13.Shear_Behavior

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Shear behavior of high-volume fly ash concrete as replacement of Portland cement in RC beam

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Abstract

An experimental program was conducted to study the shear behavior of high-volume fly ash concrete as replacement Portland cement of Reinforced Concrete (RC) beams. Eight beam specimens were tested in this study. Two beams used normal concrete as control beams, while six others beams used High-Volume Fly Ash Concrete (HVFAC) as a replacement of Portland cement by mass (two beams with 50 % of fly ash; two beams with 60 % fly ash; and two beams with 70 % of fly ash). The beams had longitudinal bars, and with stirrups were kept constant in the bending-test region. There were no shear reinforcements in the shear-test regions. The results showed that increasing substitutions of fly ash as replacement of Portland cement tend towards a reduction of shear strength and led the HVFAC beams became brittle. Comparing all the series of HVFAC beams that better results could be achieved by the beams with 50 % of fly ash due to the higher shear strength than the beam with 60 % and 70 % of fly ash. The HVFAC beams failed in shear due to low shear strength of the beams

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Keywords: high-volume fly ash; OPC replacement; shear strength;

1. Introduction

Indonesia's construction industry has been emerged since several decades ago. As emerging of construction industry in Indonesia, a need of building material for construction also increase. Concrete has been emerged as a famous material for building due to easily in making and forming the concrete, and of course concrete structures is more resistant from corrosion than steel structures. The basic materials for making concrete are Portland cement,

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fine aggregates and coarse aggregates. The Portland cement is the most essential ingredient in production of concrete. However, Portland cement also contributes to the global warming due to carbon dioxide (CO_2) emissions as a side effect of Portland cement production. Roy [1] stated that Portland cement contribution to global warming because of production of one ton ordinary Portland cement will produce one ton CO_2 which is released to the air.

One of the solutions for this global warming issue is reducing the utility of Portland cement in production of concrete. To reduce the Portland cement in production of concrete is the use of supplementary cementitious materials. Bilodeau and Malhotra [2] stated that the most available supplementary cementitious material is fly ash which is produced by coal-burning thermal power stations. Fly ash has been used as supplementary cementitious material in concrete since 1937 [3]. According to American Concrete Institute [4], fly ash is categorized into three classes: class N, F, and C based on the chemical compositions. Study of utilization of fly ash as supplementary in concrete has been extensively conducted since several decades ago [2, 5-9]. The utilization of fly ash as supplementary in concrete has benefit such as reducing heat generation, low permeability, and high durability [10]. Therefore, development of utilization of fly ash as supplementary in concrete is still promising for the future.

In the early, fly ash was used as replacement of cement limited into the range of 15-25 % [11]. While for high strength concrete the portion of replacement at 35 % to control peak hydration temperature [12]. In the next development, a high volume fly ash concrete (HVFAC) where the replacement of cement with fly ash at least at 50 % was developed [13-14]. These studies had shown that HVFAC has lower shrinkage, creep, and water permeability, and has higher modulus of elasticity compared to the conventional concrete. Koyama et al. [15] investigated the mechanical properties of concrete beam made of a large amount of fly ash where the cement content was kept constant, the results showed that the shear strength and deformability of the beam increased as the mixed quantity of fly ash increased. Rao et al. [16] investigated shear resistance of high volume fly ash reinforced concrete beams without web reinforcement where the replacement of cement with the portion of 0 % and 50 % and with the various longitudinal tensile steel reinforcement, the result showed that shear strength of the beam increased with increasing of longitudinal tensile steel ratio. Soman and Sobha [17] also investigated the shear and behavior of high volume fly ash concrete with the replacement of fly ash 50 %, the result showed that the HVFAC beams improved the deflection and the load carrying capacity of the beams. Thangaraj, R., and Thenmozhi, R. [18] investigated the performance of high volume fly ash concrete structures with the replacement of cement of 50 %, 55 %, and 60 %, it was observed that the compressive strength of HVFAC was improved by about 50 % cement replacement. Arezoumandi et al. [10] conducted an experimental program on shear behavior of high-volume fly ash concrete versus conventional concrete with the replacement of cement of 50 %, and 70 %, the results showed that the HVFAC beams gave the superior shear strength compared to the conventional concrete beams.

