Sorptivity Analysis of Lightweight Concrete Based on Fly Ash and Bottom Ash

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Abstracts: Lightweight concrete has a density lower than conventional concrete, which ranges between 1,400-1,800 Kg/cm3. The use of lightweight concrete as a more sustainable construction material continues to be developed to reduce the weight of the building. Fly ash as a residue from coal combustion has a high SiO2 content as a cement substitute. Bottom ash with a light density can also be used as a substitute for fine aggregate. Sorptivity test in lightweight concrete aims to determine concrete's ability to absorb water and how the pores in concrete behave. Sorptivity testing was carried out by a 5x5x5(cm3) mortar sample that was immersed in water. Then the mortar was weighed based on time intervals of 1, 5, 10, 20, 30, and 60 minutes, then continued for 2, 3, 4, 5, and 6 hours and 1, 2, 3, 4, 5, 6, 7, and 8 days. The results showed that the use of fly ash and bottom ash could increase the sorptivity value in the mortar up to 0.45%, where the function of the fly ash and bottom ash is to fill the pores in the mortar so that the water content that seeps into the mortar is reduced. Thus, the use of fly ash and bottom ash to support ecologically friendly and lighter building results in more sustainable material properties.

Keywords: Lightweight Concrete, Fly Ash, Bottom Ash, Sorptivity.

1. INTRODUCTION

Lightweight concrete is concrete that has a lower density than conventional concrete. The specific gravity of lightweight concrete ranges from 1200-1800 kg/m^3 [1]. According to [2], the specific gravity of lightweight concrete ranges from 1440-1840 kg/m^3. Lightweight concrete has various advantages over conventional concrete: a lighter specific gravity, reduced building weight, and a relatively low thermal conductivity. The strength and durability of concrete are the most important parameters to determine the service life and serviceability of the structure. The durability is mostly determined by the penetrating ability of water, chloride ions, sulfate ions, alkaline ions, and acids.

Indonesia's current electricity needs are supplied from coal and fossil fuel sources as well as rock and renewable energy. PLTU (Steam Power Plant) was an electric generator with coal fuel. The process of burning coal not only produces steam but also produces ash from combustion or coal ashes. Coal ash can be divided into two groups based on the size of the constituent particles, which are fly ash and bottom ash. Fly ash is a waste product from burning coal that flies in the air, while bottom ash is a combustion product from the bottom of the furnace [3]. Fly ash is waste that can replace cement as a cementitious material in concrete and bottom ash replaces sand in concrete. Fly ash particles are usually spherical and small in size. Fly ash ranges from 1 μm to μ150 m. The content in fly ash is determined by the source and method of coal burning carried out [4].

Fly ash has a silica (SiO_2) and aluminum oxide (Al_2O_3) content at a high level. Then, it could be categorized as a pozzolan material. SiO_2 dan Al_2O_3 was an important element in geopolimerization [5]. The utilization of fly ash could increase the concrete durability from chemical attacks due to C3A content decreasing while using fly ash

[6]. The use of waste material for construction sector, especially cement substitute material, has an important role in reducing the natural raw material consumption as the main source material and reducing the pollution from cement production. The composition of geopolymer concrete was fly ash, fine aggregate, and alkali solution, which is sodium hydroxide and sodium silicate as the activator [7]. The utilization of fly ash and bottom ash could produce lightweight concrete. The compressive strength that could be achieved was 14,3 MPa – 18,1 MPa with a density of

1661 kg/m^3–1688 kg/m^3 [8].

Bottom ash is a combustion product with agglomerates that do not fly into the air. Bottom ash is more suitable when used as a substitute for coarse aggregate or fine aggregate. Sawant et al [9] has studied that the substitution of bottom ash as fine aggregate could decrease the concrete’s workability. This is due to irregular shape and high porosity on bottom ash. For the fine aggregate, the porosity of the aggregate has been reduced in the manufacturing process, so it has less effect on the slump. In addition, concrete density decreases linearly with the increasing use of bottom ash in the concrete mix.

The strength and durability of concrete are the most important parameters to determine the service life and serviceability of the structure. Sorptivity is a measu re of a medium's capacity to absorb or remove liquids by capillary action. Capillarity is the medium that connects the voids in the concrete. Sorptivity in concrete is closely related to three things: absorption, permeability, and porosity. The Sorptivity test was carried out by following the procedure in standard ASTM C 1585-04.

Sorptivity is the easiest way to measure the characteristics of a material that expresses the nature of the tendency of a porous material to absorb and carry water through the capillaries. Sorptivity tests indicate the volume of voids and the ability of water to penetrate the concrete [10].

