforced concrete beam was more ductile than the normal reinforced concrete beam. The maximum load-carrying capacity of normal reinforced concrete beam was 14.30 kN with maximum deflection was 23.78 mm. While the fly ash-based geopolymer concrete with bauxite as coarse aggregates reached the maximum load-carrying capacity 14.45 kN with maximum the deflection was 49.49 mm. Comparing the shear strength based on the theory and experimental result showed that the experimental result was lower than the theory.

Keywords: Fly ash-based geopolymer concrete, Bauxite coarse aggregates, Shear behavior, Load-carrying capacity.

1. INTRODUCTION

Fly ash-based geopolymer concrete had been developed since several decades ago [1-7]. Study of geopolymer reinforced concrete beam was also investigated by several researchers. Study on flexural behavior of geopolymer reinforced concrete beam was carried by several researchers [8-12], while study on shear behavior of geopolymer concrete was conducted by several researchers [13-16].

Some region in Indonesia have bauxite material, but difficult to provide gravel stone for coarse aggregates to make concrete. Study on utility of bauxite materials for coarse aggregates in fly ash-based geopolymer concrete was conducted by Lisantono et al. [17]. The result of the study showed that compressive strength of fly ash-based geopolymer concrete was 47 MPa and did not react with activator of geopolymer concrete. It means that the bauxite material can be used as coarse aggregates for geopolymer concrete.

Lisantono et al. [18] investigated the flexural behavior of fly ash-based geopolymer reinforced concrete beam using local material (bauxite) as coarse aggregates. However, the shear behavior of fly ash-based geopolymer reinforced concrete is still needed to investigated before applying in the real project. So that, this paper presented the experimental program to study the shear behavior of fly ash-based geopolymer reinforced concrete beam with bauxite as coarse aggregates.

2. EXPERIMENTAL PROGRAM

2.1 Material

Two types of concrete were made in this study, normal concrete and fly ash-based geopolymer concrete.

2.1.1 Normal concrete

Portland cement, water, fine and coarse aggregates were using to make normal concrete. The Fine and coarse aggregates for normal concrete were taken from local material. The fine aggregates were taken from Krasak River which is located in the Northern part of Yogyakarta Province. While the coarse aggregates were taken from Clereng which is located in the Western part of Yogyakarta Province. The mix design of normal concrete can be seen in Table 1.

Table 1 The mix design of normal concrete

Material	Requirement per m^3	Unit
Cement	446	kg
Water	205	liter
Sand	830	kg
Gravel	899	kg

2.1.2 Fly ash-based geopolymer concrete

Fly ash-based geopolymer concrete in this research was made from fly ash, sodium hydroxide and sodium silicate as activators. While fine aggregates using sand, and coarse aggregates using bauxite material. The fly ash used in this research had low calcium. The chemical content of fly ash used in this study can be seen in Table 2.

Table 2 The chemical content of fly ash

Chemical content	By mass (%)
SiO_2	34.2
Al_2O_3	10.9
Fe_2O_3	18.5
SiO_2+ Al_2O_3+ Fe_2O_3	63.6
CaO	1.4
Na_2O	0.09
K_2O	0.5
MgO	1.25
SO_3	0.3

The ratio of sodium silicate solution to sodium hydroxide solution in this study was 2.5. While the concentration of the NaOH solution was taken as 8M. The proportion of fly ash versus activator was taken as 70%:30% by weight. The mix design of fly ash-based geopolymer concrete was shown in Table 3.

Table 3 The mix design of geopolymer concrete

Material	Requirement per m^3	Unit
Fly ash	477	kg
Na2SiO3	64	liter
NaOH	26	liter
Bauxite	305	kg
Sand	1526	kg

2.2 Cylinder and Beam Specimens

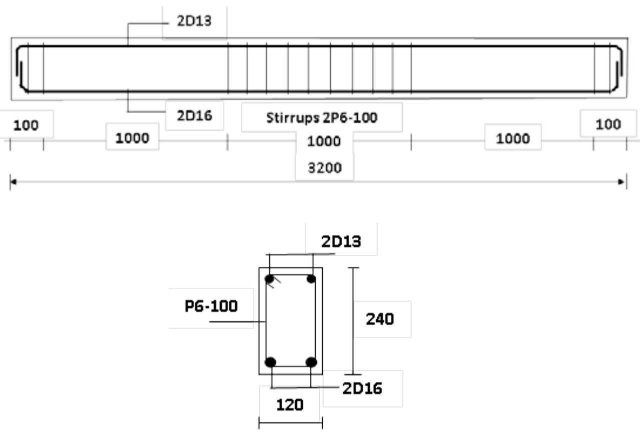
2.2.1 Cylinder specimen

Twenty-four cylinders were made and tested in this study. Twelve cylinders for normal concrete and another twelve cylinders for fly ash-based geopolymer concrete. These cylinders were made to find the mechanics properties of concrete: compressive strength; modulus of elasticity; and tensile strength. The testing was conducted on 28 days of concrete age.

