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Investigation on Foam Volume/Fly Ash Relationship of Foam Concrete, and Effect of High Content Micro-Fibre and Microstructure

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Abstract

Foam concrete is the concrete that contains large amount of air voids inside. In general, the density of foam concrete depends on parameters like water/binder ratio, foam volume, aggregate and pozzolan content, etc. In this study, the effect of foam volume and fly ash content on dry density is investigated intensively in order to find the relationship between each parameter and their abilities to counteract with each other. According to the above information, though there are quite a number of studies on the effect micro fiber on foam concrete at low volume fractions, there is still lack of information especially on the high fiber content side [1,2]. Also the objective of study is to investigate further on the use of micro fiber at higher volume fraction and fill in the lacking information [3,4]. Beside from this study, the investigation of the effect of micro-fiber (polypropylene) to enhance the properties of foam concrete is also carried out [5,6,7]. Of the two variables that are investigated in this study, the foam volume and the fly ash content, show significant effect on the properties of foam concrete. The foam volume tends to decrease the density and strength of foam concrete. In the second part of our study, a large fiber volume fraction is proved to be able to evidently increase the flexural strength of foam concrete up to about 40% due to the effect of fiber bridging over the crack and a significant number of fibers that intercepts the crack surfaces. However, the compressive strength is found to decrease severely due to the occurrence of large pores as the result of fiber being added into concrete mixture.

Keywords: Foam Concrete; Foam Volume; Fly Ash Content; Dry Density; Micro Polypropylene fiber; Microstructure

INTRODUCTION

Various studies have been conducted on foam concrete mixed with fiber. Bonakdar reported that below 0.5 % of polypropylene microfiber, the fiber volume increased while the compression and flexural strengths decreased [8]. Awang reported increased flexural strength and tensile force with decreased compression strength when 0.25-0.40 % polypropylene microfiber was included in foam concrete [9]. Sukontasukkul studied the effect of glass fiber contents ranging from 0.05 to 0.15 % on foam concrete [10]. Both the compression and flexural strengths increased at 0.05 % content. With glass fiber contents exceeding 0.05 %, both the compression strength and flexural strength rapidly decreased [11,12]. On the other hand, Yamato reported a decrease in compression strength and an increase in flexural strength with low water/cement ratio (W/C) foam concrete [13]. In that case, a polyvinyl alcohol (PVA) fiber content of 0.35-1.14% was used and the ratio of foam to mortar (F/M) increased[14].

In this study, the influence of an increased amount of micro polypropylene fiber (MPF) on foam concrete is analyzed. The study is framed within the context of complementing the flexural strength of existing foam concrete, while further decreasing the compression strength by simultaneously adding the industrial byproduct, fly ash.

The objectives of the study are twofold. First, analyze the correlation between the fly ash substitution rate and the volume of foam concrete. Since the fly ash properties affect the foam structure, the weight increase due to the use of fly ash can be complemented by the amount of foam used. Also, a predetermined range of density can be achieved by employing a certain amount of foam.

Second, analyze the changes in the physical properties of foam concrete substituted with MPF. The pores within foam concrete limit its use for panel structures. To complement this, MPF was added to improve the physical properties. Additional changes in fine structure are also analyzed.

Currently, there is no domestic standard for foam concrete panels, aside from KS F 4736 (extrusion-molded lightweight concrete panel). It is imperative that the flexural strength exceeds 1.5 MPa if foam concrete is to be used as a panel.

METHOD AND MATERIALS

Materials

1) Foaming agent

The foaming agent used in this study is a stand-alone foam type. The chemical and physical properties of the foaming agent are shown in Table 1.

Table 1: Physical properties of foaming agent

Color	Viscosity (CPS)	pH	sulphate (%)	freezing point(℃)	Specific gravity
Brown	20 ~ 50	7	0.01 ~ 0.1	-18	1.2 ~ 1.26

(Unit: %)

Water	Protein	NaCl	NH_4Cl	CaCl	MgCl	$FeSO_4$
36	32	10	1	6	5	10

2) Cement and Binder (fly ash)

Table 2: Chemical composition and physical properties of cement

Chemical composition	Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Lg. loss
	Content (%)	21.95	6.59	2.81	60.12	3.32	2.11	2.58
Physical Properties	specific surface area (cm^2/g)	Weight		Setting time		Compressive Strength (kg/cm^2)		
				Start	Ending	3days	7days	28days
	3.112	3.14		4hours	6hours	198	272	389

Table 3: Chemical composition and physical properties of fly-ash

Chemical composition					Physical Properties		
Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	Weight	Fineness (cm^2/g)	Grain size
Content (%)	92.5	1.68	2.51	0.56	2.21	263,000	1.36.

