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High volume fly ash as substitution of fine aggregates with the proportion of 50%, 60%, and 70% to the shear strength of reinforced concrete beams

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Abstract. Indonesia has plenty of fly ash as waste material of coal-burning thermal power stations. Fly ash was usually used as a supplementary cementitious material in concrete. One of the basic materials of concrete is fine aggregates which are taken from natural resources. Substitution of fine aggregates by using high volume fly ash concrete (HVFAC) can save the natural deposit of fine aggregates. Fly ash with the portion of 50 %; 60 %; and 70 % as replacement of fine aggregates in concrete was carried out to study the effect on the shear strength of reinforced concrete beam through an experimental program. Eight beams were cast and tested. Two beams were cast and made of normal concrete as control beams, while six others beams were cast and made of HVFAC as replacement of fine aggregates by mass (two beams with 50 % of fly ash; two beams with 60 % of fly ash; two beams with 70 % of fly ash). There were no shear reinforcements in the shear-test regions of the beams. The experimental results show that the load-carrying capacities of HVFAC beams increased with the increase of the portion of fly ash as replacement of fine aggregates.

1 Introduction

Indonesia as a developing country has used mineral resources to produce energy. One of the minerals that can be used to produce energy is coal. According to the Directorate General of Mineral and Coal, Ministry of Energy and Mineral Resources [1], the total coal resources in Indonesia are 124,796.74 million tons and the reserves have 32,384.74 million tons. Indonesia has many thermal power stations for electricity. The power station used coal burning to produce electricity. As a side effect of the burning of coal to produce electricity, fly ash was produced as a waste material.

Fly ash as a waste material can be used as a pozzolanic material in concrete, because of this material contents cementitious material. The cementitious material, when it is used as pozzolanic material in concrete will contribute to the hardened concrete

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through hydraulic or pozzolanic reaction. According to ASTM C618 [2], the specification of fly ash is divided into two classes based on its composition, namely class F and class C. The class F must have the composition of $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$, while the class C must have the composition of $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 50\%$.

Concrete as a material for building construction, generally composes of portland-cement, water, fine aggregates and coarse aggregates. Fine aggregates usually were taken from natural resources. When the utility of concrete in building construction increases, the need for fine aggregates also increases. Therefore, the natural resources of fine aggregates will reduce. The way out to suppress the utility of fine aggregates is to reduce the utility of fine aggregates in concrete, and the fine aggregates were substituted by waste material such as fly ash. The substitution of fine aggregates by fly ash also has the benefit that the fly ash can be used as a supplementary pozzolanic material.

Studies into the substitution of fine aggregates with fly ash have been carried out by several researchers. Siddique [3] studied the substitution of fine aggregates using fly ash class F with the proportion of substitution 10 %, 20 %, 30 %, 40 %, and 50 % by weight. Siddique [4] continued the study but with the proportion of substitution being 35 %, 45 %, and 55 % by weight. The result of the study shows that the mechanical properties of concrete increases when the proportion of fly ash also increases. Koyama et al. [5] studied the mechanical properties of concrete beams made of a large amount of fine fly ash. Their study showed that the shear strength and the beam deformation increase linearly with the increasing of fly ash. While Khanti and Kavitha [6] carried out an experimental program about the substitution of fine aggregates using fly ash in concrete with the proportion of substitution being 20 %, 40 %, 60 %, 80 %, and 100 % by weight. The result shows that substitution with the proportion 50 % gave a good result.

According to the previous studies, the mechanical property of concrete increase with increasing fly ash substitution of fine aggregates. Therefore, it needs research to study the optimum proportion of the high-volume fly ash concrete (HVFAC) that will give the maximum shear strength of the beam. This study will give the basis for future research.

2 Experimental programs

2.1 Materials

The fine aggregates were taken from Progo River the Northern part of Yogyakarta Province which had properties as follows: fineness modulus = 2.924; mud content = 0.8%; bulk specific gravity = 2.604 gr/cm^3; bulk specific SSD = 2.664 gr/cm^3; apparent specific gravity = 2.770 gr/cm^3; absorption = 2.308%; and water content = 1.595%. The coarse aggregates were taken from Clereng in the Western part of Yogyakarta Province which had a maximum size of 20 mm and had properties as follows: fineness modulus = 7.168; mud content = 1.57%; bulk specific gravity = 2.470 gr/cm^3; bulk specific SSD = 2.551 gr/cm^3; apparent specific gravity = 2.687 gr/cm^3; absorption = 3.266%; and water content = 3.704%. Fly ash that was used in this study classified was as F type, because based on the chemical testing the fly ash that was used in this study had

$SiO_2+Al_2O_3+Fe_2O_3$ = 82,034 % and CaO = 7,246 %. The reinforcement that was used for beam specimens were reinforcements with a diameter of 12 mm for longitudinal reinforcement with f_y average of three samples = 314.927 MPa and a diameter of 6 mm for stirrup with f_y average of three samples = 358.287 MPa.

