material was taken from one source in one batch. The laboratory test was performed for each batch on each material and the results are presented in the section below.

2.1.1. Fine Aggregate

The fine aggregate used in this research is local sand from the East Java area, which was collected as one batch. The specific gravity, water absorption, moisture content, and fineness modulus tests were performed for the batch. The specific gravity and water absorption were performed according to ASTM C128 [23]. The moisture content test was conducted according to ASTM C566 [24]. Furthermore, the fineness modulus and the fine aggregate's particle size were performed according to ASTM C 33 [25].

2.1.2. Coarse Aggregate

The coarse aggregate used in this research was taken from a local quarry in East Java Indonesia, which was collected as one batch. The tests of density, moisture content, and water absorption were performed for the batch. The specific gravity and water absorption were performed according to ASTM C127 [26]. The moisture content test was conducted according to ASTM C566 [24].

2.1.3. Cement

The cement used in this test is Portland cement and the chemical composition was tested by using the XRF test. The cement density test was performed according to ASTM C188 [27].

2.1.4. Fly ash and Bottom Ash

The FA and BA used in this research were acquired from a coal power plant located in Paiton East Java Indonesia operated by PT. PLN (Persero). For this research, the FA and BA were acquired from one boiler source to minimize the variation. The laboratory test was performed to get information on the chemical and several physical properties of the FA and BA. Visually, the FA from the coal power plant has brownish and fine particles (see Figure 1). While the visual of BA is darker. The size of raw BA which is taken from the power plant varies. Therefore, a sieving pre-treatment process was performed to make it suitable for fine aggregate replacement. The sieving process was performed using a 4.75-mm sieve (No. 4). The visual of the Bottom ash before and after the sieving process is shown in Figure 2. The physical and chemical characteristics test of FA and BA was performed according to ASTM 311 [28].

Figure 1. Visual of The Fly Ash

(a)

(b)

Figure 2. Visual of The Bottom Ash (a) Before and (b) After Sieving Process

2.2. Mix Proportion

A total of four mixtures, including one control mixture, were prepared in this research with a target compressive strength of 25 MPa in 28 Days. As per ACI 318 chapter 19.2 [29], for normal-weight concrete, the minimum compressive strength used for the special moment frame is 21 MPa. The residential house will be built in the Paiton Regency of East Java, which is an area with a relatively high seismic area. Therefore, the target of 25 MPa was chosen for the control mixture in this research. The water-to-cement ratio was set to be constant at 0.5. The concrete workability later was evaluated by using a slump test. The three mixtures have FA content varying from 40 – 50 % and BA from 50 to 75%. The FA was used as supplementary cementitious materials, while the BA was used as the replacement of the sand. There are a total of four sample variations used in this research which consist of Control Mixture, FB1, FB2, and FB3. The Control mixture is normal concrete without using FA and BA. While the FB code indicates that the sample uses fly ash and bottom ash in their mixture. The detail of the mixture proportion is shown in **Table 1**.

2.3. Casting and Curing Specimens

Concrete cylinders of 150 x 300 mm size were cast to determine the mechanical properties of the specimens such as compressive and tensile strength of the specimens. Furthermore, beam specimens were also prepared with sizes 150 x 150 x 600 mm to evaluate the flexure capacity of the concrete specimens. The specimens were de-moulded after 24 ± 1 h and cured at room temperature using a moist curing procedure. The moist curing procedure was performed using damp cloths and the moisture was checked every 24 hours.

2.4. Testing of the Specimens

Tests on mechanical properties performed in this research include slump test, compressive strength, splitting tensile strength, and flexural strength. All tests were performed three times for each variation except the slump test, which was only performed once for each variation.

2.4.1. Testing of Fresh Concrete

The fresh characteristics of the normal-weight concrete were assessed using a slump test. The target slump for the concrete mixture is 100 ± 10 mm. The concrete slump test was conducted right before the concrete was cast into the mold. The slump test was carried out according to the ASTM C143 [30]. The measurement process of slump can be seen in Figure 3.