3) Micro Polypropylene Fiber

Table 4: Properties of Fiber

Length (mm)	Material	Tensile Strength (MPa)	Elastic Modulus (MPa)	Specific Gravity	Melting Temperature (℃)
6	Polypropylene	459	5097	0.91	160
25	Polypropylene	425	5906	0.91	165
35	Polypropylene				

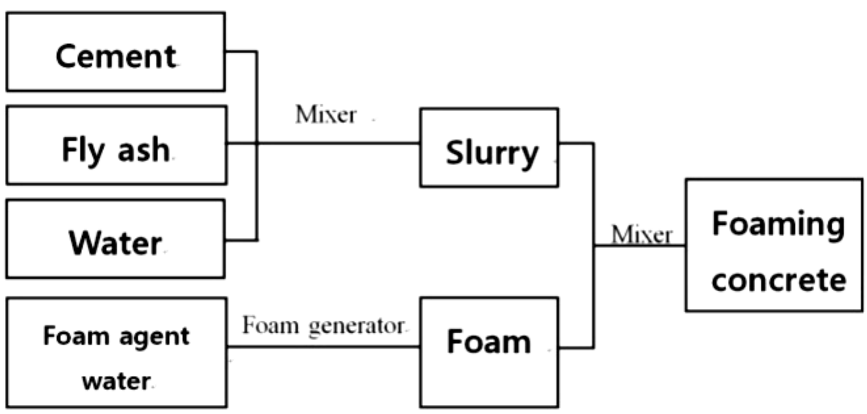

Figure 1: Foamed concrete mixing process

Mix proportion

The mixing procedure comprises two stages, as shown in Figure 1.

Stage 1: Determine the optimum mix ratio between the foam volume of foam concrete and fly ash substitution rate. This includes evaluating foam volume, fly ash substitution rate, and water/binder ratio (W/B) with respect to the physical properties of the foam concrete.

The fly ash influenced 10-50%, with its substitution rate or volumetric substitution in mix proportion. Thus, the volume of foam was changed with the volume of the mixed paste. In the initial mixing, the foam volume was adjusted to 59.1 %. It was then changed to 56.2-62.5 %. The water content was set as 0.50 %, and the changes of fly ash substitution and foam volume were applied within the range of 0.443 to 0.578 %. The optimum mixing ratio in Stage 2 was adjusted, based on the highest compression strength within the apparent specific gravity of 1,000 kg/m3. This was done to satisfy the mechanical and physical properties of KS F 4736 (extrusion-molded lightweight concrete panel), so that the result of this study could be applied to construction panels. The mixing ratios used in this study are shown in Table 6.

Stage 2: Study the mechanical properties of foam concrete with regard to the amount of added fiber. The changes in mechanical properties of foam concrete were analyzed by fiber content using the optimal mixing ratio from stage 1. Three MPF lengths were mixed volumetrically at 0.5 and 1.0 % to the weight of cement. The resulting flexural and compression strengths were assessed. Mixing ratios of Stage 2 are shown in Table 6.

Table 5: Mix Proportion of Preliminary Test

Name	C (kg/m^3)	W/C (%)	Flow (cm)	Density	Compressive strength (MPa)			Bending strength (MPa)
					3	7	28	28
T1-1	400	40	20,12	731.7	0.78	0.96	1.33	0.04
T1-2		45	21,22	729.1	0.62	1.73	1.66	0.13
T1-3		50	23,46	679.3	0.94	1.33	1.81	0.11
T2-1	450	40	19,78	682.4	0.33	0.74	1.08	0.11
T2-2		45	22,42	666.3	0.85	1.07	1.84	0.14
T2-3		50	22,54	638.9	0.62	0.98	1.91	0.14
T3-1	500	40	20,74	689.5	0.92	1.26	1.84	0.14
T3-2		45	23,22	783.3	1.49	2.14	3.87	0.15
T3-3		50	24,14	824.2	2.34	3.36	4.60	0.17
T4-1	550	40	20,3	689.5	0.72	0.92	1.25	0.10
T4-2		45	21,66	796.1	1.37	2.05	2.94	0.14
T4-3		50	24,6	828.1	1.89	2.89	4.39	0.15
T5-1	600	40	21,12	1047.6	2.87	3.93	4.06	0.18
T5-2		45	23,36	962.6	2.52	3.93	6.21	0.18
T5-3		50	23,8	926.4	2.35	3.09	5.57	0.16

