Shear behavior of fly ash reinforced concrete beam without shear reinforcement

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Abstract. An experimental study was carried out to discover the shear behavior of reinforced concrete beam (RCB) using fly ash (FA) as cement replacement material. Variation of FA composition that was used as the research variable were 10 %, 20 % and 30 % by cement mass. Each of the variations has two RCB specimens while two RCB specimens used normal concrete (non FA) as control beams. The beam was reinforced only in the longitudinal direction without shear reinforcement. The beam was tested by the static monotonically loading method. The results showed that the shear strength of RCB decreased by increasing the amount of FA.

1. Introduction
The increasing of the population makes human needs particularly in construction as well as increases so that stimulating the enhancement of construction industries, especially in the material field. Concrete is one of the most widely used materials in construction industries. The use of concrete is estimated at nearly 25 billion tons all over the world [1]. This amount makes portland cement as a primary component in concrete must be produced in large amount. It was recorded in 2005 that the quantity of Portland cement production to fulfill needs of whole the world reached 2,2 billion tons [2]. In the last decade, global greenhouse gas emission is a serious issue to be discussed in the world because of its effect on the environment. One of the main contributors on the matter is carbon dioxide (CO₂). Based on the increasing demand for cement, it then makes the production of cement factories also increase to suffice it. However, the circumstances become the environmental problem because the existence of CO₂ released to the atmosphere due to the cement factories activities. The production of 1-ton cement is also estimated to produce 1 ton CO₂ gas emissions [3]. The negative environmental effect of cement factories is a concern of material engineers to find new material to reduce using of cement.

Fly ash (FA) is the most widely available residual material from coal combustion in the worldwide. In the year 2000, it was estimated that 600 million tons of fly ash were available in the world [3]. Research on fly ash (FA) as additional material on concrete has been carried out since year of 1930s [4]. Based on the American Concrete Institute, fly ash is classified into three classes: N, F, and C based on chemical composition. Some use of fly ash as an additional material in concrete are reducing heat generation, low permeability and high durability [5]. The addition of FA in concrete can reduce the use of cement even at the optimum percentage can increase the strength of concrete. Use of FA in
Concrete is expected to be able to reduce the use of cement in large quantities so that it can reduce cement production and then its negative effects on the environment can be reduced. The addition of FA in concrete mixtures to reduce the proportion of cement use is an improvement in the field of concrete materials. However, the research at the level of structural elements is still rare to be done [5].

Koyama et al. [7] researched the mechanical properties of the concrete beam made of a large amount of fine fly ash. On the research, the quantity of cement was kept constant while fly ash was variable on each of specimen. Its result indicated that the addition of fly ash volume in concrete caused the increase in shear strength and deformability. Arezoumandi and Volz [8] investigated the effect of fly ash replacement level on the shear strength of the high-volume fly ash concrete beam. Fly ash class C was used on the research. Two identical mixes were made except the amount of fly ash used was different: 50 % and 70 % of the cement mass - and conventional concrete. The result shows that the mix with 70 % fly ash had higher shear strength than 50 % fly ash and conventional concrete. Rao et al. [9] researched shear resistance of high volume fly ash reinforced concrete beams without web reinforcement. 0 % and 50 % portion of fly ash by mass of cement was used with various longitudinal tensile reinforcement. Its result showed that the ratio of longitudinal tensile reinforcement caused the increase shear strength of a beam with 50 % fly ash. Lisantono et al. [10] investigated the shear behavior of high-volume fly ash concrete as replacement portland cement in RC beam which replaced 50 %, 60 % and 70 % mass of cement with fly ash, longitudinal and stirrups were kept constant in the bending test region while no shear reinforcement in the shear test region. The result showed that increasing of the fly ash a cement replacement material tended to reduce shear strength and led the beam became brittle.

Some factors affected the occurrence shear failure on beam were the concrete compressive strength, longitudinal reinforcement ratio, shear span to effective depth ratio and effect of member size [11]. They can be the variable of research to carry out observation of how the effect of using fly ash on the element of structure to the shear behavior of beam. This research would carry out the experimental program to investigate the shear behavior of reinforced concrete beam without shear reinforcement with various compositions of fly ash as a cement replacement material that would affect compressive strength of concrete. It is also expected to be able to enhance the result of research in this field.