2.2 Specimens

2.2.1 Cylinder specimen

The mechanicals properties of concrete that were tested in this study were compressive strength and modulus of elasticity. The specimen for compressive strength and modulus of elasticity testing was a cylinder with the standard size of (150 mm × 300 mm). The compressive strength and modulus of elasticity of concrete were tested on the age of concrete at 7; 14; and 28 days.

2.2.2 Beam specimens

Beam specimens had a section of (150 mm × 260 mm) and span of 2300 mm. The beam has simple support (roll and hinge support). Three longitudinal reinforcements with a diameter of 12 mm were put at the bottom as tensile reinforcements and two longitudinal reinforcements with diameter of 12 mm were put at the top as compressive reinforcements. Stirrup with a diameter of 6 mm and spacing of 100 mm were put at the middle span and at both ends of the beam. There were no stirrups put in the shear region. The detail of the beam specimen was depicted in Figure 1.

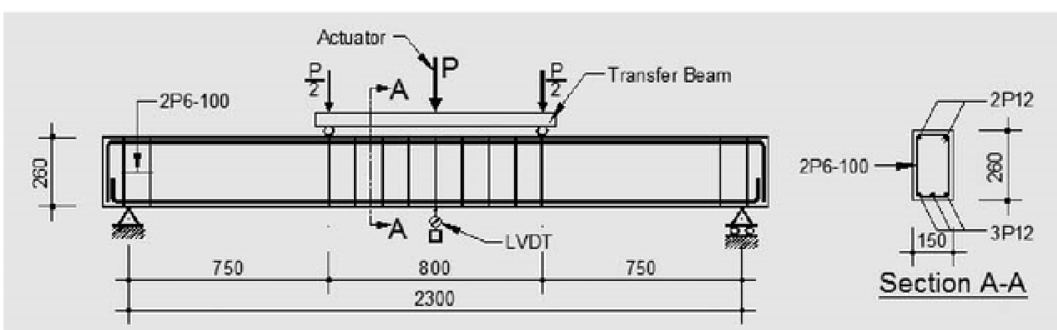

Fig. 1. The detail of beam specimen.

Designation of the eight beam specimens was written as follow:
B1-Normal : Beam was made and cast with normal concrete (specimen 1)
B2-Normal : Beam was made and cast with normal concrete (specimen 2)
B1-50FA-SP : Beam was made and cast with 50% of fly ash (specimen 1)
B2-50FA-SP : Beam was made and cast with 50% of fly ash (specimen 2)
B1-60FA-SP : Beam was made and cast with 60% of fly ash (specimen 1)
B2-60FA-SP : Beam was made and cast with 60% of fly ash (specimen 2)
B1-70FA-SP : Beam was made and cast with 70% of fly ash (specimen 1)
B2-70FA-SP: Beam was made and cast with 70% of fly ash (specimen 2)

2.2.3 Setup beam specimen

The beam specimen was tested on the loading frame. The beam specimen was tested under monotonic loading. An actuator with the capacity of 250 kN was applied through the transfer beam, so the beam specimen was subjected to two-point loadings as shown in Fig. 1. A Linear Variable Differential Transformers (LVDT) was utilized to measure the deflection of the beam specimen and was placed at the middle span to measure the deflection of the beam in the vertical direction. Measuring data of load and deflection were read using a data logger through a computerized data acquisition system. Setup of the beam specimen was depicted in Fig. 2.

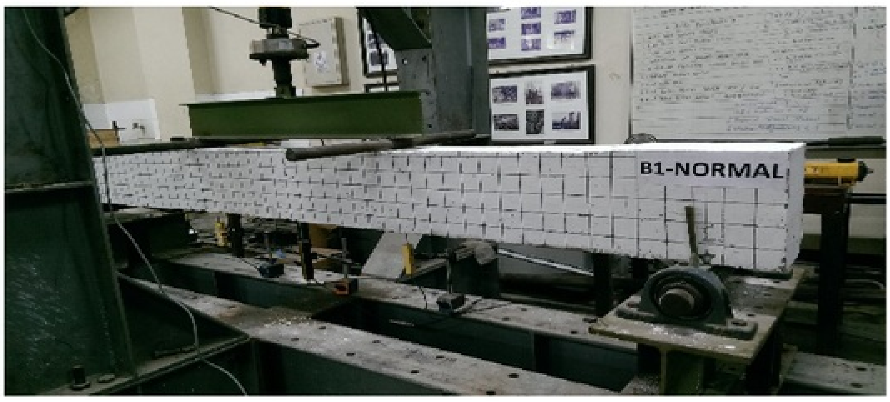

Fig. 2. Setup of beam specimen in loading frame.