2.1.2 Beam specimen

Two beams were made and tested in this experimental program. One beam was normal reinforced concrete beam with dimension of (120 mm × 240 mm) as reference beams, and the other beam was geopolymer reinforced concrete beam with dimension of (120 mm × 240 mm) which bauxite gravels were using for coarse aggregates of the concrete. The beam was simple beam and had the span length 3000 mm.

Two reinforcement bars with a diameter of 16 mm were placed at the bottom of the beam as tensile reinforcements and two reinforcement bars with a diameter of 13 mm were placed at the top of the beam as compressive reinforcements. While shear reinforcement with diameter of 6 mm and with spacing 100 mm were placed in the middle of the span and only at the support of the beams. There was no shear reinforcement in the shear region (see Fig. 1).



(unit in mm)

Fig. 1 Reinforcement Detail of the Beam

Designation of normal beam with the section dimension of (120 mm × 240 mm) was SNB-120/240. While designation of fly ash-based geopolymer concrete beam with the section dimension of (120 mm × 240 mm) was SGB-120/240.

2.3 Setup Beams

The beams were tested on the loading frame of the Laboratory of Structures and Materials. The beams were simply supported and loaded symmetrically under two-point-loadings. The load was applied through actuator with loading capacity of 250kN. The beam specimens were tested under load control. A transfer beam was used to transfer the load from the actuator to the beam specimen as depicted in Fig. 2.

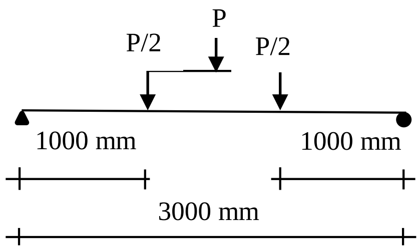
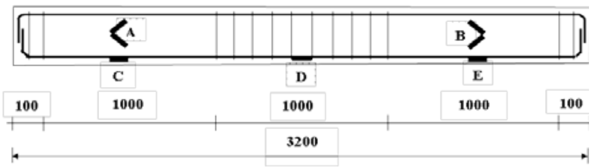


Fig. 2 Two-point Loading Test

A Linear Variable Differential Transformers (LVDT) was placed at the middle span of the beam to measure deflection. Electrical resistance strain gauges were also used to measure strain of tensile reinforcement which was placed at middle span and a quarter of the span, while strain gauges of the concrete were placed at shear zone or at a quarter of the span (see Fig. 3).



Note:
A, B : strain gauge of surface concrete
C, D, E : strain gauge of tensile reinforcement bar
Fig. 3 Location of strain gauges

Measuring data of load, deflection and strain of reinforcement and surface concrete were read through a computer driven data acquisition system using data logger. The setup testing of the beam was shown in Fig. 4.

Fig. 4 Setup Testing of the Beam

3 RESULT AND DISCUSSION

3.1 Materials Testing

The results testing of normal concrete and fly ash-based geopolymer concrete was shown in Table 4. The compressive strength, tensile strength, and modulus elasticity of normal concrete were 23.60 MPa, 2.38 MPa, and 18,109.99 MPa, respectively. While the compressive strength, tensile strength, and modulus elasticity of fly ash-based geopolymer concrete were 27.87 MPa, 3.84 MPa, and 11,604.20 MPa, respectively.

Table 4 Mechanical Properties of Concrete

	f_c' (MPa)	f_t (MPa)	E (MPa)
NC	23.60	2.38	18,109.99
GC	27.87	3.84	11,604.20

Note: f_c'= compressive strength; f_t= tensile strength; E= modulus of elasticity; NC= normal concrete cylinder; GC= fly ash-based geopolymer concrete cylinder

It can be seen from Table 4 that the compressive strength and tensile strength of fly ash-based geopolymer concrete was higher than normal concrete, except the modulus elasticity of fly ash-based geopolymer concrete was lower than normal concrete.