2. Experimental program

2.1. Materials

All concrete mixtures on this research used portland cement type I (Padang cement). Fine and coarse aggregates were taken from the local quarry. Fine aggregate had a specific gravity and exceptional modulus 2.44 and 3.39 respectively. Coarse aggregate used is split where its maximum size is 10 mm. The specific gravity of split is 3.15. Water used in this study was from material and structure laboratory of Andalas University. FA used in this study was taken from Ombilin, Sawahlunto - one of the coal-fired steam electric power plant in West Sumatera. Superplasticizer was used to increase concrete workability. Mix design was made according to the ACI 211.4R-98 [11]. The mix proportion per m³ of ordinary concrete (0 % of FA) was as follow 561.5 kg of portland cement; 638.7 kg of fine aggregates; 902.6 kg of coarse aggregates; 214.8 kg of water and 3.37 kg of superplasticizer. Concrete with 10 %, 20 %, 30 % of FA was just replaced the amount of cement as the percentage of FA.

2.2. Specimen preparation

Twelve cylinders with a size of 150 mm x 300 mm were prepared to obtain the compressive strength of concrete at the time of beam testing. There were four research variables made: 0 %, 10 %, 20 % and 30 % of FA as a cement replacement material. Each of the variables was made three cylinders (see Table 1).

The beam was made eighth specimens with a rectangular section. The size of the beams was 125 mm x 250 mm x 2300 mm. Two beams with 0 % of FA (ordinary concrete) were as control beams, and each of other variables was also made two beam specimens. The designation and numbering of
beams can be seen in Table 2. Longitudinal tensile deformed bars with 13 mm diameters were installed two layers to all beams with similar reinforcement ratios. All of the beam specimens did not apply shear reinforcement. It was expected the ultimate shear strength would be reached first before ultimate flexural strength. Beam designation and arrangement of bars is showed in Figure 1.

| Cylinder Designation | Fly Ash Content (%) | The Number of Cylinder Specimen |
|----------------------|---------------------|---------------------------------|
| FA0                  | 0                   | 3                               |
| FA10                 | 10                  | 3                               |
| FA20                 | 20                  | 3                               |
| FA30                 | 30                  | 3                               |

Table 1. Cylinder designation and the number Cylinder Specimen

Table 2. The beam designation and number of beam specimen

| Beam Designation | Fly Ash Content (%) | The Number of Beam Specimen |
|------------------|---------------------|-----------------------------|
| B-FA0-1          | 0 %                 | 2                           |
| B-FA0-2          | 0 %                 | 2                           |
| B-FA10-1         | 10 %                | 2                           |
| B-FA10-2         | 10 %                | 2                           |
| B-FA20-1         | 20 %                | 2                           |
| B-FA20-2         | 20 %                | 2                           |
| B-FA30-1         | 30 %                | 2                           |
| B-FA30-2         | 30 %                | 2                           |

Figure 1. Beam specimen preparation (measures in mm)

2.3. Chemical composition for fly ash
FA was tested in environmental engineering - Andalas University to know its chemical composition. The test result is showed in Table 3. It can be seen that the FA used in this study is not included with criteria of classified as given ASTM C 618-03 [12] where the minimum content for all the class of FA is 50 %.

2.4. Test setup and procedure
A load frame was used to apply the load to the beam specimen. The beam was loaded by static monotonically method until beam failure. Beam specimen was supported on a roller and pin support.
An LVDT (linear variable differential transformer) was installed to measure the deflection at the beam. The test setup of beam specimen was shown in Figure 2.

**Table 3. The chemical composition of fly ash**

| Chemical Element | Content   |
|------------------|-----------|
| $\text{Al}_2\text{O}_3$ | 10.5 %    |
| $\text{Fe}_2\text{O}_3$ | 13.46 %   |
| $\text{SiO}_2$       | 23.35 %   |
| **Total**           | **47.31 %**|

![Figure 2. Test setup of beam specimen](image)

3. **Result and discussion**

3.1. *The compressive strength of concrete*
From Table 4, it can be seen that the average compressive strength of concrete (at the day of testing the beam specimen) was decreased when the content of FA increased. The concrete with FA had lower compressive strength than ordinary concrete.

**Table 4. The average compressive strength of cylinder specimen**

| Cylinder Designation | Fly Ash Content (%) | Average Compressive Strength (MPa) |
|----------------------|---------------------|-----------------------------------|
| FA0                  | 0                   | 56.04                             |
| FA10                 | 10                  | 51.60                             |
| FA20                 | 20                  | 42.08                             |
| FA30                 | 30                  | 32.67                             |

3.2. *Shear test of beam specimen*
Initial crack was scrutinized visually throughout the beam test. When the initial crack appeared, the load read was noted. Table 5 shows the initial crack load for every beam specimen. From Table 5, It
can be seen that the average initial crack load of control beams was lower than all beams with FA. The addition of FA did not show a regular effect on the increase or decrease in the initial crack load.