Table 1. Mixture Proportion

Sample Name and Code	Cement, % (kg/m^3)	Fine Aggregate, % (kg/m^3)	Coarse Aggregate, % (kg/m^3)	Fly Ash, % (kg/m^3)	Bottom Ash, % (kg/m^3)	w/c (kg/m^3)
Control Mixture	100 (386)	100 (738.4)	100 (1062.6)	0 (0)	0 (0)	0.5 (193)
FB1	60 (231.6)	50 (369.2)	100 (1062.6)	40 (154.4)	50 (369.2)	0.5 (193)
FB2	50 (193)	50	100 (1062.6)	50 (193)	50 (369.2)	0.5 (193)
FB3	50 (193)	25 (184.6)	100 (1062.6)	50 (193)	75 (553.8)	0.5 (193)

Figure 3. Measurement Process of Slump

2.4.2. Testing of Hardened Concrete

a. Compressive Strength

The test for compressive strength was conducted as per ASTM C39 [31]. The compression load was applied directly to the 150 x 300-mm cylinder specimens. The SHIMADZU universal testing machine was used in this test. Equation 1 was used to calculate the strength of the specimens.

$$f_c' = \frac{P}{A} \quad (1)$$

The f'c is the compressive strength calculated using Equation 1 based on applied load (P) divided by cross-sectional area (A). Figure 4 shows the testing of the compressive strength of the specimens.

Figure 4. Compressive Strength Test of Cylinder Specimens

b. Splitting Tensile Strength

The splitting tensile test was performed as per ASTM C496 [32] as shown in Figure 5. The specimens are concrete cylinders with the size of 150 x 300 mm. The Equation (2) was used to calculate the tensile strength of the concrete specimens.

Figure 5. Tensile Test of Cylinder specimens

$$T = \frac{2P}{\pi l d} \quad (2)$$

Where P indicates the maximum applied load, d is the diameter of the concrete (mm), and l is the length of the concrete specimens (mm).

c. Flexural Strength

The Flexural strength was performed using a SHIMADZU universal testing machine according to ASTM C78 [33]. The specimens used for this test are concrete beams with size 150 x 150 x 600 mm. The flexural test and loading scheme are shown in Figure 6 and Figure 7 respectively. The flexural strength is calculated by Equation (3).

$$\sigma = \frac{3PL_o}{2bt^2} \quad (3)$$

Figure 6. Flexure Test of Beam Specimens

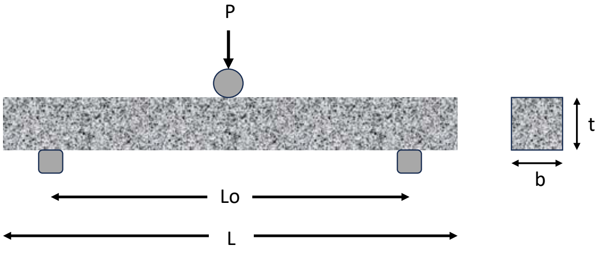

Figure 7. Loading Scheme of Flexural Strength Test

Where P indicates the applied load, b is the width of the specimens (mm), t is the depth of the specimens (mm) and Lo is the distance between the supports (mm).

3. Result and Discussion

3.1. Materials Testing

3.1.1. Fine Aggregate

The density, moisture content, water absorption, and fineness modulus tests were performed according to ASTM as stated in chapter 2.1.1. Based on the test result, the sand has a 2.74 g/cm^3 density, 4.6 % moisture content, 0.87% water absorption, and 3.11 fineness modulus. Based on the particle size distribution curve shown in Figure 8, the sand used in this research is categorized in Zone II.