The utilization of fly ash and silica fume in concrete mix design has shown a significant reduction of water absorption and sorptivity [11-14]. The water-to-cement ratio in the mix has a significant role to increase the concrete compressive strength. However, there is no direct relationship between sorptivity and compressive strength.

The addition of fly ash in the concrete could decrease the concrete mechanical properties, but in the other hand it improved the concrete durability. A high cement substitution by 70% with fly ash have a highest environtmental and durability index [13]. However, the substitution above 30% of cementitious material could have a worse behaviour than the conventional concrete [9].

Fly ash positively impacts the coefficient of the concrete's sorptivity. The addition of fly ash reduces the sorptivity of the concrete, but contrary with sawant et al [9] study. The increasing amount of fly ash and bottom ash in concrete mix led to increased of sorptivity. The curing conditions of the concrete influence the sorptivity of the concrete. Mist treatment improves the sorptivity coefficient. Fly ash also reduces the permeability of the cement paste in the transition zone around the aggregate. Furthermore, the sorptivity of concrete can be reduced [15]. This study analyzes the sorptivity of lightweight concrete made from Fly Ash as a cement substitute and Bottom ash as a fine aggregate substitute. The utilization of waste material such as fly ash and bottom ash could improve the sustainability issues in South Sumatera, especially in concrete material study.

2. MATERIALS AND METHODS

2.1. Fine Aggregate Test

The materials used in this research are class F fly ash according to ASTM C 618, bottom ash, type 1 cement, fine aggregate from Tanjung Raja, and distilled water.

Table 1. Fine aggregate test results

No	Material Properties Test	Result Test
1.	Specific Grafity and Absorption	
	a. Bulk Specific Grafity (Dry Condition)	2,178
	b. Apparent Specific Grafity	2,317
	c. Bulk Specific Grafity (SSD Condition)	2,239
	d. Percentage of Water Absorption (%)	2,886
2.	Moisture Content (%)	3,709
3.	Unit Weight	
	a. Compact Condition (kg/ltr)	1,414
	b. Loose Condition (kg/ltr)	1,256
4.	Sieve Analysis	
	a. Maximum Size (mm)	9,500
	b. Grade Area Number	4
	c. Fineness Modulus	1,542
5.	Organic Impurites	
	a. The Samples are in Colour Number	3
6.	Clay Content	
	a. Clay Content (%)	3,399

Based on the results of the fine aggregate test shown in Table 1, that the fine aggregate filter results meet the requirements of ASTM C 33, so that the fine aggregate is suitable for use in concrete mixes.

The composition of the mixture used is the percentage of fly ash used as a cement substitute of 10%, 20%, 30%, and 40% of the total weight of cement and bottom ash used as a substitute for fine aggregate is 30%, 40% and 50% of the total weight of fine aggregate.

Details of the composition of the mixture can be seen in Table 2.

2.2. Fly Ash and Bottom Ash Test Results

The test that carried out for fly ash and bottom ash was X-ray Diffraction (XRD), X-ray Fluorescence (XRF), and Scanning Electron Microscope (SEM).

For XRF test on fly ash bottom ash is shown in Tabel 2 and Table 3. Total of 74,95% for SiO_2, Al_2O_3, and Fe_2O_3 based on Table 2. Following the ASTM C 618, the fly ash is classified in class F.

Table 2. Fly ash chemical composition based on XRF test

No.	Chemical Composition	Percentage (%)	ASTM C 618 Class F (%)	
1.	SiO2	46,53	min (1+2+3)	70
2.	Al2O3	22,53		
3.	Fe2O3	5,89		
4.	CaO	3,66	Max.	10
5.	Na2O	3,48		
6.	MgO	1,36		
7.	SO3	1,13	Max.	5
8.	K2O	0,882		
9.	TiO2	0,700		
10.	P2O5	0,285		
11.	MnO	0,054		

Table 3. Bottom ash chemical composition based on XRF test

No.	Chemical Composition	Percentage (%)
1.	SiO2	65,73
2.	Al2O3	24,19
3.	Fe2O3	4,63
4.	CaO	1,02
5.	Na2O	0,665
6.	MgO	0,486
7.	SO3	0,0646
8.	K2O	0,803
9.	TiO2	0,656
10.	P2O5	0,0559
11.	MnO	0,0399

