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Development of lightweight concrete using the PCM Ⅱ:
Investigation on Foam Volume/Fly Ash Relationship of Foam Concrete, and Effect of High Content Micro Polypropylene Fiber and Microstructure

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ABSTRACT

Purpose: 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. **Method:** 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. The objective of the second study is to investigate further on the use of micro fiber at higher volume fraction and fill in the lacking information.Beside from this study, the investigation of the effect of micro-fiber (polypropylene) to enhance the properties of foam concrete is also carried out. **Result:** 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 fibre 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 fibre bridging over the crack and a significant number of fibres 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 fibre being added into concrete mixture.

KEYWORD

Foam Concrete
Foam Volume
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Microstructure

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1. Introduction

Energy saving is becoming a wordly issue with the effect of climate agreement to solve the global warming matters recently. Energy saving technology such as insulation of building using insulators has been used in cooling and heating of buildings contributing to energy saving aspect as well along with convenience of residence. Current buildings of our country use about 20% of total national energy while countries more developed in heating and cooling such as England and Japan use about 26~28% supporting expectations that about 38~40% of energy will be consumed due to future earth climate change [1)2)]. Especially, as buildings in floor heating method that exist nowadays are replaced by concrete, regenerating function decreases leading to reduction in energy efficiency because of a wide temperature change between floors and walls, thus demanding materials with insulation efficiency of more active concept that can maintain indoor temperature constantly despite extreme temperature change at outside.

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Generally foam concrete is mortar hardened after forming openings inside using a blowing agent. This possesses high fluidity and insulation efficiency being a hard body thanks to low density but also has low strength. The density of foam concrete shows a range of about 300~1,600 kg/m3 d depending on the components of blowing agent and bonding agent used[1)].

Usually foam concrete takes up about 60~70% mostly being made of pore system[2)]. The pore system of normal concrete is largely classified into 2, gel pore and capillary pore. But pore concrete is mostly made of pore form trapped in air entraining agent and porosity because of this hugely affects the property. The features of this foam concrete shows the tendency of easy change depending on the features of porosity system. Small porosity reacts as a factor hugely affecting durability[1)]. It is general to use replaced pozzolan material like blast furnace flag micropowder of fly ash as binding materials to form minute porosity distribution with uniform pore forms[3)]. The lateral effect accompanying this pozzolan reaction shows tendency that density increases along with increase in strength. However, when many pores are used like foam concrete, it shows the tendency that pore volumes increase in a certain size range leading to the features that durability and density decrease as the size is combined with the bigger pore[4)5)6)].

Like mentioned, foam concrete has a feature that bending strength not to mention the compression strength decrease exponentially despite low density as the density decreases[6)], and the ratio of compression strength to bending strength is about 0.2~0.35%[7)]. This is confirmed to be higher than the ratio of usual concrete since fine aggregate particle improves bearing and shear strength of the paste. Thus this research conducted an experiment to improve mechanical property of foam concrete by mixing Micro Polypropylene Fiber short in its length.

Studies on foam concrete mixing fibers have been carried out variously. Bonakdar[8)] reports that compression strength and bending strength decrease as fiber volume increases in addition ratio lower than 0.5% of MPF in the experimental result of foam concrete using aluminum powder. Awang[9)] conducted a study on the effect when mixing polypropylene fibers with low 0.25~0.40% foam concrete and as a result reports that tensile force and bending strength increase although compression strength decreases. Sukontasukkul[10)] conducted a study on the effect appear when flass fiber is replaced by 0.05%~0.15% in foam concrete and reports that bending and tensile strength increase in replacement ratio of 0.05%. But it is reported both compression and bending strength significantly decrease upon replacement more than 0.05%. Unlike this, Yamato[11)] presented his study result that when replacing PVA fiber of .0.35~1.14% which is quite high mixing ratio, it only happens in W/C foam concrete with reduction in compression strength decrease and bending strength increase as the ratio between foam and mortar (FM) increases.

Studies on repleacement increase are still deficient although the cases where experiments were done mixing fibers in low ratio with foam concrete have been confirmed as a result of research trend analysis.