There were several investigations on shear strength of the HVFAC beams. However it is still questionable in what portion of fly ash replacement which makes the maximum shear strength of the HVFAC beams. Therefore, this research will conduct the experimental program to investigate the shear behavior of high-volume fly ash concrete beams as a replacement of cement. The various portion of fly ash replacement in this research were 50 %, 60 %, and 70 %.

2. Experimental program

2.1. Materials

The Portland Pozzolan Cement (PPC) was used in this study. The water used in this study was taken from the Laboratory of Structures and Materials. The fine and coarse aggregates were taken from local materials. The fine aggregates were passed through sieve 4.75 mm. The specific gravity and fineness modulus of fine aggregates were 2.77 and 2.92, respectively. While the coarse aggregates used in this research were passed through 20 mm and retained on 10 mm sieve. The specific gravity and fineness modulus of coarse aggregates were 2.68 and 7.16, respectively. The fly ash class F was used in this study. To enhance the workability of concrete a super plasticizer was used to make the concrete. The mix design of concrete was designed following the ACI 211.1-91 [19]. The mix proportion per m^3 of concrete with 0 % replacement of cement was as follows: Portland Pozzolan Cement=336.07 kg; water=207.39 kg; coarse aggregates=892.09 kg; fine aggregates=958.67 kg, and with super plasticizer=2.073 kg.

For HVFAC with the replacement 50 %, 60 %, and 70 % of cement, just replaced the cement in the proportion with 50 %, 60 %, and 70 % of fly ash, respectively.

2.2. Materials testing

To see the chemical composition of fly ash, the fly ash was tested in the Laboratory of Chemical Engineering, Universitas Gadjah Mada. The tested result of fly ash was shown in Table 1. It can be seen that the fly ash can be classified as fly ash type F.

Table 1. The chemical composition of fly ash.

No	Chemical element	Content (%)	Note
1	SiO_2	43.250	
2	Al_2O_3	27.492	
3	Fe_2O_3	11.292	
4	$SiO_2 + Al_2O_3 + Fe_2O_3$	82.034	> 70 %
5	Loss on Ignition	-	
6	CaO	7.246	< 10 %
7	MgO	7.125	
8	SO_3	1.499	
9	K_2O	0.864	
10	Na_2O	-	
11	H_2O	-	

Reinforcement bar with diameter of 12 mm was used for longitudinal bar, and reinforcement bar with diameter of 6 mm was used for stirrup. The yield stress of reinforcement bars was obtained according to the guidelines in ASTM E8/E8M-09 [20], Standard Test Methods for Tension Testing of Metallic Materials. Universal Testing Machine (UTM) with capacity of 30,000 kgf was used to conduct the tension test of reinforcement bars. The average yield stresses of 240 MPa were obtained for both reinforcing bars of 12 mm and 6 mm.

2.3. Specimens preparation

Cylinder specimens with the size of 150 mm x 300 mm were cast for testing of compressive strength and modulus elasticity of concrete. Thirty six cylinder specimens were tested in this study (see Table 2).

Table 2. The number of cylinder specimens.