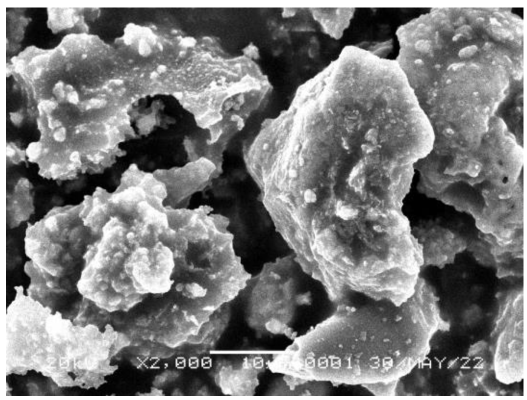


Figure 1. SEM result on fly ash

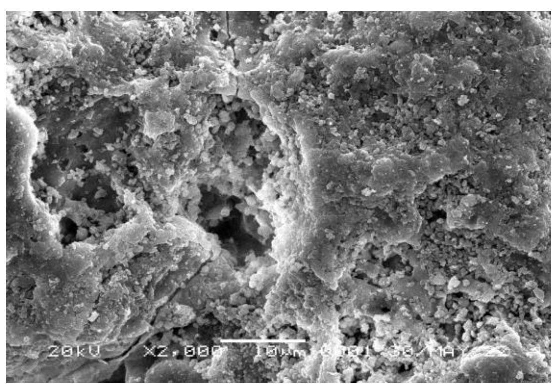


Figure 2. SEM result on bottom ash

Based on Figure 1. and Figure 2., the results of SEM testing with a particle magnification of 2000x show that fly ash and bottom ash particles have a plate-like structure with irregular shapes and different sizes. SEM results also show that these particles have many pores, especially in fly ash material, this causes low workability and is very absorbent to water.

In XRD test which shown in Figure 3.and Figure 4. explained thaat the fly ash is composed by mineral Quartz (SiO2), Gismondine (CaAl2Si2O8.4H2O), Monetite syn (CaHPO4) and Wadsleyite syn (Mg1.5Fe0.5 SiO4) with area crystalline index 37,078 %. Bottom ash is composed by mineral Quartz (SiO2), Coesite (SiO2), and Wairakite (Ca7.19Na1.12 (Si32.59Al15.38O96) (H2O)16) with area crystalline index 39,252 %,. Based on this, it shows that the bottom ash crystal phase index is more dominant than the fly ash crystal phase index

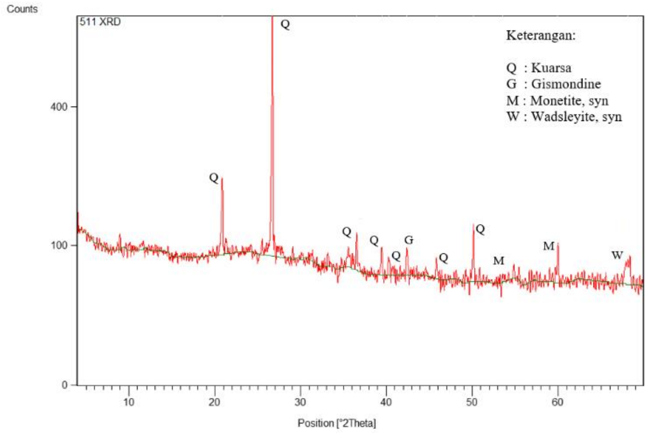


Figure 3. XRD test result on fly ash

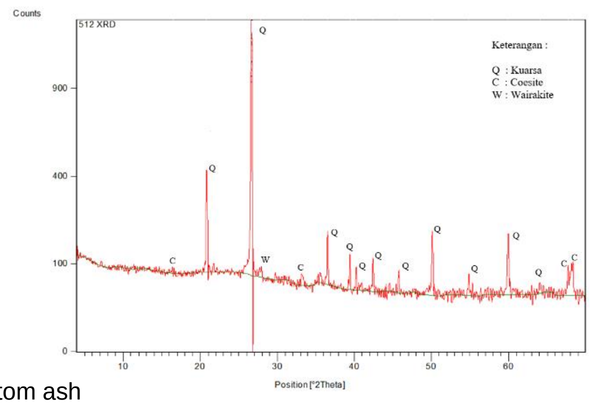


Figure 4. XRD test result on bottom ash

Table 4. Composition of a mixture of fly ash and bottom ash

No	Specimen	Cement (gr)	Fly Ash(gr)	Bottom Ash(gr)	Fine aggregate (gr)	Water (ml)
1.	FB0000	500	0	0	1375	242
2.	FB0050	500	0	687,5	687,5	242
3.	FB1040	450	50	550	825	242
4.	FB1050	450	50	687,5	687,5	242
5.	FB2030	400	100	412,5	962,5	242
6.	FB2040	400	100	550	825	242
7.	FB2050	400	100	687,5	687,5	242
8.	FB3040	350	150	550	825	242
9.	FB3050	350	150	687,5	687,5	242
10.	FB4030	300	200	412,5	962,5	242
11.	FB4040	300	200	550	825	242
12.	FB4050	300	200	687,5	687,5	242

2.3. Method

The initial stage of the research was testing the material properties of the concrete mixture. The test object is cast in a cube mold, measuring 5 cm x 5 cm x 5 cm.

