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The Effect of Water Binder Ratio and Fly Ash on the Properties of Foamed Concrete

Saloma[1, a)], Hanafiah[1, b)], and Dea Urmila[2, c)]

[1]*Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Palembang-Prabumulih KM. 32 Street, Ogan Ilir District, Sumatera Selatan, Indonesia*
[2]*Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Palembang-Prabumulih KM. 32 Street, Ogan Ilir District, Sumatera Selatan, Indonesia*

[b)] Corresponding author: hanafiah_dr@yahoo.com.sg
[a)] saloma_571@yahoo.co.id
[c)]deaurmila@gmail.com

Abstract. Foamed concrete is a lightweight concrete composed by cement, water, fine aggregate and evenly distributed foam. Foamed concrete is produced by adding foam to the mixture. The function of foam is to create air voids in the mixture, so the weight of the concrete becomes lighter. The foaming agent is diluted in water then given air pressure by foam generator to produce foam. This research utilizes coal combustion, which is fly ash as cementitious material with a percentage of 0%, 10%, 15%, and 20%. The purpose of the research is to examine the effect of water binder ratio 0.425, 0.450, 0.475, and 0.500 using fly ash on the properties of foamed concrete. Fresh concrete tests include slump flow and setting time test while hardened concrete tests include density and compressive strength. The maximum value of slump flow test result is 59.50 cm on FC-20-0.500 mixture with w/b = 0.500 and 20% of fly ash percentage. The results of the setting time tests indicate the fastest initial and final time are 335 and 720 minutes, respectively on FC-0-0.425 mixture with w/b = 0.425 without fly ash. The lowest density is 978.344 kg/m^3 on FC-20-0.500 mixture with w/b = 0.500 and 20% of fly ash percentage. The maximum compressive strength value is 4.510 MPa at 28 days on FC-10-0.450 mixture with w/b = 0.450 and 10% of fly ash percentage.

INTRODUCTION

Foamed concrete is a lightweight concrete composed by cement, water, fine aggregate and evenly distributed foam. Foamed concrete is produced by adding foam to the mixture. The function of foam is to create air voids in the mixture, so the weight of the concrete becomes lighter.

Foaming agent is a basic material to produce foam by given air pressure from foam generator. Foaming agent is composed of surfactant, a surface active substance that increase the water's ability to produce foam [1]. In general, there are two surfactant materials namely protein and synthesis surfactant. Protein surfactant is a substance from animal decomposition such as bones and skins while synthetic surfactant is a substance from chemical element.

Based on production method, foam can be formed either by preformed foam and mix-foaming. Preformed foam is made by mixing the foaming agent with water and compressed air to produce foam, then the foam is added to the mixture. Meanwhile, mix-foaming is made by added the foaming agent to the mixture then stirred until the foam becomes stable [2].

Foaming agent generates chemical reaction in the mixture while stirred, which forms bubbles in the mixture. Bubbles spread in the mixture and gradually merged in the hardened concrete. The compressive strength of foamed concrete decrease as the percentage of foaming agent increase. This is due to the increase of bubbles in the foamed concrete and the thinning of the bubbles membrane, so the bubbles break easily [3].

Fly ash is a fine residue generated from coal combustion and transported into the air by flue gasses [4]. According to the research [5], fly ash is one of the most widely used cementitious materials because it has chemical

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compositions similar to cement. The increase of fly ash substitution to cement decrease the compressive strength of foamed concrete. Therefore, fly ash percentage in foamed concrete is recommended to be not too high [3,6]. According to the research [7], the percentage substitution of fly ash should be 10 - 20% to the amount of cement. This indicates that there is a limit to use fly ash as cementitious material so it is not affecting the compressive strength. Therefore, the maximum percentage of fly ash in foamed concrete is 20% to the amount of cement [5].

Water cement ratio (w/c) is greatly influences both fresh and hardened properties of foamed concrete. Compressive strength of foamed concrete decreases as the w/c value increases [8]. Based on research [9], the maximum compressive strength of foamed concrete at 28 days is with w/c = 0.35 and 25% of foam percentage.

MATERIALS AND METHODS

This research used fly ash as cementitious material with a percentage of 0%, 10%, 15%, and 20%. Several of w/b value to be used are 0.425, 0.450, 0.475, and 0.500. The properties of foamed concrete tests include fresh and hardened properties. Fresh concrete tests include slump flow and setting time test while hardened concrete tests include density and compressive strength. Hardened concrete test used 10 x 20 cm cylinder mould. The samples were tested at 7, 14, and 28 days after curing. The test method for fine aggregate and compressive strength were according to the ASTM standard.