Thus this research conducted the study to reduce the ratio regarding decrease in compression strength using fly ash which is the industrial byproduct at the same time complementing bending efficiency that current foam concrete has by analyzing effect on foam concrete where mixing ratio of MPF is increased. For this, this research conducts the experiment based on two research objectives. The fist is to analyze the correlation between bubble volume of foam concrete and replacement ratio of fly ash.

If features of fly ash that affects pore structure described, pore volume usage can complement the increase in quantity depending on the use of fly ash and it is judged it is possible to reach the range of fixed density using specific pore amount.

The second is to analyze the property change regarding physical features of pore concrete that replaced MPF. Pore concrete shows lacking property to be used as a panel structure because of its decreased bending strength as many pore systems form. To complement this, we intend to proceed to the research to complement the physical property by mixing MPF in addition and \analyze the change in microstructure according to MPF contents.

Currently our country does not provide the standards for pore concrete panel. All it has is KS F 4736 (Light concrete panel for compression making) standard. To be applied as a panel, it is important to satisfy the bending strength features more than 1.5 MPa as presented in this standard.

This research is an experimental one to develop light concrete panel with insulation efficiency and aimed to be used as basic data for development as building materials to reduce cooling and heating load such as warehouses at the background of the result.

2. Used materials and experimental methods

2.1. Used materials

1) Foaming agent

Table 1 shows the physical property and chemical creation of the foaming agent, independent pore type used in this research.

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 boding agent

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	4 hours	6 hours	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	263000	1.36.

3) Micro polypylene 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				

Table 5. Mix Proportion of Preliminary Test (Part 1)

Designation	C (kg)	Fly Ash (kg)			Binder (kg)	W (kg)	W/B	Foam Volume (%)
		% Replc.	by Volume	by Weight				
Control	500.0	-			500.0	250.0	0.500	59.1%
Control W/B ratio								
FV10B50	450.0	10.0	36.5		486.5	243.3	0.500	59.8%
FV20B50	400.0	20.0	73.0		473.0	236.5	0.500	60.5%
FV30B50	350.0	30.0	109.5		459.5	229.8	0.500	61.2%
FV50B50	250.0	50.0	182.5		432.5	216.3	0.500	62.5%
FW10B50	450.0	10.0		50.0	500.0	250.0	0.500	58.5%
FW20B50	400.0	20.0		100.0	500.0	250.0	0.500	58.0%
FW30B50	350.0	30.0		150.0	500.0	250.0	0.500	57.4%
FW50B50	250.0	50.0		250.0	500.0	250.0	0.500	56.2%
Varied W/B ratio								
FV10B514	450.0	10.0	36.5		486.5	250.0	0.514	59.1%
FV20B529	400.0	20.0	73.0		473.0	250.0	0.529	59.1%
FV30B544	350.0	30.0	109.5		459.5	250.0	0.544	59.1%
FV50B578	250.0	50.0	182.5		432.5	250.0	0.578	59.1%
FW10B490	450.0	10.0		50.0	500.0	244.8	0.490	59.1%
FW20B478	400.0	20.0		100.0	500.0	238.8	0.478	59.1%
FW30B466	350.0	30.0		150.0	500.0	233.0	0.466	59.1%
FW50B443	250.0	50.0		250.0	500.0	221.3	0.443	59.1%

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

Designation	C (kg)	Fly Ash (kg)		Binder (kg)	W (kg)	W/B	Foam Volume (%)	Fiber	
		% Replc.	by Weight					Type	Vf
Control	400	20	100	500	250	0.5	58.0%	-	-
6P-10	400	20	100	500	250	0.5	58.0%	6 mm	1.0%
25P-05	400	20	100	500	250	0.5	58.0%	25 mm	0.5%
25P-10	400	20	100	500	250	0.5	58.0%	25 mm	1.0%
35P-05	400	20	100	500	250	0.5	58.0%	35 mm	0.5%
35P-10	400	20	100	500	250	0.5	58.0%	35 mm	1.0%

2.2. Mix

The mix process in this research is made of 2 stages.