The mixing procedure began with mixing fine aggregate and cement with a mixer, then add fly ash and bottom ash with the composition referring to the mix design. Next, add water and superplasticizer to the mixture. The mixture is stirred for approximately 5 minutes until evenly distributed. After the mixing is complete, the mixture is cast into a cube mold measuring 5 cm x 5 cm x 5 cm, where each specimen of each mix design has 6 specimens. Then the mold was released after 24 hours. Then, the concrete is cured by wrapping the specimen with plastic wrap for 28 days.

The composition of the mixture used is shown in Table 4. The percentage of fly ash used as a cement substitute of 10%, 20%, 30%, and 40% of the total weight of cement and bottom ash used as a substitute for fine aggregate is 30%, 40% and 50% of the total weight of fine aggregate. The chemical Sikasim is employed to increase the workability of up to 3% of the total Portland cement, and the amount of water was adjusted to w/w of 0.9680. This stage involves putting a sample of the test object into the water in the pan with a maximum height of 3mm from the concrete foundation that has been provided specimen support so the concrete does not directly contact the pan's bottom.

Sorptivity testing was carried out with intervals of 1, 5, 10, 20, 30, and 60 minutes, followed by 2, 3, 4, 5, and 6 hours and 1, 2, 3, 4, 5, 6, 7, and 8 days. Sorptivity testing is done by weighing the mass of the test object. The mass weighing was carried out according to the time specified in ASTM C1585-04 regarding sorptivity.

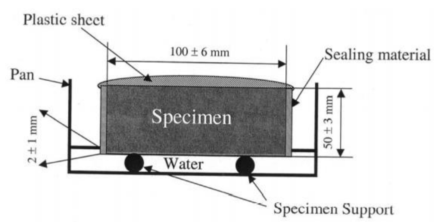


Figure 4. Sorptivity test sketch

3. RESULTS AND DISCUSSION

3.1. Density Test

Target density testing is carried out on cube specimens measuring 50x50x50 mm at the age of 28 days divided by the volume of the specimens. While the target of specific gravity to be achieved from Light Weight Concrete is in the range of 1440-1840 kg/m^3. The results of the specific gravity test can be seen in Figure 5.

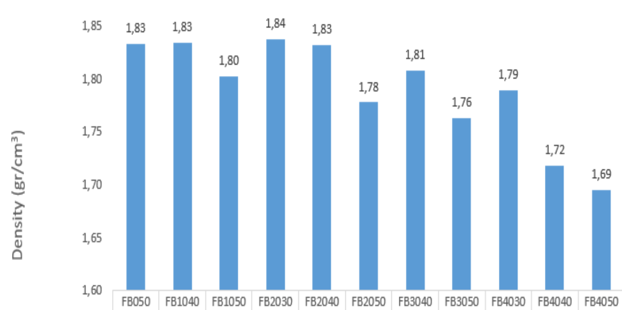


Figure 5. Density Test Result of Lightweight Concrete

Based on Figure 5, it shows that the density for all component is ranged from 1,69 – 1.83 g/cm^3, where the density is satisfied with the requirement of 1,44-1,84 g/cm^3.

The comparison between FB2030 and FB4030 shows that the addition of 20% fly ash made for the replacement of cement into fly ash for concrete with a 30% bottom ash content decreased the concrete's specific gravity by 2.60% or 0.05 gr/cm^3.

The effect of adding fly ash to concrete with a bottom ash content of 50% has shows that concrete FB0050 has a density of 1.83 gr/cm^3, then the density decreases to 1.69 gr/cm^3 in FB4050 concrete so that the decrease that occurs in this condition reaches 0.14 gr/cm^3 or by 5.96%.

3.2 Compressive Strength Test

The compressive strength test was carried out at 28 days of concrete mortar age with a cube sample size of 5x5x5 cm, while the compressive strength test results can be seen in Figure 6.

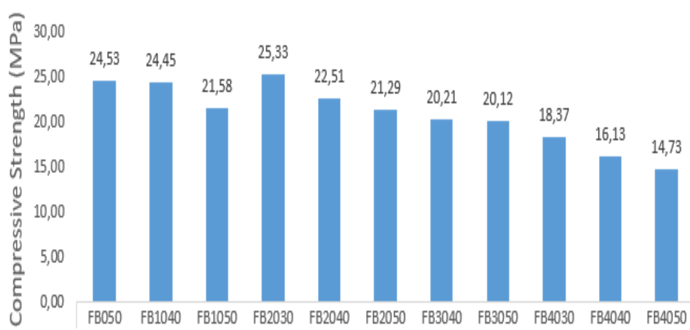


Figure 6. Compressive Strength Test Result

From the graph in Figure 6., it can be seen that concrete FB2030 has a concrete compressive strength of 25.33 MPa and for concrete FB4030, there is a decrease in compressive strength to 18.37 MPa. The addition of 20% replacement of cement with fly ash for concrete with a bottom ash content of 30% resulted in a reduced concrete compressive strength of 27.5%.