Table 6: Mix Proportion of Foam Concrete Mixed with Micro PP Fiber

Factors	Levels
Type of foam agent	FP (Fe-protein)
Concentration of foam agent (%)	5
Percent of foam (%)	70
Cement (kg/㎥)	500
Water cement ration (%)	50
Fly ash (%)	20,
P.P 6mm (%)	1
P.P 25mm (%)	0.5, 1

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P.P 35mm (%)	0.5, 1

Note. P.P-*(/PolyPropylene/ Micro Fiber)

Test Method

Cement paste was mixed with a foam concrete mixer. First, the cement and water were mixed for 60 s. Then the foaming agent was added and mixed for 180 s. The dilution ratio of foaming agent to water was 5 %.

Samples for testing the unit volume weight, compression strength, and flexural strength were manufactured by molds with the respective dimensions of Ø100×200, 40×40×160, and 50×50×50 mm. Samples were cured for 24 h inside the lab, and were removed thereafter. The curing was a standard water curing at the temperature of 20 ± 2℃ until the required age.

Three pieces of each sample were manufactured for the measurement of specific gravity, compression strength, and flexural strength. The results were arithmetically averaged. In order to measure the depth of subsidence as a function of foaming rate of concrete, the specific gravity was measured primarily in Fresh concrete. The subsidence depth was measured as a function of time and was compared with the specific gravity for analysis.

1) Physical Properties

Specific Gravity Experiment (KS F 2459)

- After curing, the sample was dried at 105±5℃ until the mass was constant. The mass was measured when the sample temperature dropped to room temperature inside the desiccator.

Flow Test (KS F 4039)

- An acrylic cylinder with the inner diameter of 80 mm was placed on a glass plate (350×350 mm). The direction in which the sample dispersed after 1 min was measured and averaged.

2) Mechanical Properties

Compression Strength Test (ASTM C 39)

Flexural Strength Test (ASTM C 293)

- The Flexural Strength Test: A sample with dimensions of 40×40×160 mm was used. The distance between points was set as 100 mm. When the sample was formed, the maximum load was obtained by applying 50±10 N/s on the center of the lateral side.

3) Porosity

A scanning electron microscope (SEM) was used for the observation of fine structure.

RESULTS AND DISCUSSION

Influence of fiber contents on physical properties

Experimental results are shown in Figure 2 and Table 7. The compression strength decreased when fiber was mixed into the concrete. The rate of decrease was larger when the volume of the fiber was high. This is due to the formation of large pores which are created by the addition of fibers into the concrete. This conclusion is further confirmed by observations in Figures 3-6. For compression strength, the ratio between the standard fiber-mixed foam concrete samples was 0.33-0.66 %.

MPF typically results in a decrease in contraction instead of an increase in strength. Although, decreases in strength from similar causes have been previously reported. In those cases, the amount of fiber was insufficient for alleviating cracks due to pore formation.

However, in this study, application of larger amounts of MPF effectively increased the flexural resistance. The large number of fibers reduced the generation of cracks, and lowered the rate of strength decrease caused by large pores.

Table 7 shows the correlation between fiber length and flexural strength. The flexural strength increased with fiber length in the 6 to 35 mm range. Theoretically, if the fibers with identical diameters are uniformly mixed, the flexural strength should increase until reaching the next critical fiber length. However, in order to achieve such conditions, the matrix strength, fiber array length, external pressure, among other variables, should be adjusted. To be clear, a decrease in flexural strength was not observed because the intensity of mixing is low, and the shape and surface of the fiber are straight and soft, respectively.

These conditions cannot directly influence the increase of the tensile force of the fiber. Thus, it is unlikely that the maximum critical point of the fiber will be reached in this study. For the same reason, the flexural strength seemed to be increasing constantly.