Three diameters of reinforcement were used for the beam specimen. Diameter 6 mm for stirrup; diameter 13 mm for compressive reinforcement; and diameter 16 mm for tensile reinforcement. The results testing of reinforcement bars gave that the yield stress of reinforcements bar of 6 mm; 13 mm; and 16 mm were 366.78 MPa; 547.15 MPa; and 506.50 MPa, respectively.

3.2 Load-Carrying Capacity

Comparison load-displacement relationship of the normal concrete beam and fly ash-based geopolymer concrete beam can be seen in Fig. 5.

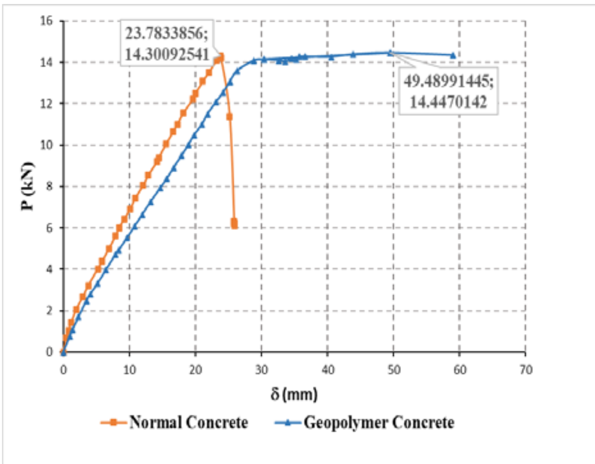


Fig.5 Load-Displacement Relationship

It can be seen from Fig. 5 that the load-displacement relationship curve of normal beam was approximately straight line from the beginning up to reach the maximum load. After reaching the maximum load, the curve was decreasing which indicated that the beam was failure and brittle.

The load displacement relationship curve of fly ash-based geopolymer concrete from the beginning up to reach the maximum load was also straight line, however after reaching the maximum load the curve still continuing to give large displacement without increasing the load until the beam was failure.

Comparing the load-displacement relationship between the normal beam and the fly ash-based geopolymer concrete showed that the normal beam was stiffer than fly ash-based geopolymer concrete beam. This was appropriated with the modulus elasticity that the modulus elasticity of normal concrete was higher than modulus of elasticity of fly ash-based geopolymer concrete. The load-displacement curves also indicated that the fly ash-based geopolymer concrete was more ductile than normal concrete beam, because the fly ash-based geopolymer concrete beam gave large displacement after reaching the maximum load. It can be seen also when the normal concrete beam reached the maximum load 14.30 kN, the deflection was 23.78 mm, while the fly ash-based geopolymer concrete reached the maximum load 14.45 kN gave the deflection 49.49 mm.

3.3 Crack Pattern

The first crack of normal concrete beam was 8.00 kN, while the first crack of fly ash-based geopolymer concrete beam was 11.76 kN. The first crack of fly ash-based geopolymer concrete beam was higher than the first crack of normal concrete beam. This result of the first crack was in accordance with the tensile strength of the fly ash-based geopolymer concrete was higher than tensile strength of normal concrete. The crack pattern of normal concrete beam and fly ash-based geopolymer concrete beam showed that both beams were failure in shear failure (see Fig. 6 and Fig. 7).

Fig.6 Crack Pattern of Normal Concrete Beam

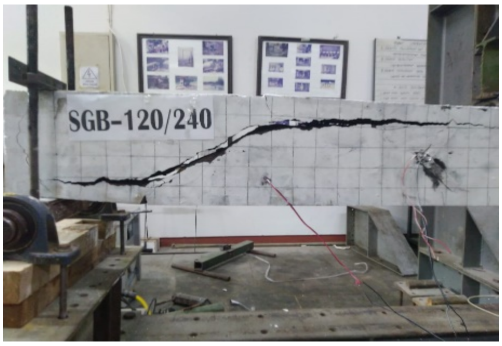


Fig.7 Crack Pattern of Fly Ash-Based Geopolymer Concrete Beam.

3.4 Strain of Concrete and Reinforcement

The surface of concrete strain in shear zone was measured using strain gauge. The relationship curve of load versus strain of surface concrete strain was shown in Fig. 8.