For FB1040, the compressive strength of concrete is 24.45 MPa and for concrete FB4040, there is a decrease in compressive strength to 16.13 MPa. The addition of 40% replacement of cement with fly ash for concrete with a bottom ash content of 40% resulted in a reduced concrete compressive strength of 7.94% to 20.20%.

The concrete FB0050 has a compressive strength of 24.53 MPa and for concrete FB4050, there is a decrease in compressive strength to 14.73 MPa. The addition of 40% replacement of cement with fly ash for concrete with a bottom ash content of 50% reduced concrete compressive strength up to 39.95%.

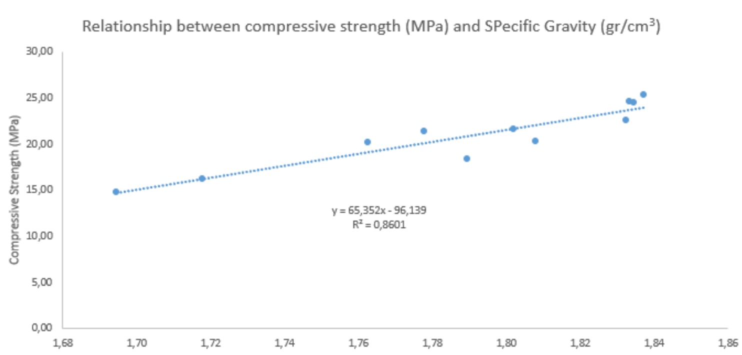


Figure 7. Relationship of Specific Gravity and Compressive Strength

3.3 Sorptivity Test Result

The test was carried out on 5x5x5 cm3 concrete and time intervals of 1, 5, 10, 20, 30, and 60 minutes, then continued for 2, 3, 4, 5, and 6 hours and 1, 2, 3, 4, 5, 6, 7, and 8 days

Tabel 5. Sorptivity Test Result

Time			FB 0000	FB 0050	FB 1040	FB 1050	FB 2030	FB 2040	FB 2050	FB 3040	FB 3050	FB 4030	FB 4040	FB 4050
days	sec	√time												
	60.00	8.00	0.04	0.02	0.02	0.02	0.01	0.01	0.05	0.00	0.04	0.03	0.03	0.06
	300.00	18.00	0.06	0.03	0.03	0.03	0.02	0.01	0.08	0.01	0.07	0.07	0.07	0.10
	600.00	25.00	0.07	0.04	0.05	0.05	0.03	0.01	0.10	0.02	0.08	0.10	0.10	0.13
	1,200.00	35.00	0.09	0.05	0.06	0.06	0.03	0.03	0.13	0.03	0.10	0.13	0.14	0.18
	1,800.00	43.00	0.10	0.06	0.08	0.07	0.04	0.03	0.15	0.04	0.12	0.16	0.18	0.21
	3,600.00	60.00	0.12	0.07	0.10	0.10	0.05	0.04	0.17	0.06	0.15	0.22	0.25	0.27
	7,200.00	85.00	0.14	0.10	0.14	0.13	0.07	0.05	0.21	0.09	0.19	0.32	0.38	0.37
	10,800.00	104.00	0.16	0.12	0.17	0.18	0.09	0.06	0.23	0.12	0.22	0.39	0.49	0.47
	14,400.00	120.00	0.18	0.14	0.20	0.22	0.11	0.07	0.25	0.15	0.25	0.44	0.57	0.55
	18,000.00	135.00	0.20	0.17	0.23	0.25	0.12	0.09	0.27	0.17	0.28	0.49	0.62	0.61
	21,600.00	147.00	0.21	0.18	0.24	0.28	0.13	0.10	0.28	0.19	0.29	0.52	0.65	0.64
1.00		304.00	0.33	0.32	0.38	0.46	0.14	0.26	0.44	0.41	0.47	0.60	0.67	0.68
2.00		440.00	0.36	0.36	0.43	0.49	0.18	0.30	0.47	0.45	0.53	0.61	0.68	0.68
3.00		519.00	0.39	0.37	0.43	0.49	0.19	0.30	0.46	0.47	0.55	0.63	0.69	0.70
5.00		658.00	0.38	0.37	0.43	0.49	0.19	0.33	0.47	0.47	0.55	0.63	0.69	0.70
6.00		727.00	0.39	0.38	0.43	0.50	0.20	0.33	0.47	0.48	0.56	0.63	0.70	0.71
7.00		789.00	0.40	0.38	0.43	0.50	0.20	0.34	0.48	0.48	0.56	0.64	0.71	0.72
8.00		832.00	0.38	0.38	0.44	0.50	0.21	0.34	0.48	0.48	0.56	0.64	0.71	0.72
Average			0.21	0.19	0.23	0.25	0.11	0.14	0.27	0.22	0.29	0.38	0.44	0.45