St age 1: It is optimum mix induction and correlation between fly ash replacement ratio and pore volume of foam concrete. We have 3 variables here. The effect of pore volume, fly ash replacement ratio and W/B each influencing factors on physical property was reviewed.

Fly ash gave change by 10%~50% as a replacement of replacement ratio and volume. Therefore, pore volume was changed according to the volume of mix paste.

The pore volume was adjusted to be 59.1% in basic mix and changed up to 56.2%~62.5%. Optimum binder ratio regarding basic mix was set as 0.50% and changes were given to pore volume and replacement ratio of fly ash in range of 0.443%~0.578% .

In 2nd stage, optimum mix ratio was adjusted based on the highest compression strength in apparent specific gravity of 1,000 kg/m³ to satisfy mechanical, physical property conditions corresponding to the standards of SP 4736 (light concrete panel for compression making) to apply the result of this research to panel for architecture. Table 5 shows the mix of this research.

2nd stage : A study on mechanical property of pore concrete depending on mixed fiber amount was done. Based on optimum mix ratio induced in the 1st stage, experiment and result analysis regarding mechanical property change of pore concrete was done.

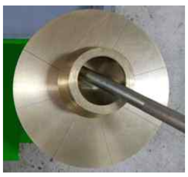
The experiment was done by mixing MPF which are in 3 different length each in 0.5%, 1.0% volume ratio compared to the cement weight used and an evaluation regarding bending strength and compression strength accordingly was done. Table 6 shows mix in 2nd stage.

2.3. Experimental method

Mixture of cement paste used a mixer for pore concrete and specimen was made mixing for 180 seconds after putting pore liquid prior to mix for 60 seconds after putting cement and mixing water. Dilution ratio of foaming agent was water 95%, pore agent 5%.

Specimen with unit volume weight and compression strength, bending strength was made using the mold with size of ∅100×200 mm, 40×40×160 mm, 50×50×50 mm. Made specimen had its mold removed after curing for 24 hours inside the laboratory and standard water curing was done at 20±2℃.

For specific gravity, compression strength, bending strength measurement, the quantity of specimen was made each 3 by each test and the result was presented through calculating average.



a) Slump flow test

b) Compressive strength

c) Flexural strength

Figure 1. Test Methods

Besides, specific gravity in fresh state was measured primarily to measure the depth and the depth was measured depending on the time elapsed and the result was analyzed comparing this to apparent specific gravity.

1) Physical feature

・Apparent gravity test (KS F 2459)

- Test piece done with curing was dried up until it becomes a certain weight at (105±5)℃ then the weight when cooled until it reaches room temperature inside the desicator was measured.

・Flow test (KS F 4039)

- Average value was used measuring in intervals regarding 4 directions reagent spread after 2 minute using acrylic cylinder which is 80mm in its inner diameter on 350×350 mm glass panel.

2) mechanical feature

・compression strength test (ASTM C 39)

・bending strength test (ASTM C 293)

- Bending strength test used specimen in size of 40×40×160 mmsetting the distance between points as 100 mm and obtained the maximum load by measuring load velocity of (50±10) N every second in center of aspect where specimen is molded.

3) Fracture plane

Microstructure was observed using electron microscope(SEM)

3. Experimental result and contemplation

3.1. Stage 1 : The effect of fly ash replacement ratio and pore volume on pore concrete

(1) The effect of fly ash replacement ratio and pore volume on pore concrete

Table 7 shows average apparent specific gravity regarding every result. Apparent specific gravity of pore concrete was confirmed to be applied differently on 3 variables set in this study.

When fly ash is replaced, Figure 1 shows the correlation between fly ash replacement ratio regarding pore concrete of W/B fixed at 0.05% along with apparent specific gravity showing the effect of fly ash replacement ratio on apparent specific gravity. This shows the tendency of increasing apparent specific gravity as replacement ratio of fly ash increases. Increase in apparent specific gravi쇼 due to fly ash can be seen as the result of pozollan reaction and aside from this, it is judged to be the effect of pore charge of fly ash particles. Pozzolan reaction between fly ash and potassium hydroxide changes potassium hydroxide ($Ca(OH)_2$) into high density material like calcium silicate hydrate(CSH) with high density. This change reduces the pore size and increases apparent specific gravity of pore concrete since concrete generally possesses potassium hydroxide by about 20~25%.