3 Results and discussion

3.1 Properties of materials

The properties of concrete that were tested in this study were density, compressive strength and modulus of elasticity. The average density, compressive strength and modulus of elasticity of concrete at 28 days were shown in Table 1. It can be shown in Table 1 that the average density of the concrete with the larger proportion of fly ash has the larger density. The average compressive strength of the concrete which contains of fly ash has the higher compressive strength compared to the normal concrete and beyond the prediction. This indicates that the amount of fly ash in the concrete as a supplementary cementitious material will react with portland-cement and give better properties of the hardened concrete through the hydraulic or the pozzolanic activity of the fly ash and portland-cement as stated by [7]. The highest compressive strength was the cylinder specimen with 70 % of fly ash as substitution of fine aggregates. While the average modulus elasticity for the cylinder specimen with 70 % fly ash a little bit decreases compared to the cylinder specimen with 60 % fly ash. The different values of the modulus of elasticity might be due to the fact that the specimen of 70 % fly ash was not compacted properly when made into the cylinder specimen.

Table 1. The density, compressive strength and modulus elasticity of concrete at 28 days.

Cylinder specimen	Content of fly ash	Average density (kg/m³)	Average compressive strength f'c (MPa)	Average modulus elasticity E (MPa)
0FA	0%	2256.22	20.44	19817.17
50FA	50%	2380.50	39.98	30006.89
60FA	60%	2399.50	45.53	30295.42
70FA	70%	2443.08	56.00	27543.29

3.2 The load-deflection relationship of the beam specimen

The load-deflection relationship of the beam specimen was shown in Fig.3. Fig.3 shows that the beam specimens cast by fly ash have longer deformation compared to the beam specimens cast by normal concrete. This indicates that the beam specimen made of fly ash concrete as substitution of fine aggregates has better ductility compared to the beam specimen made of normal concrete. This result meets with the study conducted by [8] that the reinforced concrete beam cast with high volume fly ash was able to have large deflection prior to failure.

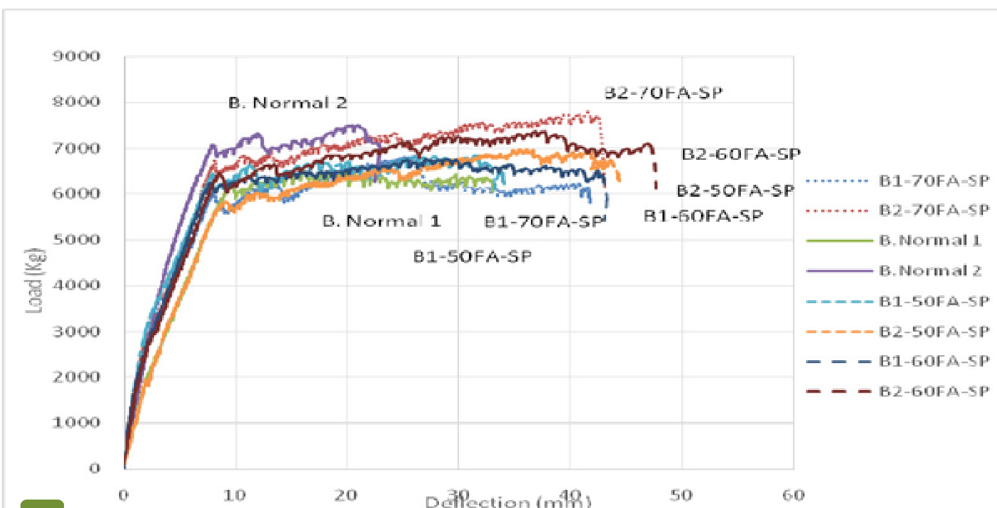

Fig. 3. The load-deflection relationship of the tested beam specimen.

3.3 The load-carrying capacity of the beam specimen

The load-carrying capacity of the beam specimens was shown in Table 2. Table 2 shows that compared to the others, the beam specimen with 70 % fly ash as substitution of fine aggregates has the highest load-carrying capacity. The highest load-carrying capacity of this beam specimen is due to the fact that this specimen has the highest compressive strength (see Table 1).

Table 2. The load-carrying capacity of the tested beam specimens.