From Table 5, there is an initial mass of concrete mortar for all specimen. The I value or sorptivity value on each specimen is obtained from the table by dividing the mass difference by the surface area and density of the water.

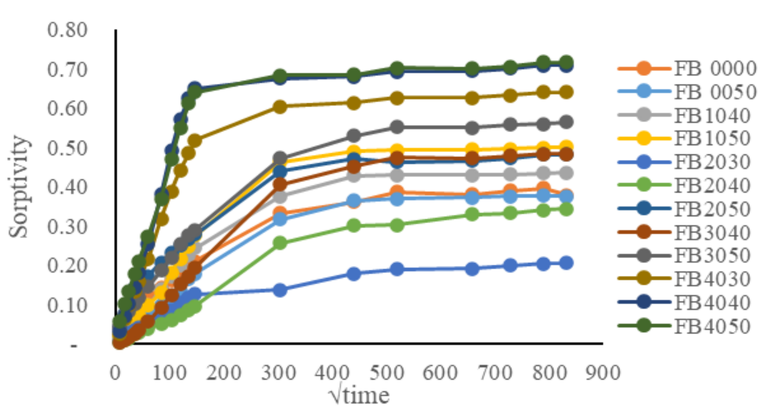
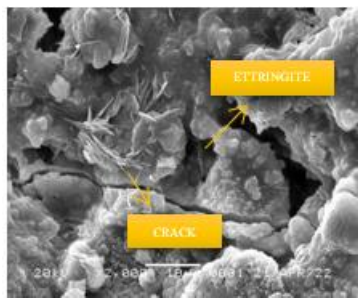


Figure 8. Relationship of Sorptivity and √time

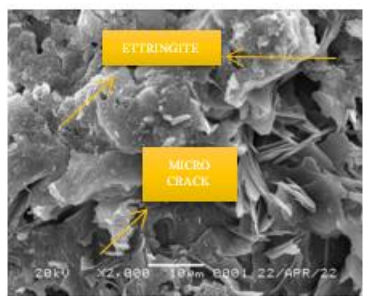
Figure 8. shows that water absorption is very high at the start of the sorptivity procedure. The increase occurred very high until the second day. After the sorptivity procedure was carried out for two days, the test object experienced an increase in mass caused by the absorption of water into the concrete through the pores in the concrete. On the second day, the mass addition of the specimens was less than on the first day. The addition of the mass of the test specimens occurred even less on the 3rd day because the concrete pores were filled with water.

3.4 The Result of Scanning Electron Microscope

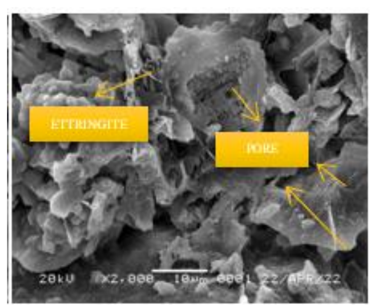
Figure 9 (a) is a concrete with a mixture of 0% fly ash and 50% Bottom ash, there are Crack and Ettringite formed in the mixture, the crack formed is caused by the high-water absorption capacity of bottom ash resulting in the concrete mixture during the manufacture of the test object experiencing a decrease in the water-cement ratio so that the concrete becomes dry and causes cracks.



(a)



(b)



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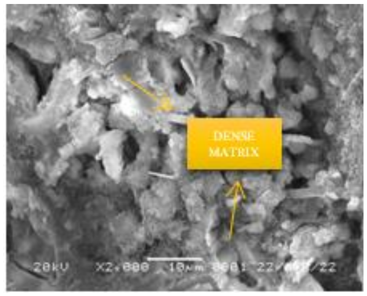
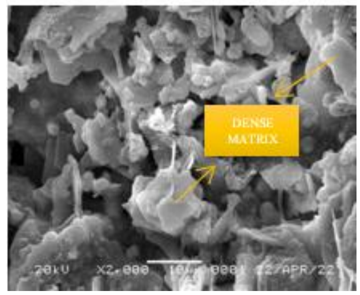
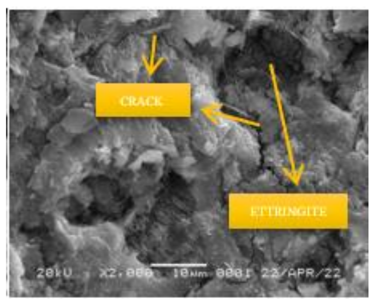