In pore charge effect, there are more fly ash particles than cement ones in same weight since it is smaller than cement and has a fixed weight but not all fly ash particles are used in pozollan reaction. Non-hydration particles can be used as charge reaction to fill the pore inside the cement.

In WB, apparent specific gravity was confirmed to decrease at the same time binding ratio of W/B decrease as shown in Figure 2. Usually, normal concrete has its apparent specific gravity increase in accordance with decrease in pore contents as water contents decrease.

But this phenomenon can be explained related with pore volume in the research result. Like described, pore plays a role of pore charge in this study and its amount changes depending on hardening volume. Thus if W/B gets lower more pore group should fill the lacking pore due to contents decrease in inside water and decrease in apparent specific gravity shows that pore amount affects apparent specific gravity6 than the effect of W/B.

Figure 3 shows relation between remaining two variables (fly ash replacement rate, pore volume) and apparent specific gravity. Two variables play an important role in apparent specific gravity of pore concrete in different ways. Along with tendency to increase apparent specific gravity of fly ash replacement rate, pore amount can decrease it. This study conducted a review on changes depending on fly ash replacement rate maintaining apparent specific gravity under the high load of pore group.

Contemplation of Figure 3 can be divided into 2 parts mainly. By dividing marked curve into two parts based on 59.1% (mix control) point with same pore amount. each was differentiatd and the review was done. The first part(left) shows decreasing fly ash replacement rate when pore amount increases. This is a general curve showing the effect of fly ash replacement ratio decrease and pore amount increase bind together with lower density gradually.

But the result shown in right of Figure 3 presents the result that both fly ash replacement rate and pore amount increase together. This part surely indicates counteraction between fly ash and pore amount.

Usually, apparent specific gravity decreases as pore amount increases. But in this result, it gradually increases as fly ash replacement rate increases. This shows that fly ash can actually fill additional pore generated as pore amount increases. This counteraction can keep apparent specific value at a constant level and when fly ash replacement ratio is increased it is increased as well.

Table 7. Average Dry Density

Designation	Dry Density (kg/m^3)
Control	475.5
FV10B50	528.0
FV20B50	632.3
FV30B50	617.8
FV50B50	819.0
FW10B50	715.7
FW20B50	836.5
FW30B50	1,058.4
FW50B50	1,228.7
FV10B514	633.0
FV20B529	806.6
FV30B544	783.4
FV50B578	828.1
FW10B490	698.4
FW20B478	782.0
FW30B466	817.7
FW50B443	1,199.0