Foamed concrete is composed by cement, fly ash, fine aggregate, water and foaming agent. This research used OPC type I cement and fine aggregate passed sieve number 16 from Tanjung Raja. Foaming agent used is synthetic based surfactant.

This research used fly ash from Bukit Asam Inc, which is type F and passed sieve number 200. Fly ash chemical composition test was done at Semen Baturaja Laboratory, Palembang while fly ash sem test was done at Pusat Survei Geologi Laboratory, Bandung with 1000x magnification. The results of fly ash chemical composition and SEM test are shown in Table 1 and Fig. 1, respectively.

TABLE 1. Chemical composition of fly ash

Composition	Weight (%)
Silicon Dioxide (SiO_2)	52.96
Aluminum Oxide (Al_2O_3)	27.14
Iron (III) Oxide (Fe_2O_3)	5.00
Calcium Oxide (CaO)	5.00
Magnesium Oxide (MgO)	2.60
Sulfur Trioxide (SO_3)	1.20
LOI	-

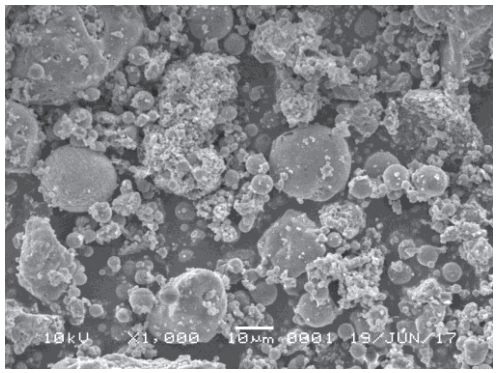


FIGURE 1. SEM microstructure fly ash

Mix proportion of foamed concrete was designed by modification based on ACI 523.3R "Guide for Cellular Concretes above 50 pcf, and for Aggregate Concretes above 50 pcf with Compressive Strengths Less than 2500 psi" and research journals. Foam percentage used is 50% by 1 m^3 foamed concrete volume. Ratio of foaming agent and water are 1:30 with a density of 50 kg/m^3. Fly ash as cementitious material serves to produce a secondary hydration process with a percentage of 0%, 10%, 15%, and 20% to the amount of cement. Several of water binder ratio value to be used are 0.425, 0.450, 0.475, and 0.500. Foamed concrete mixture composition used is shown in Table 2.

TABLE 2. Mix proportion of 1 m^3 of foamed concrete

Mix	OPC (kg)	*Fly ash* (kg)	Sand (kg)	*Foam solution*	
				FA (gr)	Water (kg)
FC-0-0.425	463.4	0.00	463.4	806.5	172.8
FC-10-0.425	417.1	46.3	463.4	806.5	172.8
FC-15-0.425	393.9	69.5	463.4	806.5	172.8
FC-20-0.425	370.7	92.7	463.4	806.5	172.8
FC-0-0.450	453.4	0.00	453.4	806.5	179.8
FC-10-0.450	408.1	45.3	453.4	806.5	179.8
FC-15-0.450	385.4	68.0	453.4	806.5	179.8
FC-20-0.450	362.7	90.7	453.4	806.5	179.8
FC-0-0.475	443.8	0.00	443.8	806.5	186.6
FC-10-0.475	399.4	44.3	443.8	806.5	186.6
FC-15-0.475	377.2	6.70	443.8	806.5	186.6
FC-20-0.475	355.0	88.8	443.8	806.5	186.6
FC-0-0.500	434.6	0.00	434.6	806.5	193.1
FC-10-0.500	391.1	43.4	434.6	806.5	193.1
FC-15-0.500	369.4	65.1	434.6	806.5	193.1
FC-20-0.500	347.7	86.9	434.6	806.5	193.1

RESULT AND DISCUSION

The Result of Fresh Concrete Test

Slump flow

The results of slump flow test are shown in Fig. 2 and Fig. 3. Slump flow test results ranged 48 – 60 cm. The value was obtained by the average measurement of diameter distribution in four orthogonal directions. The maximum slump flow value was 59.50 cm on FC-20-0.500 mixture with w/b = 0.500 and 20% of fly ash percentage. Meanwhile, the minimum slump flow value was 48.75 cm on FC-0-0.425 mixture with w/b = 0.425. Figure 2 shows that the lower w/b value decreases the slump flow result of foamed concrete. This was due to higher water content. Fig. 3 shows the increase of fly ash percentage from 0 to 20% along with the increase of slump flow. This was due to round microstructure of fly ash so it gives lubrication effect and minimize the friction. Meanwhile, fly ash hasn't high water absorption so it increases workability of foamed concrete.