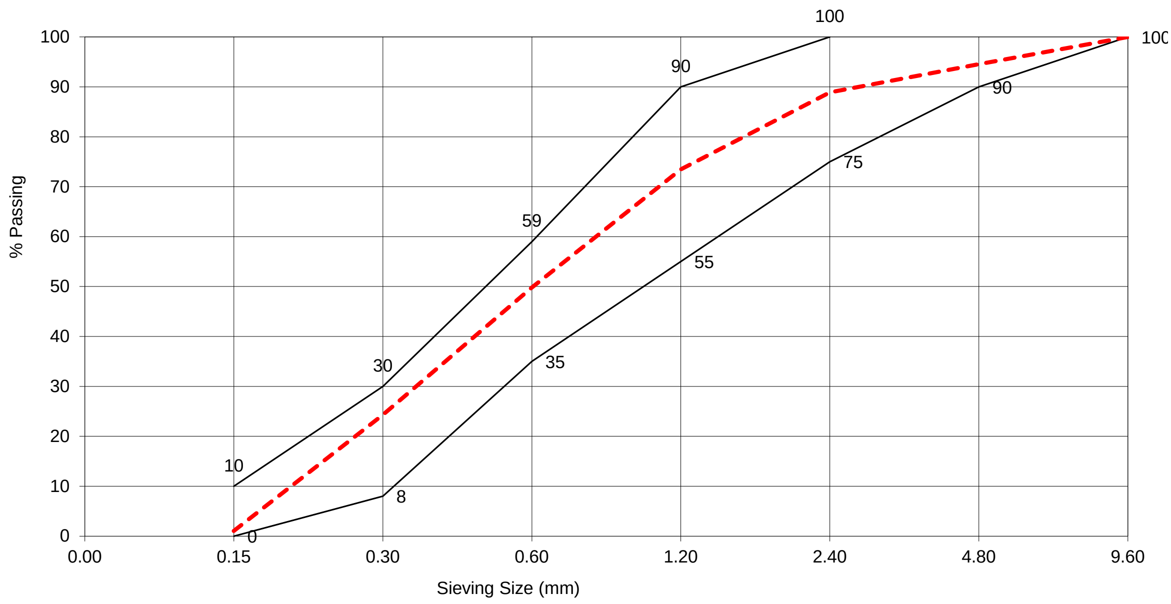

Figure 8. Particle size distribution of sand

3.1.2. Coarse Aggregate

The test was performed for coarse aggregate according to ASTM as stated in chapter 2.1.2. The density, moisture content, water absorption, and aggregate size tests were performed for the batch. It has a 2.82 gr/cm^3 density with 0.5% moisture content and 0.67 water absorption. The maximum size of the aggregate used in this research is 40 mm.

3.1.3. Cement

The cement used in this test is Portland cement. The chemical composition test was performed using XRF test and the result is shown in Table 2. The cement has a density of 3.15 gr/cm^3.

Table 2. Chemical Composition of Cement [34]

Chemical Composition	Value (%)
SiO_2	10.00
Al_2O_3	1.60
Fe_2O_3	4.91
CaO	76.03
MgO	1.20
Na_2O	1.50
K_2O	0.39
TiO_2	0.39
MnO_2	0.088
SO_3	2.3

3.1.4. Fly ash and Bottom Ash

The test was performed for Fly Ash (FA) and Bottom Ash (BA) according to ASTM C-311 [28]. The test results show that FA has a density of 2.61 gr/cm^3. The fly ash was tested using XRF to find the chemical properties and determine the class of the FA. Based on ASTM C618-19, Fly Ash is classified into two categories: class F and C. Class F includes FA comprising more than 70% of SiO_2 + Al_2O_3 + Fe_2O_3. However, class C includes FA with more than 50% of these oxides and a high CaO content. Based on the XRF test results in Table 3, the FA was categorized as Class C.

Table 3. Chemical Composition and Physical Properties of FA and BA

Parameter	Fly Ash (%)	Bottom Ash (%)
SiO_2	37.75	50.63
Al_2O_3	19.11	14.04
Fe_2O_3	12.49	13.79
CaO	13.46	7.46
MgO	6.25	3.48
Na_2O	5.40	3.28
K_2O	1.92	1.62
TiO_2	0.86	0.78
MnO_2	0.27	0.17
P_2O_5	0.38	0.21
Cr_2O_3	0.01	0.01
SO_3	0.98	0.43
Loss of Ignition (LOI)	0.57	3.53
Specific Gravity(gr/cm^3)	2.61	2.28
Water Absorption (%)	-	1.88
Moisture Content (%)	1.8	5.30

Different from FA, the BA obtained from the power plant has a porous structure, so the water absorption capacity is bigger than natural sand. Furthermore, it also has a density significantly less than sand. The density of the BA in this research is 2.28 gr/cm^3. The particle size distribution test indicated that the bottom ash confirming for zone II was used in concrete manufacturing.

The SEM test was conducted to get data related to the particle shape of FA and BA. The SEM test result is shown in Figures 9 and 10. Based on the SEM imaging presented in Figure 9, it can be seen that the FA has varying sizes of spherical vitreous particles. However, unlike FA, the microstructure of BA is typically composed of irregularly shaped particles, which can be rough and varied in size and shape as shown in Figure 10. These differences can influence the behavior of concrete such as the workability, water demand, and strength of the concrete.