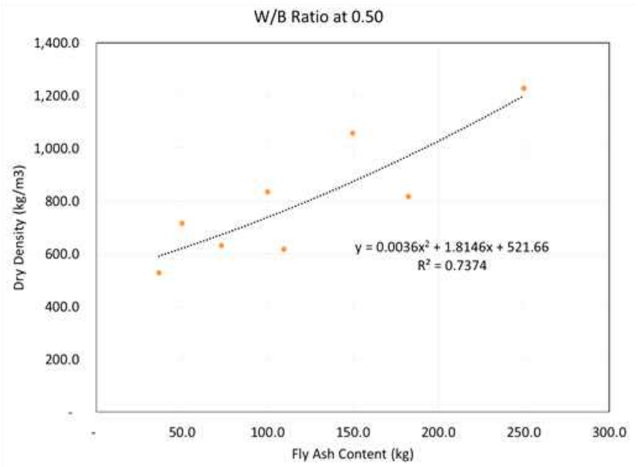


Figure 1. Relationship between Fly Ash Content and Dry Density

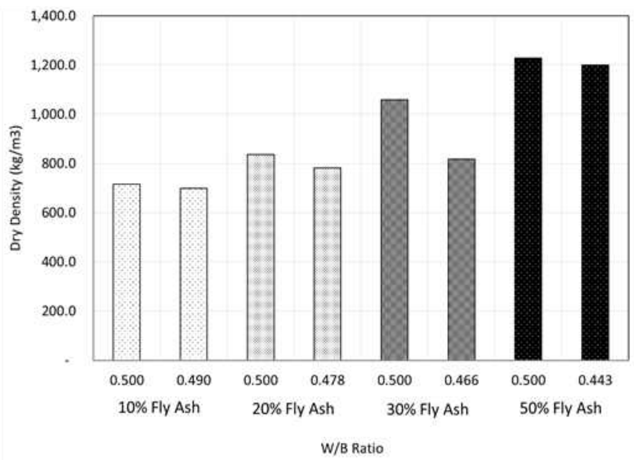


Figure 2. Effect of W/B Ratio on Dry Density

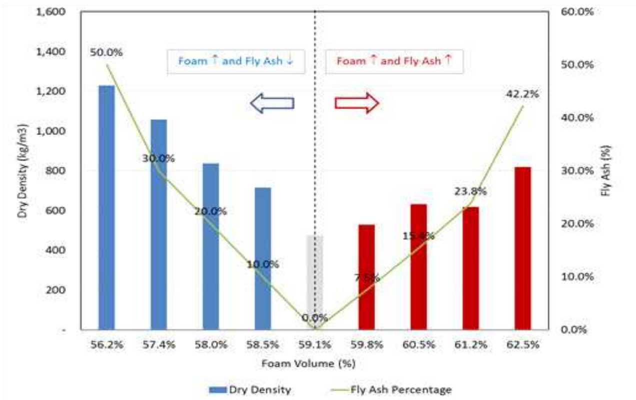


Figure 3. Relationship between Dry Density, Foam Volume and Fly Ash Content

(2) Optimum mix ratio and mechanical property

Compression strength induced the result based on the strength of 28 material ages. Like shown in Figure 4, compression strength was confirmed to be largely influenced by fly ash replacement ratio and pore amount. As described, fly ash increases compression strength but also increases apparent specific gravity of pore concrete. On the other side, pore amount increases lowering apparent specific gravity when compression strength gradually decreases.

Like shown in Figure 5, there is a directly balancing result since bending strength, compression strength are all affiliated with apparent specific gravity in the same way. By mix ratio, the ratio of bending strength and compression strength was confirmed to be somehow low by 0.04%~0.12%(4%~12%).

Two standards in optimum mix, as described in mix process, show the highest compression strength not beyond 1,000 kg/m³. Table 8 shows every experimental result of each group and mix number FW20B50 was applied to stage 2 experiment since it is the nearest to the standard of KS 4736 which this study aims for showing dry density of about 837 kg/m3 and compression strength of about 8.09 MPa, 0.38 MPa bending strength.