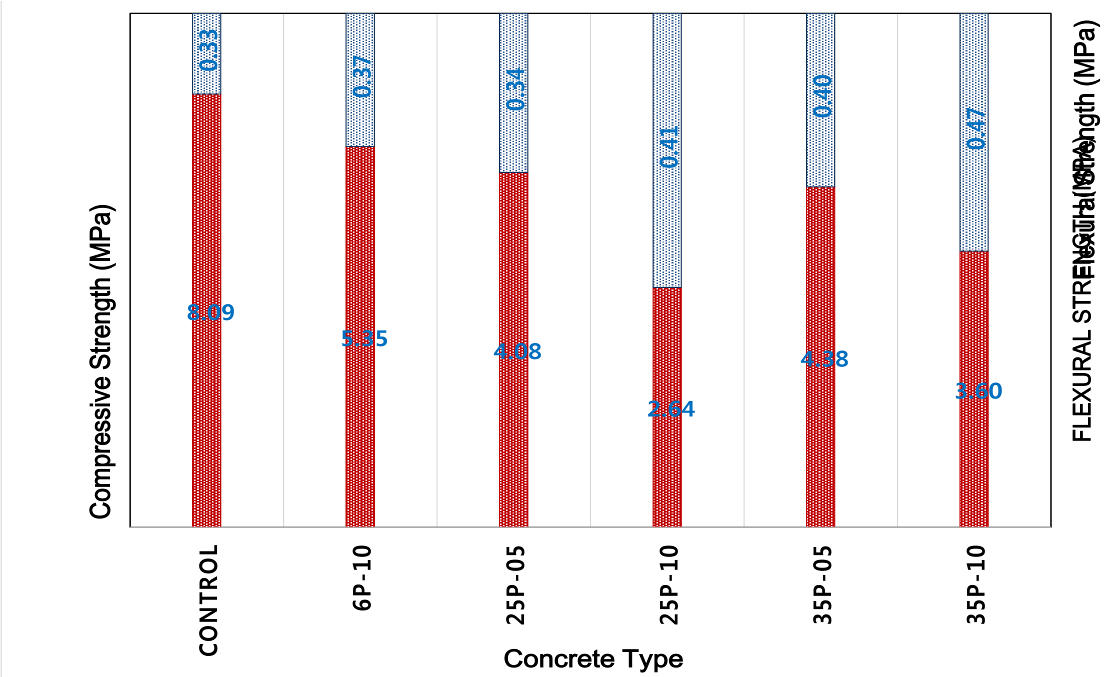

Figure 2: compressive strength test results

(25p - 05 : P.P 25mm (%) – 0.5%, 25p - 10 : P.P 25mm (%) – 1.0)%

Table 7: Compressive and Flexural Strength of Foam Concrete Containing Fiber

PP size	C (kg)	Flyash (%)	W/C (%)	PP (%)	Oven dried density (kg/m^3)	28 days	
						Compressive stregth (MPa)	Bending stregth (MPa)
0	500	20	50	0	836.5	5,42	0,38
6mm	500	50	50	1	734,4	4.8	0.34
25mm	500	20	50	0.5	752	3.36	0.34
35mm	500	20	50	0.5	759	3.75	0.38
25mm	500	20	50	1	816,8	2.87	0.36
35mm	500	20	50	1	832	2.87	0.42