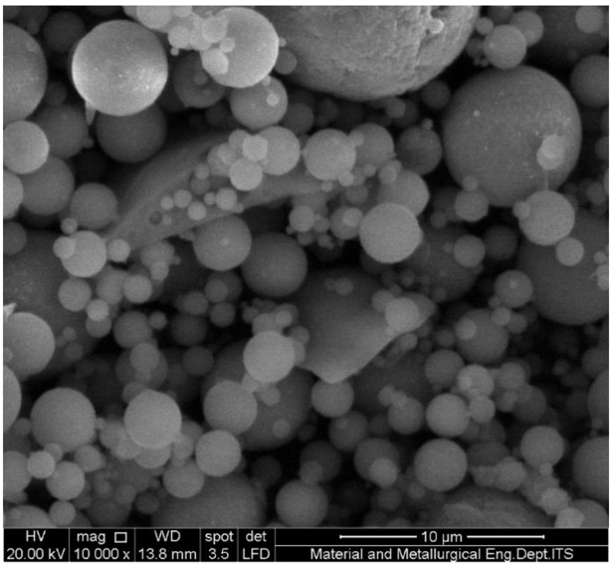

Figure 9. SEM Result of Fly Ash

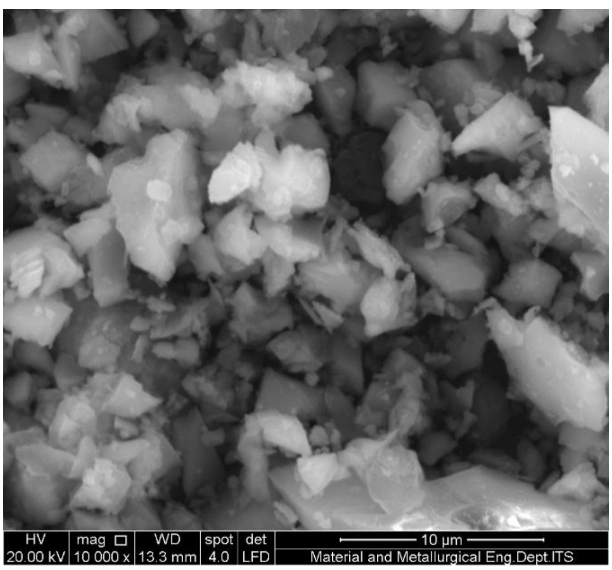

Figure 10. SEM Result of Bottom Ash

3.2. Concrete Testing

3.2.1. Fresh Properties

The fresh property of the concrete in this research is indicated by the slump test result, which is very important for construction. Workability indicated by slump comprised of multiple issues such as compatibility, mobility, and stability of fresh concrete. A larger slump indicates simpler concrete casting and less labor. Consistency can prevent bleeding and segregation by ensuring homogeneity and uniformity of the concrete. Appropriate fresh characteristics influence formwork pressure, early strength, and setting time, resulting in a long-lasting, high-quality structure. Using HVFA and HVBA in concrete certainly can affect the fresh concrete properties.

The slump values, as shown in Table 4 of the control mixture, FB1, FB2, and FB3 were 95, 102, 110, and 98 respectively. Using HVFA and HVBA to concrete simultaneously affects the slump value of the concrete. For concrete using FA of 40% and BA of 50%, the slump value increases by 7 mm. Generally, the slump value of concrete incorporating FA is increased due to its spherical-shaped particle. This shape can reduce the friction between particles. The research performed by researchers shows that by using FA to replace cement in the range 40% to 60%, it can increase the slump up to 40 mm [35–38]. Those research results align with slump test results performed in this study. By adding 10% more fly ash, which is indicated by the result of the samples FB1 and FB2, the slump also increased from 102 mm to 110 mm.

Table 4. Slump Test Result.

Sample	Slump (mm)
Control Mixture	95
FB1	102
FB2	110
FB3	98

However, in this study, the increase in slump is less than previous study. This condition happened due to the use of Bottom ash simultaneously with FA in the concrete mixture. The use of BA as a substitution for the sand can enhance the concrete's texture due to more irregular, porous, and fine-shaped particles that are usually very rough. More porous particles in BA compared to regular sand cause an increase in the water demand significantly. Furthermore, according to the research by [39,40], 25% to 50% extra water is required in the mixture to achieve similar workability to the regular concrete mixture. Furthermore, the irregular and rough particles of the BA are also responsible for obstructing the flow of the concrete. These results are compatible with the slump test result performed in this research. The sample FB3 has a lower slump value compared to the sample FB2 due to the increased percentage of BA as a substitute for regular sand.