Cylinder Designation	Fly ash content (%)	For 7 days testing	For 14 days testing	For 28 days testing
0FA	0	3	3	3
50FA	50	3	3	3
60FA	60	3	3	3
70FA	70	3	3	3

Eight beam specimens were tested in this study. Two beams used normal concrete as control beams, while six others beams used High-Volume Fly Ash Concrete (HVFAC) as a replacement of Portland cement by mass (two beams with 50 % of fly ash; two beams with 60 % fly ash; and two beams with 70 % of fly ash). The beams had a rectangular section of 150 mm x 260 mm and overall length of 2600 mm. The beams had longitudinal bars with diameter of 12 mm. Three bars were for bottom reinforcement and two bars for top reinforcement. The shear reinforcements used diameter of 6 mm with stirrups spacing of 100 mm were kept constant in the bending-test region, and there were no shear reinforcements in the shear-test regions. The beam designation and the number of the beam in every variant can be seen in Table 3.

Table 3. The beam designation and the number of beam specimens.

Beam Designation	Fly ash content (%)	The number of beam specimen
B1-Normal	0	2
B2-Normal	0	
B1-50FA-SS	50	2
B2-50FA-SS	50	
B1-60FA-SS	60	2
B2-60FA-SS	60	
B1-70FA-SS	70	2
B2-70FA-SS	70	

2.4. Setup of beam specimens

The beam specimens were tested on the loading frame of the Laboratory of Structures and Materials. The actuator with load capacity of 250 kN was used to test all beam specimens. The specimen was tested under load control. A transfer beam was used to transfer the load from the actuator to the beam specimen. The beams were simply supported and loaded symmetrically under two-point-loading. A Linear Variable Differential Transformers (LVDT) was used to measure deflection of the specimen. The LVDT was placed at the middle of the specimen. Measured data of load and deflection were read through a computer driven data acquisition system using data logger. The setup of the beam specimen was shown in Fig.1.

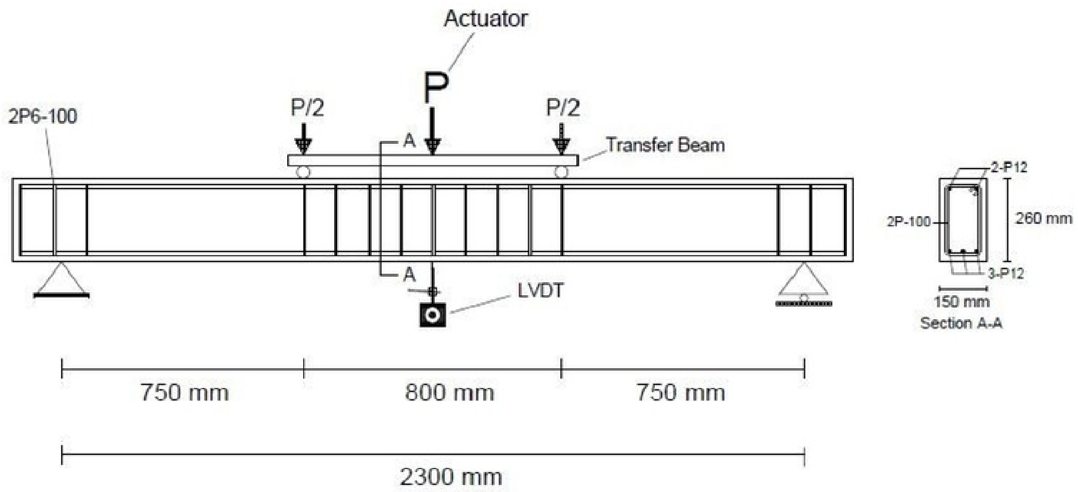


Fig.1. Setup of beam specimen

3. Results and discussion

3.1. Properties of concrete

The average density, compressive strength, and modulus of elasticity of concrete tested at 28 days were shown in Table 4. It can be seen from Table 4 that the average density of HVFAC increased when the content of fly ash increased. While the average compressive strength and modulus of elasticity of HVFAC decreased when the content of fly ash increased. Compare to the normal concrete, it can be seen also from Table 4 that the average compressive strength and average modulus of elasticity of HVFAC were lower than normal concrete.

Table 4. The mechanical properties of concrete.

