3.2 Materials

Type 1 OPC produced by company A in Korea is used with the physical and chemical properties of Table 3. The aggregates are originated from Korea and present the physical properties listed in Table 4. The fine aggregates are a 6:4 mix of river sand and crushed sand. For the admixtures, type 2 FA from the thermoelectric power plant B in Korea and type 3 BS from company H with the physical and chemical properties arranged in Tables 5 and 6 are adopted.

In addition, superplasticizer (SP) and air-entraining (AE) agent as well as ERCO and emulsion produced by company D in Korea are used. The physical and chemical properties of these admixtures are listed in Tables 7 and 8.

Table 3. Physical properties of cement

Density (g/cm^3)	Blaine (cm^2/g)	Soundness (%)	Setting time (min)		Compressive strength (MPa)		
			Initial time	Final time	3 days	7 days	28 days
3.15	3 390	0.05	230	345	24.8	39.3	56.9

Table 4. Physical properties of aggregates

Type	Density (g/cm^3)	FM	Water absorption (%)	Passing amount through 0.08 mm sieve (%)
Natural fine aggregates	2.50	2.85	0.46	2.87
Crushed fine aggregates	2.63	2.54	0.46	3.00
Coarse aggregates	2.68	6.55	0.58	-

Table 5. Physical and chemical properties of FA

Density (g/cm^3)	Blaine (cm^2/g)	L.O.I (%)	SiO_2 (%)	Moisture content (%)
2.21	3 520	4.60	52.3	0.13

Table 6. Physical and chemical properties of BS

Density (g/cm^3)	Blaine (cm^2/g)	L.O.I (%)	Moisture content (%)	Chemical composition (%)				
				MgO	SO_3	Cl	SiO_2	CaO
2.90	4254	1.91	0.23	5.26	1.95	0.002	34.20	42.50

Table 7. Physical properties of agent

Admixture	Main property	Shape	Color	Density (g/cm^3)
Superplasticizer	Polycarboxylate	Liquid	Dark brown	1.05
Air-entraining agent	Naphthalene	Liquid	White	1.04

Table 8. Physical properties of ERCO

Admixture	Density (g/cm^3)	Main component (%)				Viscosity (cP)
		Saturated acid	Multi-unsaturated acid	Omega-3 Acids	Simple saturation	
ERCO	0.98	15	54	8	23	25

3.3 Test method

Concrete was mixed using a forced fan-type mixer.

For fresh concrete, the slump and air content were measured in compliance with the test methods regulated in KS F 2402 and KS F 2421, respectively.

For hardened concrete, compressive strength test and carbonation resistance test were conducted according to the methods specified in KS F 2405 and KS F 2584, respectively.

4. TEST RESULTS AND DISCUSSION

4.1 Characteristics of fresh concrete

Fig. 3 compares the values of the slump according to the mix ratio of ERCO. For the ERCO mix ratio of 0%, the mixes OPC, FA30 and BS60 satisfied the target slump of 150±10 mm with respective values of 155 mm, 160 mm and 150 mm, but the fluidity degraded with larger mix ratios. Concretely, for the ERCO mix ratio of 1%, the slumps of mixes OPC, FA30 and BS60 are respectively 145 mm, 150 mm and 130 mm, representing a degradation of the fluidity by 7 to 15%. For the ERCO mix ratio of 2%, the fluidity of mixes OPC, FA30 and BS60 degraded by approximately 20 to 28% compared to the plain mix. This loss of fluidity can be explained by the larger viscosity of ERCO than water and the water dispersion action inside concrete.

Fig. 4 presents the variation of the air content with respect to the mix ratio of ERCO. For the ERCO mix ratio of 0%, all the mixes satisfied the target air content of 4.5 ±1.5 % but the air content reduced by minimum 50% to maximum 80% with larger mix ratios of ERCO. The larger reduction of the air content with larger mix ratios of ERCO can be attributed to the adsorption by the air-entraining agent according to the use of the organic substances of the lipid component.