3.2.2. Compressive Strength

The result of the compressive strength test is shown in Figure 11. As shown in Figure 11, the compressive strength at early curing days indicates that concrete incorporating HVFA and HVBA has significantly lower compressive strength than the control mixture. For FB1 concrete, which consists of 40% FA and 50% BA, the compressive strength of 3 days is 31% lower compared to the control mixture. Furthermore, samples FB2 and FB3, have compressive strengths 44% and 46% lower compared to the control mixture, respectively at 3 days. Furthermore, at 7 days, the concrete compressive strengths of the sample, which consists of FA and BA, are still lower than the control mixture. The compressive strength differences between samples FB1, FB2, and FB3 with the control mixture reach 24%, 34%, and 37%, respectively. This difference is lower than in 3 days.

The lower early-age compressive strength is mainly due to a delay in calcium-silicate-hydrates (C-S-H) formation. At an early age, the pozzolanic reaction in concrete is mainly contributed by the hydration of cement. For concrete with HVFA, the cement content is replaced by Fly ash, which in this research varies from 40% to 50%. Due to this replacement, there are fewer cement particles available for hydration compared to the control mixture. Therefore, the compressive strength became much lower.

As an increase of curing days, the strength gain of concrete with HVFA and HVBA starts to occur. The results of compressive strength at later ages are shown in Figure 11. In this stage, the fly ash contributes to the pozzolanic reaction which results in higher compressive strength gain in 28 and 56 days. In 28 days, the compressive strength differences of samples FB1, FB2, and FB3 with the control mixture reached 8%, 14%, and 20%, respectively. This compressive strength is still lower than the control mixture, even though the differences became smaller. As the target strength of this mixture is 25 MPa, only the FB1 complies with the targeted compressive strength. However, the other sample (FB2 and FB3) still has lower strength than the targeted compressive strength. In 56 days of curing age, FB1 starts to gain more strength which results in slightly higher compressive strength compared to the control mixture. However, for the FB2 and FB3 samples, the strength is still lower than the control mixture. The compressive strength differences of samples FB2 and FB3 with the control mixture reach 8% and 12%, respectively.

The enhanced compressive strength of concrete incorporating HVFA and HVBA at later ages is affected by several factors such as the alkalinity of the amorphous content of SiO_2 and Al_2O_3, the specific surface area of the Fly Ash. Furthermore, the Bottom Ash content which has similar chemical properties compared with fly ash also helps to enhance the compressive strength of the concrete. Cheriaf and Singh and Rafieizonooz observed that the consumption of portlandite by pozzolanic action of CBA between 28 d and 91 d was notable [4,22,41].

3.2.3. Splitting Tensile Strength

The tensile test was conducted as per ASTM C 496 [32]. Based on the result shown in Figure 12, it was found that concrete with HVFA and HVBA has a lower splitting tensile test than the control mixture at 28 days. The average splitting tensile test in 28 days for the control mixture is 3.38 MPa which is 10% higher than FB1. Furthermore, the sample FB2 and FB3 have 19% and 31% lower splitting tensile test compared to the control mixture. At this relatively early age, the tensile strength is still low mainly due to a delay in calcium-silicate-hydrates (C-S-H) formation. The pozzolanic reaction in concrete is mainly contributed by the hydration of cement, so for the concrete with HFVA, the cement content is lower resulting in low C-S-H formation.

3.2.4. Flexural Strength

For this test, the sample is a beam with 150 x 150 x 600 mm dimension. The flexural strength of all samples was evaluated, and the result is shown in Figure 13. Compared to the control mixture, the samples FB1, FB2, and FB3 have lower flexural strength. The sample FB1 has 5% lower flexural strength, while the FB2 and FB3 have 10% and 11% differences in flexural strength compared to the control mixture, respectively.