Code	Fly ash content (%)	Average density (Kg/m3)	Average Compressive Strength (MPa)	Average Modulus of Elasticity (MPa)
0FA	0	2256.222	20.441	22527.32
50FA	50	2252.100	15.342	15200.28
60FA	60	2305.669	13.753	14541.86
70FA	70	2402.134	11.672	11482.64

3.2. Shear Behavior of HVFAC Beam

The first crack was observed visually during the testing specimen. The first crack load was noted as the load at first crack occurred. The first crack load of every beam specimen was presented in Table 5. It can be seen from Table 5 that the average first crack load of HVFAC beams was lower than the control beam. It can be seen also that the first crack load of HVFAC beams decreased when the replacement of the cement by fly ash was increased.

Table 5. The first cracking load of every beam specimen.

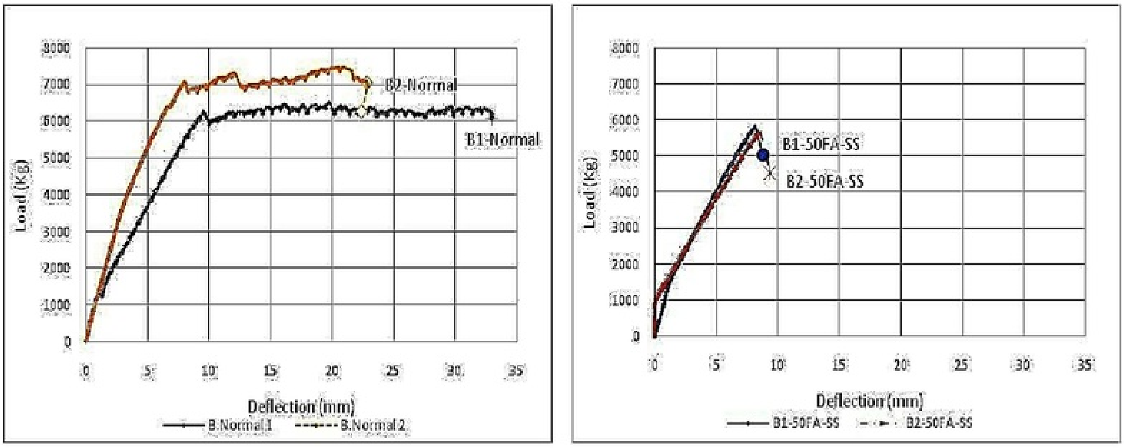
Beam Designation	Fly ash content (%)	The load at first crack (kN)	Average load at first crack (kN)
B1-Normal	0	26.12	31.31
B2-Normal	0	36.50	
B1-50FA-SS	50	25.50	22.30
B2-50FA-SS	50	19.10	
B1-60FA-SS	60	22.00	18.73
B2-60FA-SS	60	15.46	
B1-70FA-SS	70	21.85	18.55
B2-70FA-SS	70	15.25	

The ultimate load of every beam specimen was shown in Table 6. Compared to the control beam, it can be seen that the average ultimate load of HVFAC beams were lower than the control beam. It can be seen also that the ultimate load of HVFAC beam was decreased when the replacement of cement by fly ash was increased. Among the HVFAC beams, it can be seen that the HVFAC beam with 50 % fly ash was the optimum replacement of fly ash, because it had the largest ultimate load compared to others HVFAC beams. If the HVFAC beam with 50 % fly ash had the largest ultimate load, it means that the HVFAC beam with 50 % fly ash had the largest shear strength compared to others HVFAC beams.