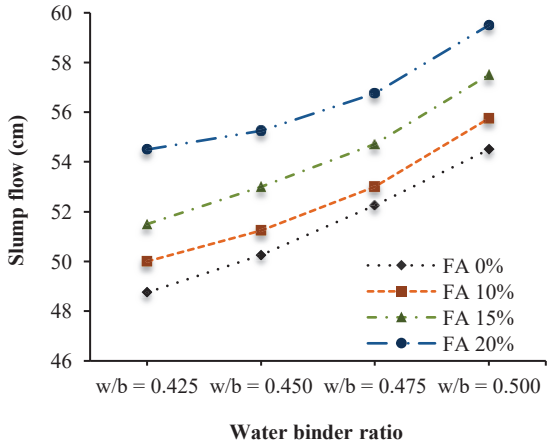


FIGURE 2. The effect of water binder ratio on slump flow

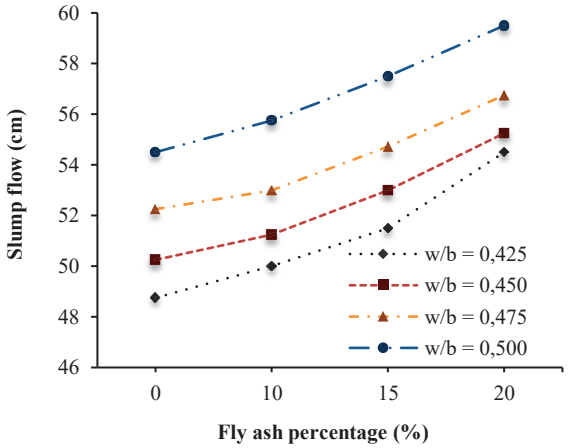


FIGURE 3. The effect of fly ash percentage on slump flow

Setting time test

The results of setting time test based on w/b variation are shown in Fig. 4 (a) and Fig. 4 (b) while based on fly ash percentage are shown in Fig. 5 (a) and Fig. 5 (b). Initial time results ranged between 335 – 430 minutes while final time results ranged between 720 – 815 minutes, respectively.

Figure 4 (a) and Figure 4 (b) show that the higher w/b value, the longer setting time of foamed concrete gets. This was due to higher water content cause the longer of cement hydration process, so the setting time of foamed concrete becomes longer.

Fig. 5 (a) and Fig. 5 (b) show that the higher w/b value, the longer setting time of foamed concrete gets. This was due to fly ash isn't produced hydration process when mixed with water, so the setting time of foamed concrete becomes longer.