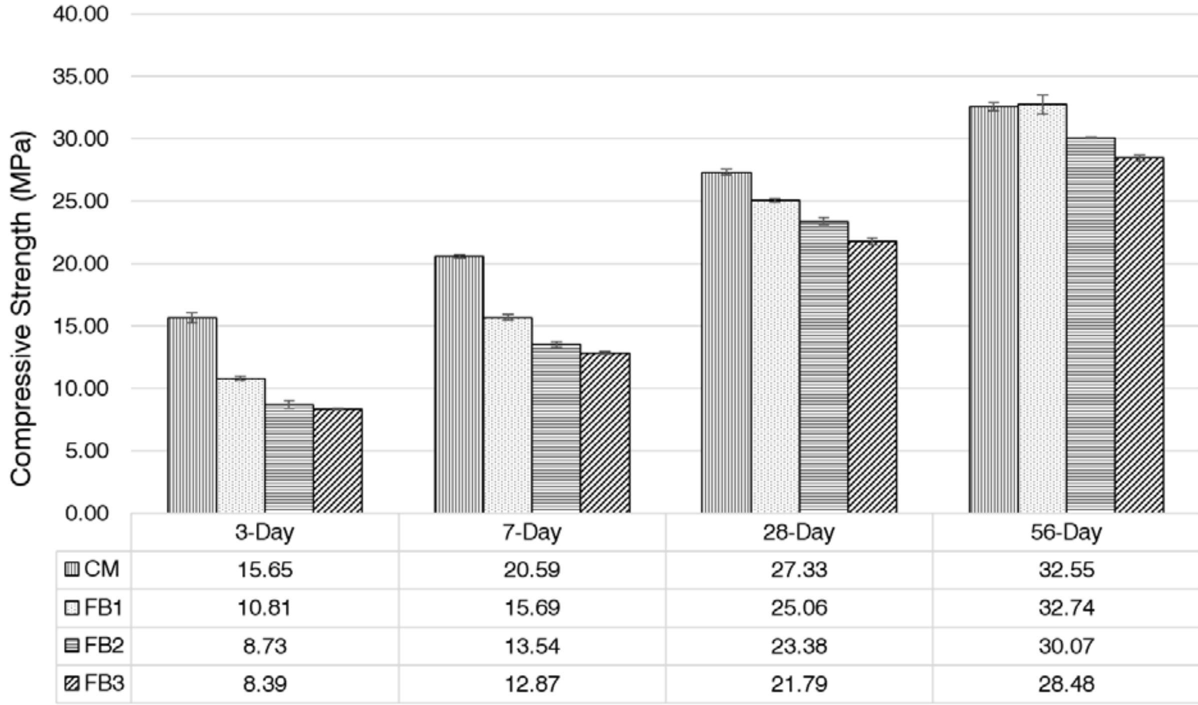

Figure 11. Average Compressive Strength

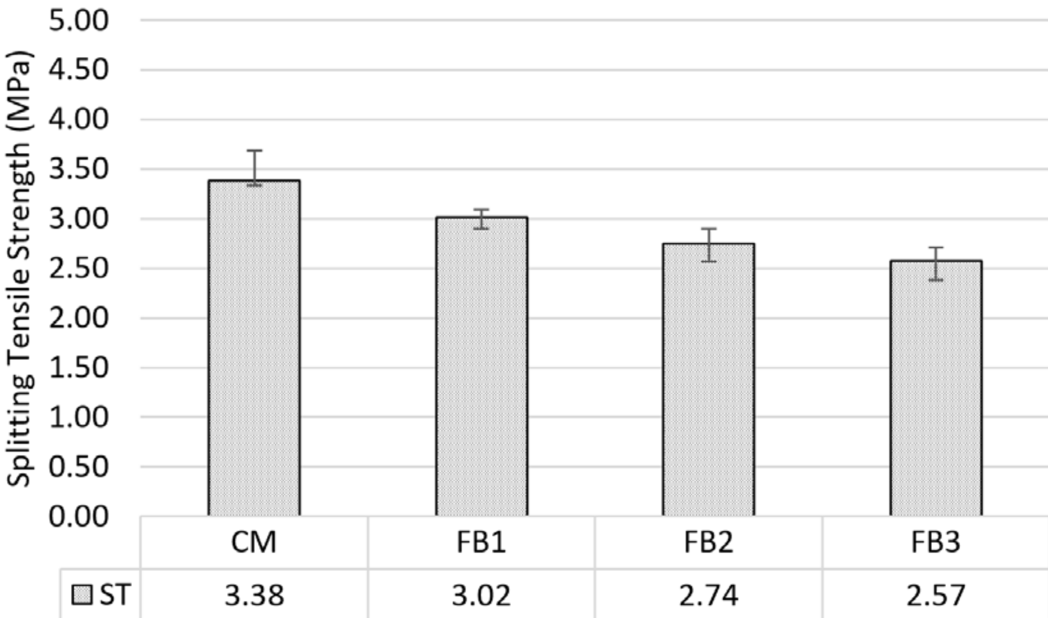

Figure 12. Splitting Tensile Strength Result

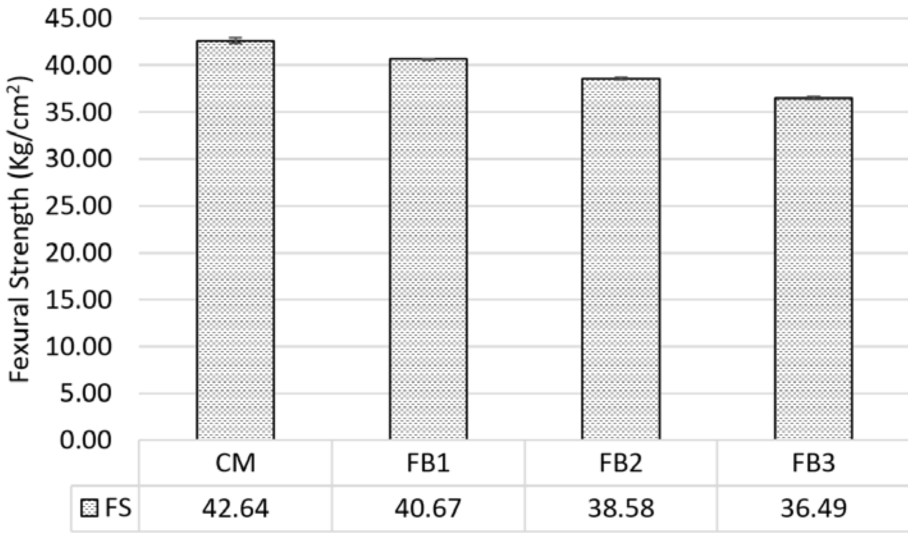

Figure 13. Flexural Strength Test Result

3.3. Case Study: Village-Owned Enterprise Building in Sumberejo Village - Paiton

3.3.1. Project Overview

This project is located in Sumberejo Village Paiton, East Java, Indonesia, which is the area around the PLTU Paiton, which is the coal power plant in the Paiton area. This coal power plant is the largest power plant that supplies electricity in the Java and Bali areas. From these operational results, around 130 thousand tons of Fly Ash and Bottom Ash (FABA) were produced from the combustion process of coal annually. The massive use of FABA is still very limited because until the last 2-3 years, according to Indonesian regulations, FABA was still classified as toxic and hazardous waste, so its use was still very limited and had to be under strict supervision. However, after FABA was no longer classified as toxic and hazardous waste, its application increased quite significantly, especially in construction materials such as pavement and brick. Therefore, in this research, the utilization of FABA as a structural material for buildings can begin to be applied directly.

In this research, FABA is used as a building material, especially structural components, such as strap beams for foundations, beams, and columns. The Paiton area is an area prone to high earthquakes, so the selection of concrete strength criteria is also designed to meet the requirements of SNI 2847 and ACI 318 [29] for special moment-resisting frame structures. The building built as a case study in this research is the Village-Owned Enterprise Building which will later be used by the village to develop a business related to the use of FABA as a building material in collaboration with PT. PLN (Persero) which is the holding company of PLTU Paiton. This building is a one-story building that has a design similar to typical residential housing in Indonesia. It is also a pilot project in this area, which incorporates the use of HVFA and HVBA for residential buildings. The building has a 6 x 6-meter square area and has a minimalist design to accommodate the activity in that building. Figure 14 presents the design of the building which consists of the main building, garden, and carport. This building has a customized design to accommodate the function of the building.