Table 6 shows the ultimate load for every beam specimen. It can be seen that the average ultimate load of beams with FA was lower than the average ultimate load of control beams. Generally, the average ultimate load of beams decreased when the amount of FA as cement replacement material in concrete increased. Comparing among beam specimens with FA, beam specimens with 10 % FA were the highest shear strength because of their higher ultimate loads.

The relationship of shear load-deflection for every beam specimen can be seen in Figure 3; 4; 5 and 6. The curve of all shear load-deflection relationship tended to change almost linearly until the ultimate load reached.

**Table 5. The initial crack of each beam**

| Beam Designation | Fly Ash Content (%) | Initial Crack Load (kN) | Average Initial Crack Load (kN) |
|------------------|---------------------|-------------------------|--------------------------------|
| B-FA0-1          | 0                   | 25.0                    | 22.95                          |
| B-FA0-2          | 0                   | 20.9                    |                                |
| B-FA10-1         | 10                  | 41.2                    | 34.20                          |
| B-FA10-2         | 10                  | 27.2                    |                                |
| B-FA20-1         | 20                  | 27.9                    | 23.70                          |
| B-FA20-2         | 20                  | 19.5                    |                                |
| B-FA30-1         | 30                  | 24.2                    | 31.65                          |
| B-FA30-2         | 30                  | 39.1                    |                                |

The beams with the same FA content has shear load-deflection relationship virtually identical. These showed the homogeneity of the concrete mixture produced in this study. After the ultimate load was reached, shear load decreased drastically with a small increase of deflection, and then the beams collapsed suddenly. These occurred on control beams and beams with 20 % and 30 % of FA (see Figure 3, 5 and 6). However, the beams with 10 % of FA showed the different behavior of failure. After the ultimate load was reached, the deflection still kept increasing while the shear load experienced ups and downs and then a collapse occurred (see Figure 4).

**Table 6. The ultimate load and deflection of beam specimens**

| Beam Designation | Fly Ash Content (%) | Ultimate Shear Load (kN) | Average Ultimate Shear Load (kN) |
|------------------|---------------------|--------------------------|----------------------------------|
| B-FA0-1          | 0                   | 42.10                    | 41.78                            |
| B-FA0-2          | 0                   | 41.45                    |                                  |
| B-FA10-1         | 10                  | 35.85                    | 36.15                            |
| B-FA10-2         | 10                  | 36.45                    |                                  |
| B-FA20-1         | 20                  | 35.30                    | 33.75                            |
| B-FA20-2         | 20                  | 32.20                    |                                  |
Combined all shear load-deflection relationship was shown in Figure 7 as the comparison among all beam specimens. It can be seen that the stiffness of control beams was nearly similar to all beam specimens with FA due to the slope of curves. The beams with 10% of FA had the large deflection among the other beam specimen.

Figure 8 showed the failure mode and cracked pattern of the beams. The initial crack appeared in the maximum moment region and followed by another flexural crack. Few cracks occurred in the mid-span while the load continued to be increased until the ultimate load.
Figure 7. Combined shear load-deflection relationship of all beams
An inclined flexural-shear crack appeared, propagated and widened suddenly in the shear region (between load and one of the supports) and then beam collapsed suddenly. It occurred on all beams except the beams with 10% of FA. On these beams, it propagated and widened slowly when the inclined flexural-shear crack first appeared before the beams collapsed. It was guessed that the replacement of cement with 10% of this type of FA caused change microstructure of concrete so that intermaterial bonding in concrete also changed. Based on crack occurred, all beams failed in shear due to ultimate shear strength was reached first before ultimate flexural strength, this is in accordance with planning in beams specimen preparation which expected ultimate shear strength was reached first.

4. Conclusion
Based on the result of this study, some conclusions can be presented:
- The shear strength of the beam decreased with increasing the amount of FA as a cement replacement material.
- The initial crack loads were not affected by increasing of FA regularly.
- All of the beam specimens failure in shear due to ultimate shear strength was reached first.

Acknowledgment
This experimental study was financially supported by LPDP-Ministry of Finance, the Republic of Indonesia for the thesis research funds on the scholarship of the master program.

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