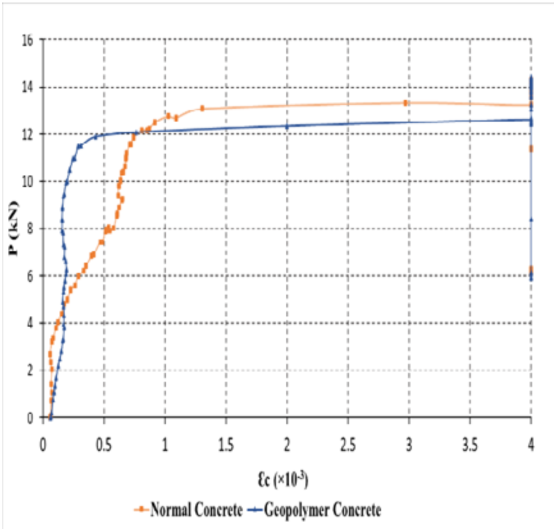


Fig. 8 Load-Strain of Surface Concrete Relationship

It can be seen from Fig. 8 that the strain of surface concrete at the same strain of (0.5×10^{-3}), the load-carrying capacity of normal concrete beam was lower than the load-carrying capacity of fly ash-based geopolymer concrete. In other word it can be said that in the same load, the deformation of normal concrete beam at shear zone would larger than fly ash-based geopolymer concrete. This indicated that the shear crack of normal concrete beam at shear zone will occur faster and brittle. While the fly ash-based geopolymer concrete will have ductile behavior.

The load-strain relationship reinforcement strain was shown in Fig. 9.

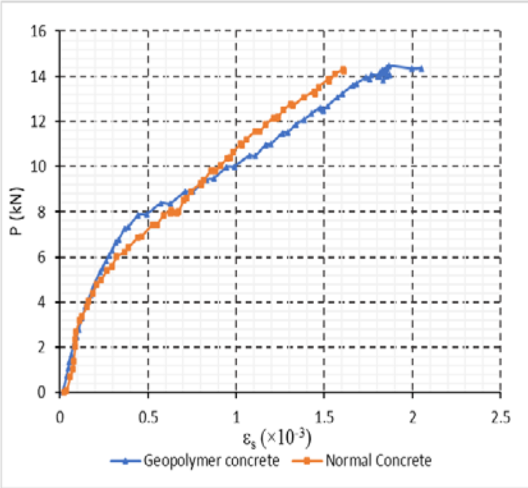


Fig. 9 Load-Strain of Tensile Reinforcement Bar Relationship

It can be seen from Fig. 9 that the normal concrete beam reached the maximum shear load before the strain of tensile reinforcement bar reached the yield stress. After reached the yield stress, the beam was suddenly failure. While the fly ash-based geopolymer concrete reached the maximum shear load capacity and still gave deformation until the tensile reinforcement reached the yield stress. This phenomenon was appropriate with the curve in Fig. 5 which showed that the fly ash-based geopolymer concrete beam was more ductile than normal concrete beam.

3.5 Theoretical Analysis

According to Indonesian Concrete Code [19] that the shear strength of concrete beam can be calculated using the following equation:

$$V_c = 0.17\lambda\sqrt{f'_c}b_w d \quad (1)$$

Where,

V_c = nominal shear strength provided by concrete

λ = modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normal weight concrete of the same compressive strength
= 1.0 for normal concrete

$f_c{}'$ = specified compressive strength of concrete

b_w = web width

d = distance from extreme compression fiber to centroid of longitudinal tension reinforcement

Based on Eq. (1), the theoretical nominal shear strength provided by normal concrete was 20.91 kN, while the theoretical nominal shear strength provided by fly ash-based geopolymer concrete was 22.72 kN. However, based on experimental program, the normal concrete beam gave the value of shear strength capacity 14.30 kN and the fly ash-based geopolymer concrete beam gave the value of shear strength capacity 14.45 kN.

Comparing the shear strength based on theory and experimental result, it can be seen that the shear strength of experimental result was lower than the theory. So, it seems that the nominal shear strength in the theory especially for fly ash based-geopolymer concrete needs to modify the modification factor λ to adjust with the experimental result. Unfortunately, in this study the specimen of the fly ash-based geopolymer concrete was only one. So, it cannot be made as a basic to propose the modification factor for nominal shear strength of fly ash-based geopolymer concrete due to limited specimen.

4 CONCLUSION

Based on the experimental program and discussion above, the following cocnclusions can be drawn:

1. The load-displacement curves gave that the fly ash-based geopolymer concrete beam was more ductile than the normal concrete beam
2. The shear strength based on the experimental program was lower than the theory.
3. The modification factor λ needs to adjust with the experimental result, so that the theory of shear strength might be closer to experimental program.

5 ACKNOWLEDGMENTS

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