Figure 14. Design of the Building

3.3.2. Design of the Building

The concrete mixture for structural elements was selected from the result of the laboratory testing performed prior to the construction. Based on the results of the evaluation of the concrete quality shown in Chapter 2.5, the FB1 concrete which consists of 40% of FA and 50% of BA was used in this research. This variation has a laboratory compressive strength of 25.06 MPa in 28 Days which meets the requirements of ACI 318 for concrete used in special moment resisting frame structures. The wall non-structural elements were also made from fly ash, but it was not covered in this research.

The cross-section dimensions of the column used in this research are 220 x 220 mm. The column was designed to have a cut in the inner side to accommodate the interlock between the column and the wall. Furthermore, the beam used in this research has cross-sectional dimensions of 150 x 200 mm. The reinforcement was designed using a deformed bar with a 13 mm diameter. The shear reinforcement for concrete for the column and beam used reinforcements with 8 mm diameter with spacing of 150 and 100 mm, respectively.

3.3.3. Design of the Building

Concrete production and casting for structural elements were performed using the cast-in-place method. For each batch, the slump of the concrete was checked, and the sample was taken to the laboratory and tested to ensure the concrete quality. The sample taken to the laboratory consists of 6 sample 150 x 300-mm cylinder specimens for each batch and tested at 28 days. The concrete was cast by pouring concrete into formwork manually. Based on the field observations, the concrete has good consistency. The slump test for all concrete batches meets the requirements of the design slump. The result of the concrete compressive strength and slump test for each batch is shown in Table 5.

Table 5. Compressive and Slump Test Results of Field Specimens

No	Batches	Elements	28 Days					Slump mm	Average Slump (Element) mm
			Compressive Strength MPa	Average Compressive Strength (Batch) MPa	Average Compressive Strength (Element) MPa	Standard Deviation (Batch) MPa	Standard Deviation (Element) MPa		
1	Batch 1	Strap Beam	24.53 25.78 25.38	25.23	25.10	0.64	0.39	98.00	100.33
2	Batch 2	Strap Beam	24.89 25.36 24.90	25.05		0.27		101.00	
3	Batch 3	Strap Beam	25.29 25.07 24.70	25.02		0.30		102.00	
4	Batch 4	Column	25.42 25.46 24.74	25.21	25.35	0.41	0.34	95.00	96.00
5	Batch 5	Column	25.09 25.73 25.75	25.52		0.38		96.00	
6	Batch 6	Column	25.22 25.08 25.64	25.31		0.29		97.00	
7	Batch 7	Beam	25.73 24.63 24.75	25.04	25.04	0.60	0.42	102.00	101.33
8	Batch 8	Beam	24.79 25.53 24.75	25.02		0.44		103.00	
9	Batch 9	Beam	25.49 24.73 24.95	25.06		0.39		99.00	

Furthermore, there was also no bleeding and segregation observed while casting the concrete. After casting and removing the formwork, a wet cover was used for curing the concrete. The construction process of concrete is shown in Figure 15. After constructing all concrete structural elements, finishing works were performed to preserve and protect the materials and thereby increase the life span of the materials. The final product of the building is shown in Figure 16.

Figure 15. Construction Process of Concrete for Strap Beam, Column, and Beam

Figure 16. Final Product of the Village-Owned Enterprise Building

4. Conclusions

Concrete properties containing HVFA and HVBA were evaluated through a series of experimental investigations. From the results, the following conclusions can be drawn:

1. The slump test shows that using 40% of FA and 50% of BA can enhance the slump value of the concrete. However, using more BA content in the concrete can reduce the slump value due to its particle characteristics.
2. Using HVFA and HVBA in concrete reduces the early-age compressive strength. However, due to increases in pozzolanic activity at later ages, the strength is improved. It is observed that the compressive strength of sample FB1 has equal strength compared to the control mixture in 56 days, while other samples containing more FA and BA still had lower compressive strength.
3. The tensile strength of the concrete containing HVFA and HVBA in 28 days is still lower than the control sample due to a delay in calcium-silicate-hydrates (C-S-H) formation.
4. Similar to tensile strength, the flexure strength of the concrete containing HVFA and HVBA in 28 days is lower than the control sample.
5. The field application of HVFA and HVBA in the pilot project in Paiton East Java, Indonesia, shows no notable differences between the laboratory and field compressive strength. The consistency of the concrete was also observed to be good, indicated by the slump test value, which meets the requirements of the design slump.

Acknowledgments

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