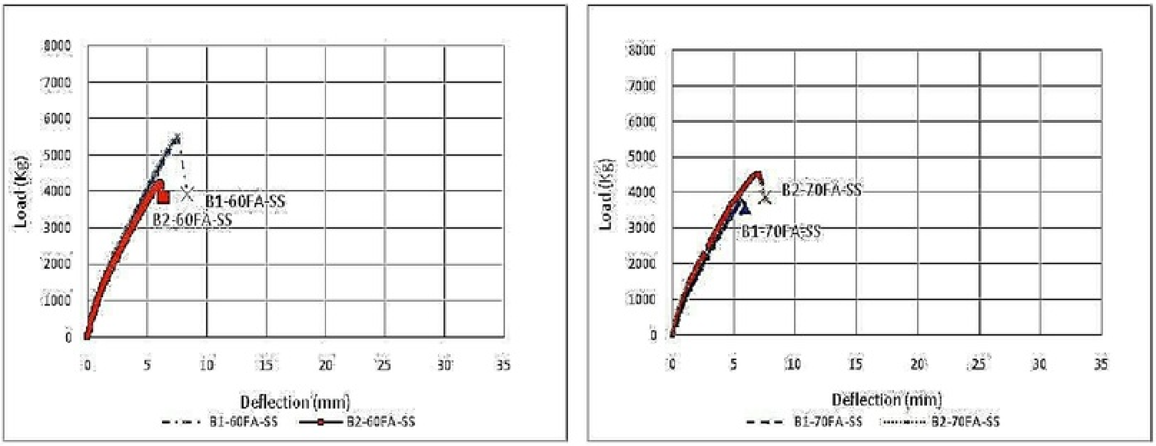
Table 6. The ultimate load of beam specimens.

Beam Designation	Fly ash content (%)	Ultimate load (kN)	Average ultimate load (kN)
B1-Normal	0	65.094	70.003
B2-Normal	0	74.912	
B1-50FA-SS	50	58.091	57.263
B2-50FA-SS	50	56.434	
B1-60FA-SS	60	55.256	48.869
B2-60FA-SS	60	42.482	
B1-70FA-SS	70	38.182	41.893
B2-70FA-SS	70	45.604	

The load-deflection relationship of every beam specimen was shown in Fig. 2(a); (b); (c); and (d). It can be seen from Fig. 2(a), the load-deflection behavior of B1-Normal and B2-Normal (control beams) were virtually identical. Before first cracking the curve increased linearly which was presenting elastic behavior. After cracking, the curve increased nonlinearly up to an ultimate load. After reaching the ultimate load, the curve decreased non-linearly and proceeded with a section of an approximately horizontal curve, indicating a state of yielding and large deformation of the beam before collapse.



a) Load-deflection of B1-50FA-SS and B2-50FA-SS (b) Load-deflection of B1-Normal and B2-Normal



(c) Load-deflection of B1-60FA-SS and B2-60FA-SS (d) Load-deflection of B1-70FA-SS and B2-70FA-SS

Fig.2. The load-deflection relationship of beam specimens

While the load-deflection of the HVFAC beams (B1-50FA-SS; B2-50FA-SS; B1-60FA-SS; B2-60FA-SS; B1-70FA-SS; and B2-70FA-SS) were virtually also identical (see Fig. 2(b), (c), and (d)). Before cracking, the curve displayed linearly elastic behavior. After cracking, the curve increased nonlinearly until reaching the ultimate load. After reaching the ultimate load, the load drop rapidly prior to collapse. The collapse of the HVFAC beams was indicated with a sudden failure and large shear crack in shear-test-region (region without stirrups).

The comparison among the beam specimens can be seen in Fig. 3. It can be seen that the control beams was more ductile compared to the HVFAC beams. It indicated that replacement of cement by fly ash made the HVFAC beams became brittle due to the lower compressive strength of HVFAC beams compared to the control beams.

The crack pattern of beam specimens was shown in Fig. 4. The control beams (B1-Normal and B2-Normal) failed in flexural. The first crack appeared in the maximum moment region, and then followed by additional flexural crack which developed vertically. As the load increased, a small inclined flexure-shear crack appeared then the beam gave large deformation prior to collapse. While all HVFAC beams failed in shear. The first crack appeared in the maximum moment region, and then followed by additional flexural crack. As the load increased, a large inclined flexure-shear crack appeared between the load and support then the beam was collapse suddenly. It indicated that the shear strength of the HVFAC was low and it was easily to be crack in the shear-test-region.