(d)



(e)

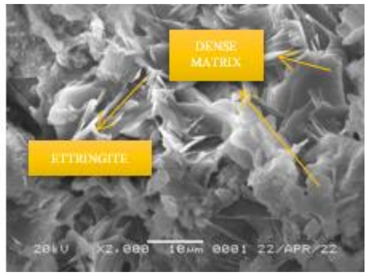


(f)

Figure 9. Result of Scanning Electron Microscope (SEM) (a) FB0050, (b) FB1040, (c) FB1050, (d) FB2030, (e) FB2040, (f) FB2050

Figures 9. (b) and (c) are concrete with the same fly ash content, namely 10% and different bottom ash content, namely (b) 40% and (c) 50%. From the figures, it shows a difference that occurs due to the addition of 10% bottom ash causes the concrete to have more cavities. This is also evidenced by the specific gravity of FB1050 concrete which is lighter than FB1040 concrete, and the sorptivity value of FB1050 concrete is greater than that of FB1050 concrete.

Figure 9. (d), (e), and (f) are concrete with the same fly ash conditions, namely 20% and bottom ash, namely 30% (d), 40% (e), and 50% (f). There is a dense matrix at the bottom ash content of 30% and 40% where the dense matrix indicates a good reaction from fly ash and bottom ash which is indicated by a smooth surface. Meanwhile, at the bottom ash content of 50%, the surface is rougher and brittle, and even cracks occur. This causes the concrete FB2050 to have a lower specific gravity and compressive strength than FB2030 and FB2040. The FB2050 concrete also has a higher sorptivity value, which means that FB2050 concrete has more pores than FB2030 and FB2040 concrete.


DENSE
MATRIX
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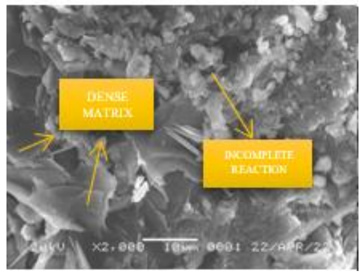
20kV X2,000 10μm 0001 22/APR/22

(a)


DENSE
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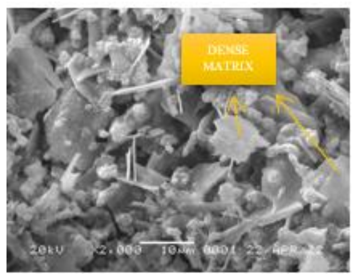
(b)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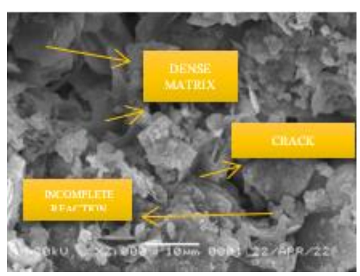
(c)


DENSE
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CRACK
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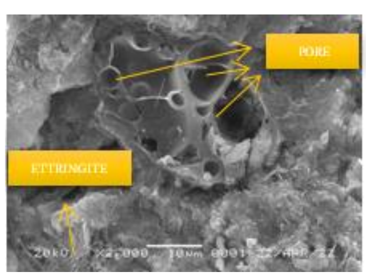
(d)


PORE
ETTRINGITE

(e)

Figure 10. Scanning Electron Microscope (SEM) results on (a) FB3040, (b) FB3050, (c) FB4030, (d) FB4040, (e) FB4050

Figure 10. (a) and (b) are concrete with the same mixture of fly ash, namely 30% and a different mixture of bottom ash, namely 40% (a) and 50% (b). Figure 10 (a) and (b) show that the FB3040 concrete has denser matrix than the FB3050 concrete, while the FB3050 concrete has an incomplete reaction which is indicated by the lumps in the picture. This is also evidenced by the results of the specific gravity and compressive strength of FB3050 concrete which is lower than that of FB3040 concrete. and the sorptivity value of FB3050 concrete is greater than that of FB3050 concrete.