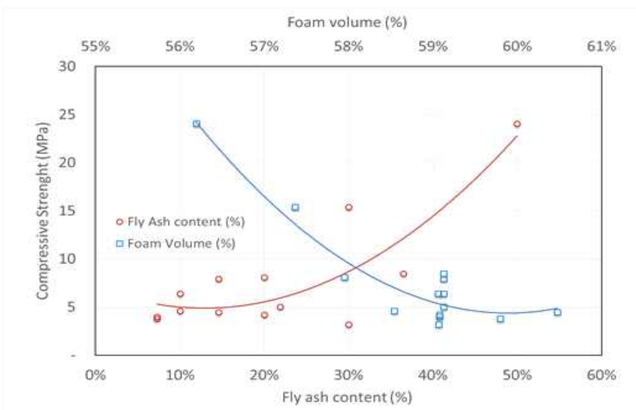


Figure 4. Relationship between Fly Ash, Foam Volume, and Compressive Strength

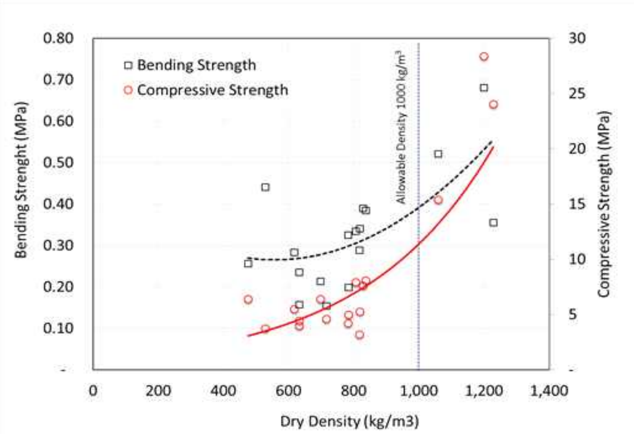


Figure 5. Relationship between Dry Density and Strengths

Table 8. Average Strength

Designation	Dry Density (kg/m^3)	Compressive Strength (MPa)	Flexural Strength (MPa)	B/C Ratio
Control	475.5	6.40	0.26	0.04
FV10B50	528.0	3.76	0.44	0.12
FV20B50	632.3	4.46	0.16	0.04
FV30B50	617.8	5.52	0.28	0.05
FV50B50	819.0	5.27	0.34	0.06
FW10B50	715.7	4.62	0.15	0.03
FW20B50	836.5	8.09	0.38	0.05
FW30B50	1,058.4	15.39	0.52	0.03
FW50B50	1,228.7	24.06	0.36	0.01
FV10B514	633.0	3.99	0.24	0.06
FV20B529	806.6	7.95	0.33	0.04
FV30B544	783.4	5.01	0.20	0.04
FV50B578	828.1	7.62	0.39	0.05
FW10B490	698.4	6.39	0.21	0.03
FW20B478	782.0	4.22	0.33	0.08
FW30B466	817.7	3.21	0.29	0.09
FW50B443	1,199.0	28.40	0.68	0.02

3.2. Stage 2 : Effect of fiber contents based on mechanical property

Table 9 and Figure 6 show the study result. Compression strength showed the tendency to decrease when fibers are mixed in concrete. Decreasing tendency becomes greater when fiber volume increases. This is judged to be formation of big pores (combination of small pores) produced by the addition of fibers in concrete. This is clearly shown in fracture plane observation result of Figure 9~12. The ratio of standard specimen to fiber mix pore concrete was confirmed to be 0.33~0.66%.

Bending strength showed the result exceeding standard specimen in every specimen. It increased from 3% to 42% in every result compared to standard specimen. Bending strength showed clearer raise as fiber contents increase. There was a pore with longer diameter upon fracture plane measurement confirmed, but it showed the tendency to increase strength compared to reduction rate by big pores because of connection with each fiber.

Generally MPF is used for shrinkage reduction, not increasing strength. Besides, results of strength reduction due to this have continuously been reported. This is judged to be deficient fiber contents to improve strength reduction rate and crack generated by formation of big pores.

But pore connection effect was confirmed to be bigger in bending strength especially when high ratio is applied like in this study. This is judged because series effect of countless fibers improve strength reduction rate by bigger pores since they reduce crack generation.

Like connection between fiber length and bending strength ratio is shown in Figure 7, bending strength was confirmed to increase when fiber length is in range of 6 mm~35 mm. Theoretically, bending strength increases at the same time fiber length increases and continuously increases until it reaches the length of critical point in fibers with the same diameter under the condition of perfect combination. But to complete these conditions, we need each condition such as matrix strength, form arrangement of fiber, length, outer pressure. Nonetheless there is no decrease in bending strength generally. This is because mix strength is low and fiber shape, surface are straight, soft. These two conditions do not play direct effect on increasing stress of fibers. Thus it is judged they cannot reach the maximum critical point used in this research and that is why bending strength continuously increased.