4.2 Characteristics of compressive strength

Fig. 5 plots the variation of the compressive strength with the age per type of binder and mix ratio of ERCO. Until 56 days, OPC exhibited the highest strength compared to the other mixes regardless of the mix ratio of ERCO.

Besides, all the mixes with ERCO mix ratios of 1% and 2% developed smaller compressive strength than the mixes without ERCO. This loss of the strength can be explained by the fact that the fat component of ERCO degrades the hydration of cement and reduces the shrinkage.

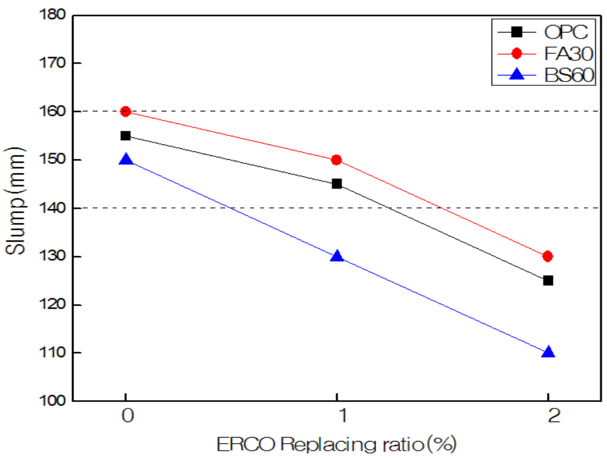

Fig. 3 Slump according to the mix ratio of ERCO

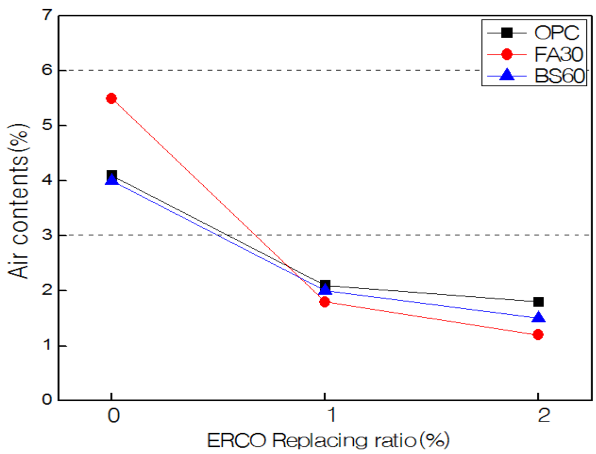

Fig. 4. Air content according to the mix ratio of ERCO

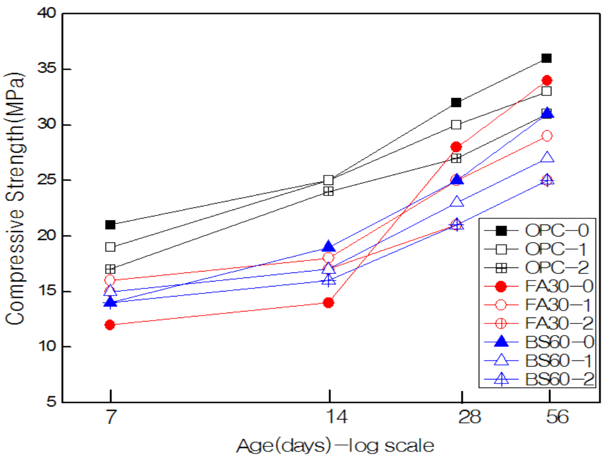

Fig. 5 Variation of compressive strength with age (MPa)

4.3 Characteristics of carbonation

4.3.1 Effect of ERCO on the carbonation of concrete

Fig. 6 presents the progress of the carbonation depth with the age per type of binder and mix ratio of ERCO. The carbonation depth is shown to increase with the age. The carbonation appears to be larger with larger replacement ratios by the admixtures. For the ERCO mix ratios of 1% and 2%, the measured carbonation depth reduced more significantly with time than the mixes without ERCO. The reduction of carbonation depth can be explained by the mitigation of the carbonation through the prevention of the penetration of CO_2 owing to the filling of the capillary pores inside the hardened concrete by the soap fine particles resulting from the accelerated generation of fatty acid calcium salts by the hydrolysis of the fatty acids of ERCO in calcium hydroxide $Ca(OH)_2$ according to the absorption of ERCO in concrete.