Content of fly ash	Beam specimen	Maximum load (kg)	Average load (kg)
0%	B1-Normal	6509.47	7000.37
	B2-Normal	7491.28	
50%	B1-50FA-SP	6840.73	6910.95
	B2-50FA-SP	6981.18	
60%	B1-60FA-SP	6751.71	7059.62
	B2-70FA-SP	7367.54	
70%	B1-70FA-SP	6829.13	7311.39
	B2-70FA-SP	7793.66	

3.4 The crack pattern of the beam specimen

The crack pattern of the specimen B1-Normal; B1-50FA-SP; B1-60FA-SP; B1-70FA-SP can be seen in Fig. 4; Fig. 5; Fig. 6; and Fig. 7, respectively. It can be seen that none of the beam specimens failed due to the shear. This indicates that the shear capacity of the concrete was higher than the maximum shear force of the beam, as no shear crack failure occurs on the shear region of the beam.

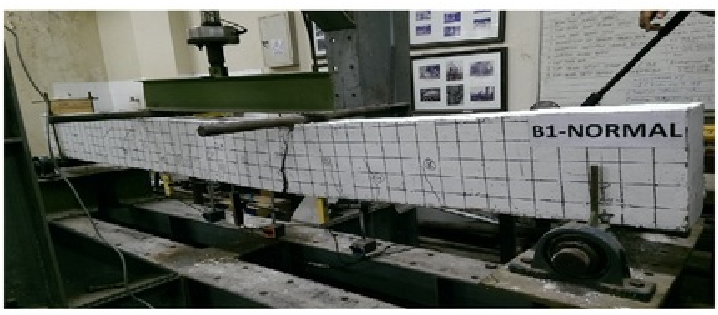

Fig. 4. The crack pattern of B1-Normal specimen.

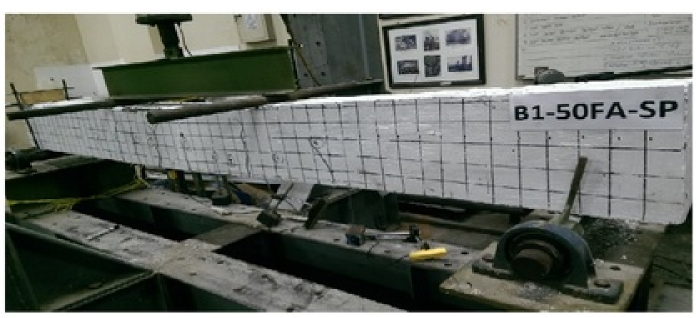

Fig. 5. The crack pattern of B1-50FA-SP specimen.

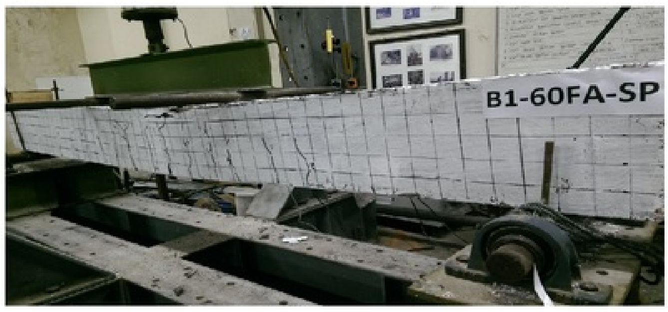

Fig. 6. The crack pattern of B1-60FA-SP specimen.

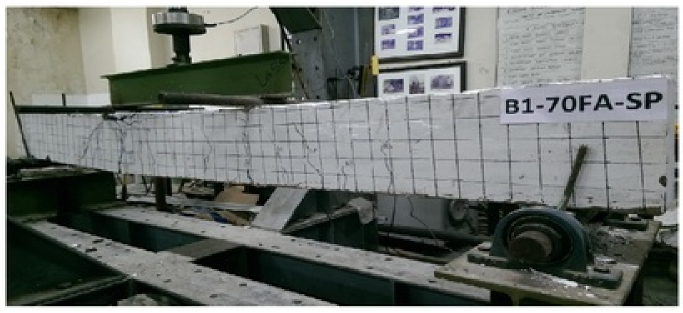

Fig. 7. The crack pattern of B1-70FA-SP specimen.

4 Conclusions

Based on the experimental program and discussion above, several conclusions can be drawn as follows:

1. Substitution of fine aggregates in concrete using fly ash will increase the compressive strength of concrete. The increase of compressive strength due to the fly ash as pozzolanic material reacts with the portland-cement and gives the hardened concrete better properties through the hydraulic or the pozzolanic activity of the fly ash and portland-cement
2. The behavior of the beam specimens made of fly ash have better ductility compare to the beam specimens made of normal concrete. This indicates that the reinforced concrete beam cast with high volume fly ash was able to have large deflection prior to failure.
3. The load-carrying capacity of the beam specimens with 70 % fly ash as substitution of fine aggregates has the highest load-carrying capacity. The highest load-carrying capacity of this beam specimen is due to the fact that this specimen has the highest compressive strength.
4. None of the beam specimens was failed due to shear, because the shear capacity of the concrete made with fly ash was higher than the maximum shear force of the beam.

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