In Figure 10. (c), (d) and (e) are concrete with the same mixture of fly ash, namely 40% and different mixtures of bottom ash, namely 30% (c), 40% (d) and 50% (f). The difference seen in this mixture is that there is denser matrix in FB4030 concrete, while FB4040 concrete has cracks and incomplete reactions so that the concrete has a lower compressive strength than FB4030. In FB4050 concrete there is ettringite which is indicated by a needle-like shape. Ettringite is formed as a result of the reaction of calcium in the concrete mixture with sulfate salts, the formation of ettringite makes the concrete volume larger and the concrete expands so that it can cause the concrete to crack and break. The FB4050 mixture has large pores as shown in Figure 10. (f), as a result, FB4050 concrete has the lowest specific gravity and compressive strength of concrete compared to other mixtures and the sorptivity value of the concrete is the highest compared to other concrete mixtures.

3.5 Relationship Between Density, Compressive Strength, And Sorptivity

Based on the test results of concrete density, compressive strength, and sorptivity, Table 12. summarize the test results of the concrete. Concrete with code FB2030 has the highest specific gravity and compressive strength with a specific gravity of 1.84 gr/cm3 and compressive strength of 25.33 MPa. Besides that, FB2030 concrete has the lowest sorptivity value, which means it has the lowest water absorption capacity.

Table 6. Summarize the test result of density, compressive strength, and sorptivity

No	Code	Density	Compressive Strength	Sorptivity
		Average	Average	Average
1	FB0050	1,83	24,53	0,19
2	FB1040	1,83	25,45	0,23
3	FB1050	1,8	21,58	0,25
4	FB2030	1,84	25,33	0,11
5	FB2040	1,83	22,51	0,14
6	FB2050	1,78	21,29	0,27
7	FB3040	1,81	20,21	0,22
8	FB3050	1,76	20,12	0,29
9	FB4030	1,79	18,37	0,38
10	FB4040	1,72	16,13	0,44
11	FB4050	1,69	14,73	0,45

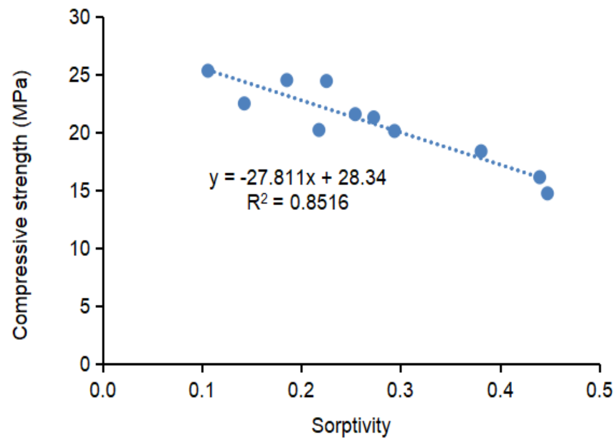


Figure 11. The relationship between compressive strength and sorptivity graph

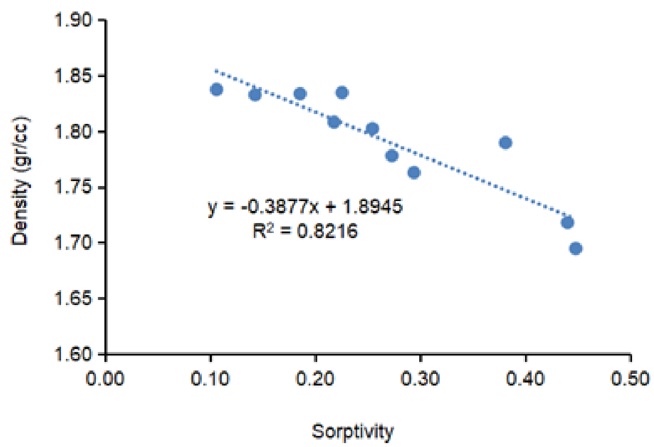


Figure 12. The relationship between density and sorptivity graph

Conclusion

The conclusion of the lightweight concrete with fly ash and bottom ash studies is shown below:

1. Using 10% more fly ash will reduce the density by 1.47-3.78%, while using 10% more bottom ash will reduce the density by 1.49 - 5.59%.

2. Using 10% more fly ash will result in a reduced compressive strength of 5.37% -16.99%, while using 10% more bottom ash will result in reduced compressive strength of 9.98 -16.38%.

3. Water absorption is very high at the start of the sorptivity procedure. The increase was very high until the first day. After the sorptivity procedure was carried out for one day, there was an increase in the mass of the test object, which was less than before. The addition of the mass of the test object occurs less on the second day because the pores of the concrete have been filled with water.

4. The most optimum and suitable concrete used as lightweight concrete is found in mixed concrete FB2030, where the concrete has a specific gravity of 1.84 gr/cm3 and is still included in lightweight concrete. FB2030 concrete also has the highest compressive strength of 25.33 MPa, and the sorptivity or absorption of the concrete is also the lowest.

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