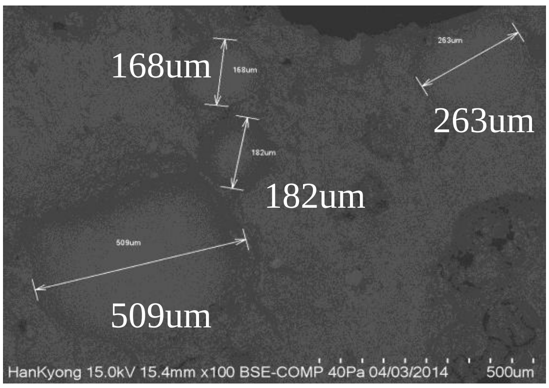

Figure 3: PP Light weight concrete microstructure with fiber length of 6mm

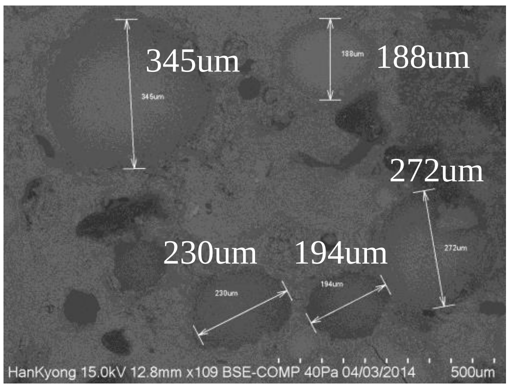

Figure 4: PP Light weight concrete microstructure with fiber length of 25mm

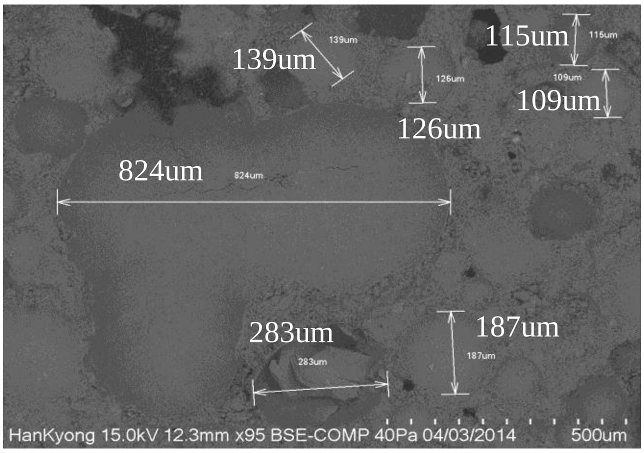

Figure 3: PP Light weight concrete microstructure with fiber length of 6mm

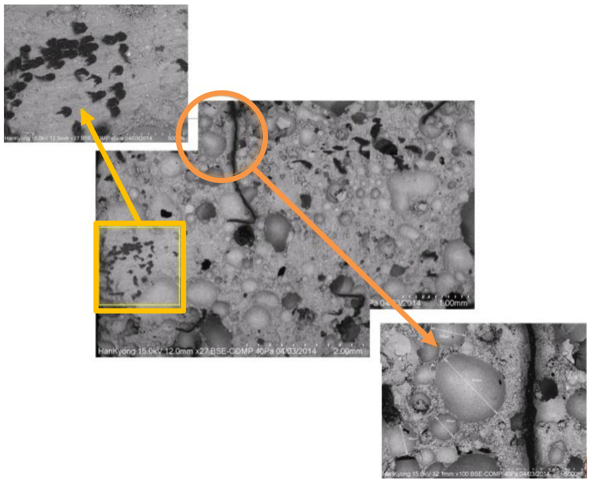

Figure 6: Long micro fibre at high content Less: uniform air bubble distribution Non: uniform fibre distribution

Observation of porosity

(1) Porosity

The porosity changed when fibers were mixed into the foam concrete. The SEM observations confirmed that the fiber connects two individual pores when they are added. Therefore, the pores were either destroyed or they became larger. As such, their shape also became more irregular. These large and irregular pores decreased the compression strength of the hardened fiber-mixed foam concrete. Corresponding results are shown in Figures 3-6.

(2) Fiber distribution

Since the fiber content in this study was higher than the particles constituting common MPFs, there have been a few irregular fiber distributions observed in some parts of the sample. The SEM images confirmed the presence of several fiber balls in the cross-section. As shown in Figure 6, the fiber balls do not negatively influence the flexural strength of foam concrete since the flexural strength still increased.

CONCLUSIONS

The amount of foam and fly ash significantly affected the physical properties of foam concrete. Three main conclusions can be drawn from these results.

1. Due to the air absorption of unburned carbon, as the substitution rate of fly ash increased, the foam volume decreased. This result was similar to the use of the AE (air-entraining) agent where the internal pores expanded through the combination of pores with the fibers. If the fly ash substitution rate was above 30 %, the specific gravity increased greatly, compared with the increased strength. As such, the optimum mixing ratio includes a fly ash substitution range of 20-30 %.
2. The result of stage 2 confirmed that large volumes of fiber can increase the flexural strength of foam concrete up to 40 %. This result was due to both alleviating the damages caused by cracks and preventing them in general. However, the compression strength decreased due to the large pores which were created by mixing the fibers into the concrete.
3. SEM examination indicated that the fibers disturbed the pore structure of foam concrete. At the same time, the connection ring inside the pores created by the mixing process was destroyed or abnormally coupled.

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