Table 9. Compressive and Flexural Strength of Foam Concrete Containing Fiber

Designation	Fiber		Density (kg/m^3)	Compressive Strength		Flexural Strength		F/C Ratio (%)
	Type	Vf		(MPa)	Ratio	(MPa)	Ratio	
Control	-	-	836.50	8.09	1.00	0.33	1.00	4.1%
6P-10	6 mm	1.0%	755.92	5.35	0.66	0.37	1.12	6.9%
25P-05	25 mm	0.5%		4.08	0.50	0.34	1.03	8.4%
25P-10	25 mm	1.0%		2.64	0.33	0.41	1.23	15.4%
35P-05	35 mm	0.5%		4.38	0.54	0.40	1.22	9.2%
35P-10	35 mm	1.0%		3.60	0.44	0.47	1.42	12.2%

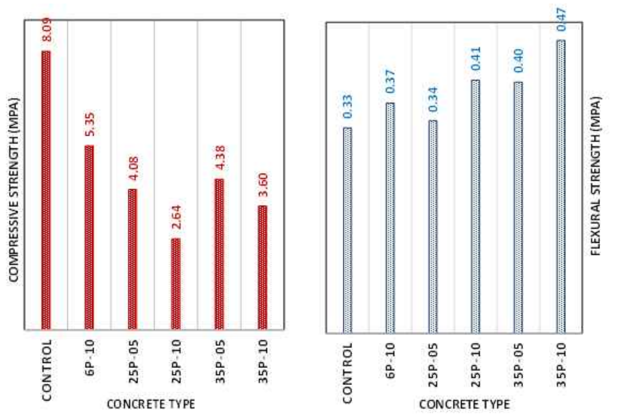


Figure 6. Compressive and Flexural Strength of Fiber Reinforced Foam Concrete

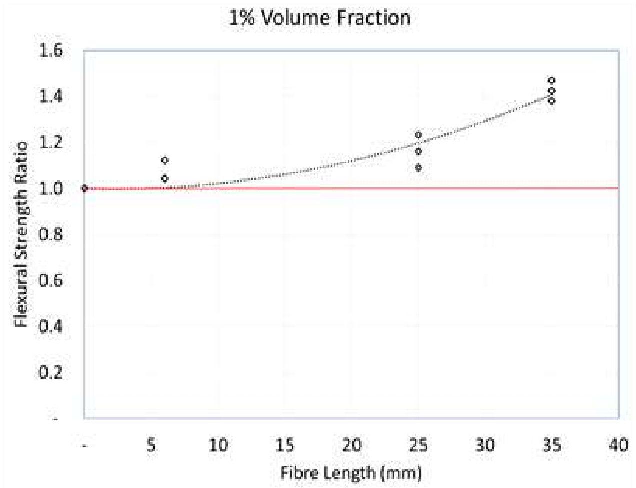


Figure 7. Strength Ratio and Fiber Length

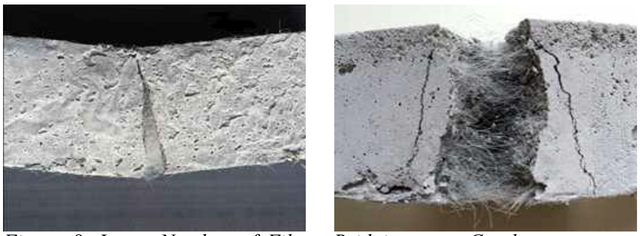


Figure 8. Large Number of Fibers Bridging over Crack

3.3. Observation result of fracture plane

Fracture plane was observed using SEM and microscope to check pore structure of pore concrete and fiber effect in microstructure stage.

(1) Pore system

It was seen that pore system changes when fibers are mixed in pore concrete. It was also seen that it becomes a mediator that connects two pores into one when fibers are mixed in independent pore structure as a result of SEM confirmation. Due to this, pores were destroyed or transformed into a bigger pore, with its form becoming irregular. This big and irregular pore is judged to be applied as reduction factor in compression strength of fiber mixed pore concrete hardened. Figure 9, 10, 11, 12 shows the result.

(2) Fiber distribution

Fiber contents used in this study is higher than general particles of MPF usually used leading to irregular fiber distribution in some parts of tests. Fiber ball was seen in many parts of planes as a result of SEM observation.