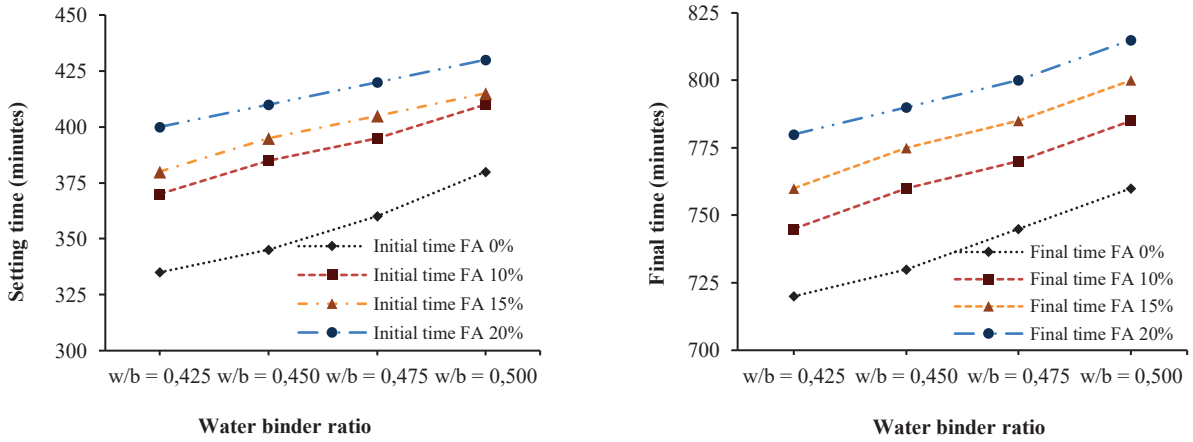
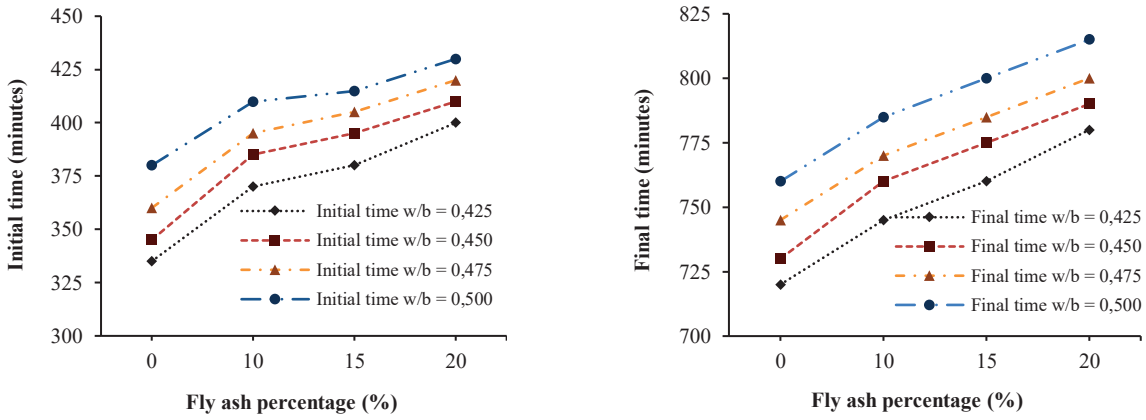


FIGURE 4. (a) The effect of water binder ratio on initial setting time (b) The effect of water binder ratio on final setting time



(a) (b)

FIGURE 5. (a) The effect of fly ash percentage on initial setting time (b) The effect of fly ash percentage on final setting time

The Result of Hardened Concrete Test

Properties of foamed concrete includes physical properties and mechanical properties. Physical properties test is density while mechanical properties test is compressive strength.

Density

The results of density based on w/b variation shown in Fig.6. Figure 6 shows that w/b variation affect density of foamed concrete at 28 days. The increase of w/b value decrease density resulted. This was due to higher water content in the concrete, so the weight of foamed concrete becomes lighter.

The results of density based on fly ash percentage shown in Fig. 7. Fig. 7 shows that fly ash percentage affect density of foamed concrete at 28 days. The increase of fly ash percentage decrease density resulted. Fly ash density is lower than cement density, so the higher fly ash substitution to cement decrease density of foamed concrete. The lowest density is 978.344 kg/m^3 on FC-20-0.500 mixture with w/b = 0.500 and and 20% of fly ash percentage.