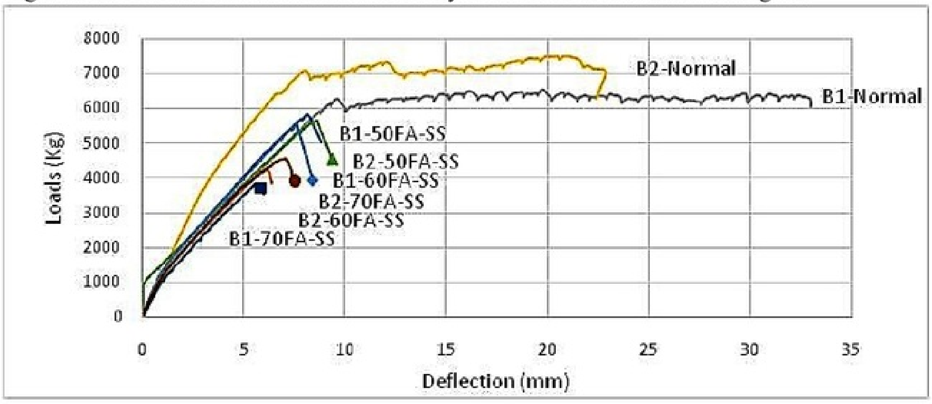


Fig. 3. Comparison load-deflection relationship among the beam specimens

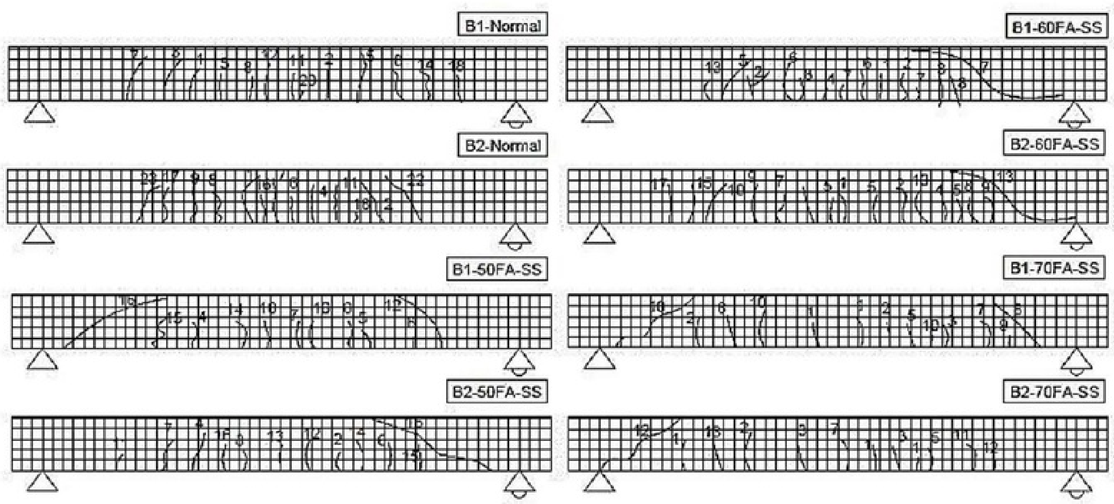


Fig. 4. The crack pattern of beam specimens.

4. Conclusions

Based on the obtained experimental results, the following conclusion can be drawn:

- Increasing the substitutions of fly ash as replacement of portland cement tend towards a reduction of shear strength and led the HVFAC beams became brittle.
- Comparing all the series of HVFAC beams that better results could be achieved by the beams with 50 % of fly ash due to the higher shear strength than the beam with 60 % and 70 % of fly ash.
- The HVFAC beams failed in shear due to the low shear strength of the beams.

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