Like shown in Figure 13, this fiber ball is judged not to be shown as negative effect in bending strength of pore concrete as described result shown because of increasing bending strength.

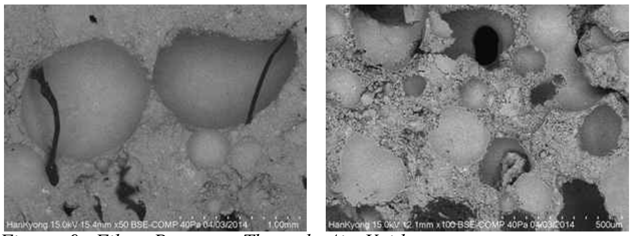


Figure 9. Fiber Puncture Through Air Voids

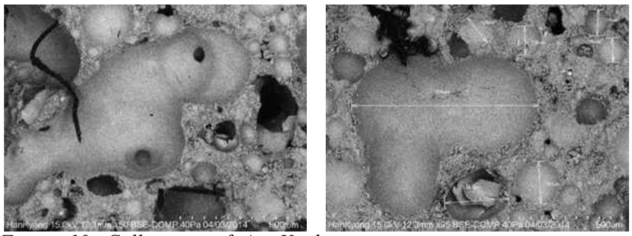


Figure 10. Colligation of Air Voids

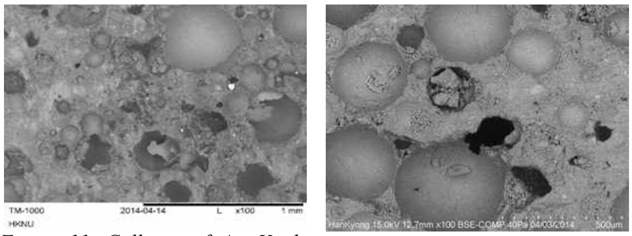


Figure 11. Collapse of Air Void

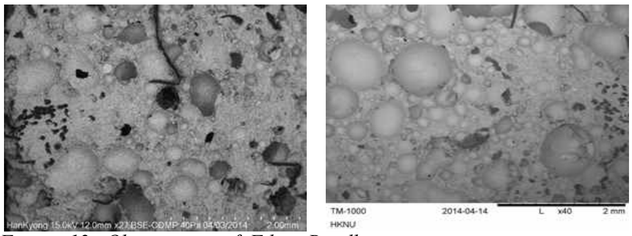


Figure 12. Observation of Fiber Bundles

4. Conclusion

The effect of 2 variables, pore amount and fly ash replacement ratio, affect property of pore concrete significantly drawing following conclusions.

1. As a result, it shows strong relation that counteraction towards other side of one side is possible. Fly ash can be used to improve apparent specific gravity reduced by pore amount increase when many pores are used. On the contrary, it is possible to adjust to desirable apparent specific gravity by adjusting pore amount when much fly ash that can increase apparent specific gravity of pore concrete is used in terms of economic aspect.
2. Strength increase range gets smaller as inner pores expand as a result of pore volume decrease and pore combination reaction just like the case of using AE admixture due to air absorption of unburned carbon when replacement ratio of fly

ash increases. Apparent specific gravity range increase in a wide range compared to strength increase range when fly ash replacement ratio is over 30% and it is judge to be more effective to determine the optimum mix in range of 20~30% replacement ratio.

3. Pore volume was confirmed to increase bending strength of pore concrete up to 40% with the effect of countless fibers that prevent crack and fiber connection effect that improve damage from crack in study result of stage 2. Compression strength, however, was confirmed to decrease because of big pores formed by mixing fibers in concrete.
4. Fibers actually annoy pore system and the link between inner pore formed by fiber mix destroys pores or abnormally connects from observation result of SEM.

It is judged that emission amount of CO^2 is possible through load reduction of energy used when applying it to buildings or warehouses through panel development study of light concrete for energy reduction with high insulation efficiency by actively utilizing industrial byproducts.

The result of this study is expected to be used as basic data for basic material development but it is also considered that there would be a need for additional research regarding thermal and mechanical features about pore changes in hardening process and mix amount of fibers afterwards.

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