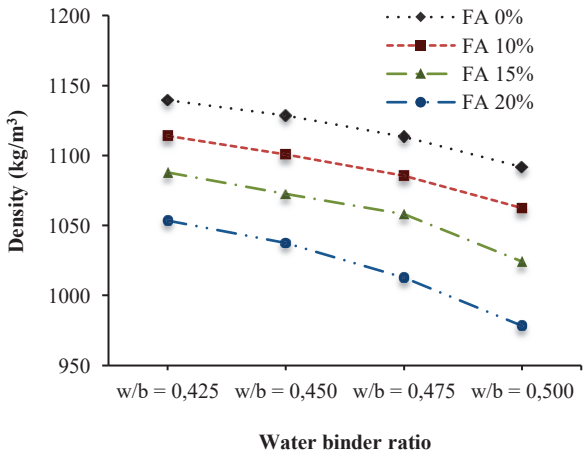


FIGURE 6. The effect of w/b variation on density at 28 days

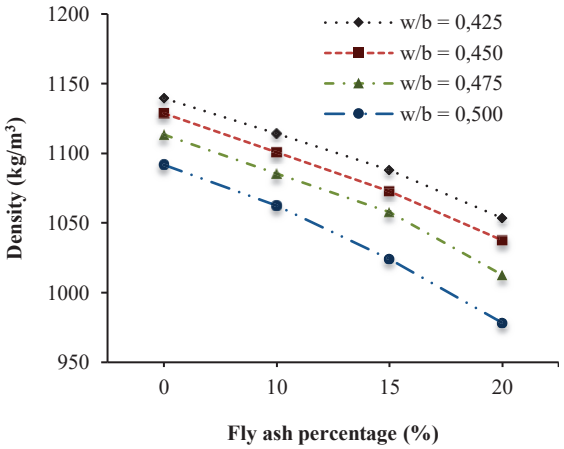


FIGURE 7. The effect of fly ash percentage on density at 28 days

Compressive strength

The results of compressive strength based on w/b variation shown in Fig. 8. Fig. 8 shows that the maximum compressive strength at 28 days is on w/b = 0.450 for all fly ash percentage. The increase of w/b value from 0.425 to 0.450 increases the compressive strength resulted significantly. This was due to well-formed pore structure because the setting time of foamed concrete matches the foam spread, so foam was evenly distributed in the mixture. When w/b value is lower than w/b maximum, the mortar becomes too stiff, so adding foam to the mixture was not evenly distributed. In addition, the low w/b value cause setting time becomes faster than foam spread time in the mixture.

The increase of w/b value from 0.450 to 0.475 decreases the compressive strength resulted significantly. It happens because the denseness of the mixture is low, so it breaks foam and creates pores in the concrete. In addition, the high w/b value cause setting time becomes longer than foam spread time in the mixture. It causes pores form capillary system, so the strength of pore structure in the concrete decreases which will decrease the compressive strength resulted.

The result of compressive strength based on fly ash percentage shown in Fig. 9. Figure 9 shows that the maximum compressive strength at 28 days is on 10% of fly ash percentage for all w/b values e.g. 0.425, 0.450, 0.475, and 0.500. The increase percentage of fly ash from 0% to 10% increases the compressive strength resulted significantly, then the increase percentage of fly ash from 10% to 20% decreases the compressive strength resulted significantly. This indicates that there is a limit to use fly ash as cementitious material. The increase in 10% percentage of fly ash increases the the compressive strength resulted because fly ash has function as filler so it fill pores in the concrete.

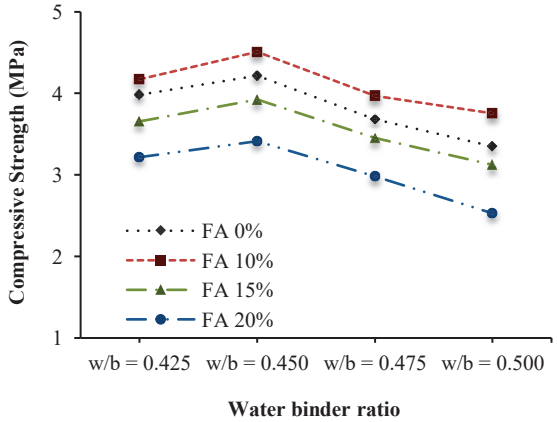


FIGURE 8. The effect of w/b variation on compressive strength at 28 days

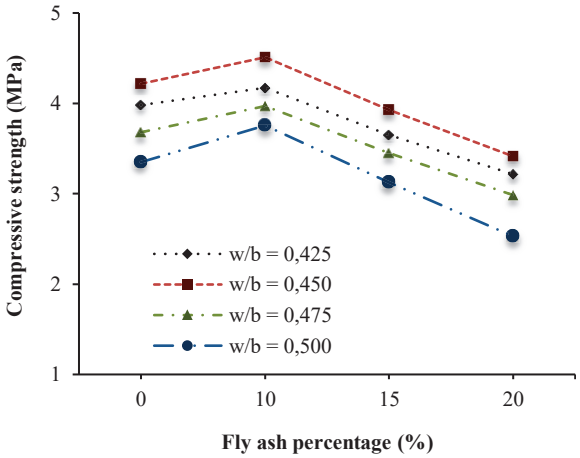


FIGURE 9. The effect of fly ash percentage on compressive strength at 28 days

CONCLUSION

Based on the research about the effect of water binder ratio and fly ash on the properties of foamed concrete, the results can be concluded as follow:

- The optimum composition foamed concrete mixture is on FC-10-0.450 mixture with w/b = 0.450 and 10% of fly ash percentage.
- The higher w/b value and the increase of fly ash percentage from 0 to 20% causes the larger slump flow, the longer setting time and the lower density of foamed concrete get.
- In this research, w/b = 0.450 gave the maximum compressive strength. Water binder ratio is greatly influenced the compressive strength resulted, w/b value above w/b = 0.450 decrease the compressive strength. Fly ash percentage is influences the compressive strength resulted also. In this research, 10% of fly ash percentage gave the maximum compressive strength.

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