On the other hand, FA30 and BS60 with ERCO mix ratio of 1% showed that the carbonation could be prevented to a level quasi-identical to the mix OPC without ERCO despite of their large replacement ratio by the admixtures.

4.3.2 Porosity by mercury intrusion penetration

Fig. 7 shows the accumulative pore distribution measured at 28 days in the high volume admixture concretes with 1% of ERCO and without ERCO. It can be observed that, regardless the pore size, the pore volume inside concrete decreases as ERCO dosages increase. This is because, after emulsifying, the waste cooking oil distributes homogeneously inside the concrete and the products generated by its saponification reaction fill the pores. As ERCO belongs to fatty acid ($RCOOCH_2$), the chemical reactivity is activated with high OH^- in the concrete, and the so-generated products fill the pores in the concrete. The chemical reaction can be expressed as follows,

$$C_3H_5(OCOR)_3 + 3Ca(OH)_2 \rightarrow C_3H_5(OH)_3 + 3RCOOCa. \quad (1)$$

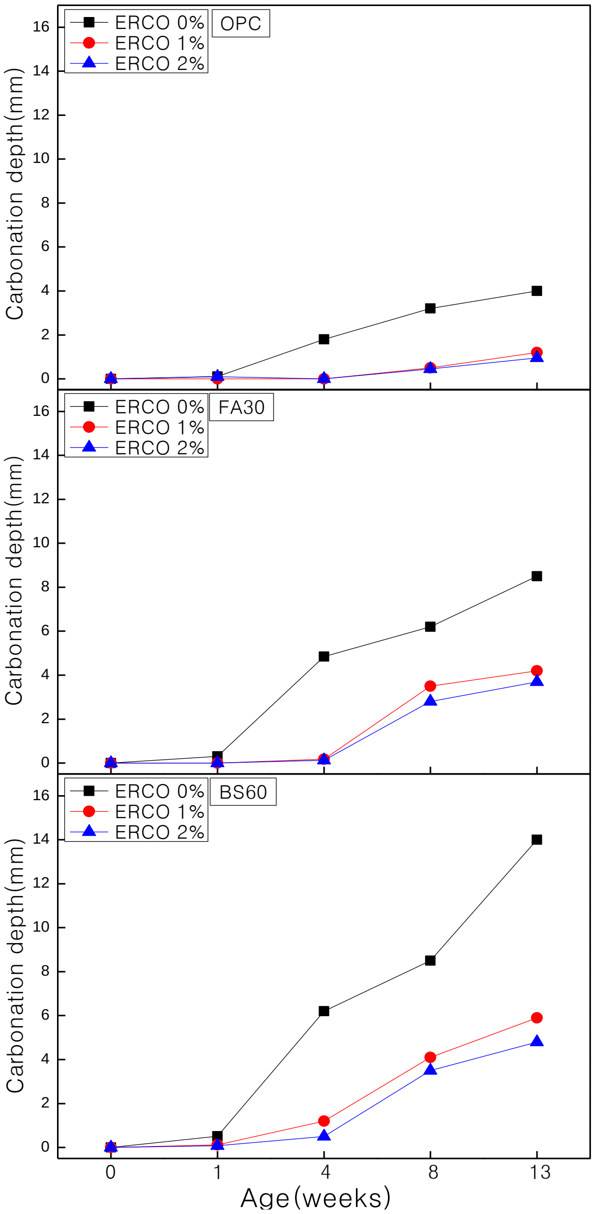

Fig. 6 Progress of carbonation depth with age

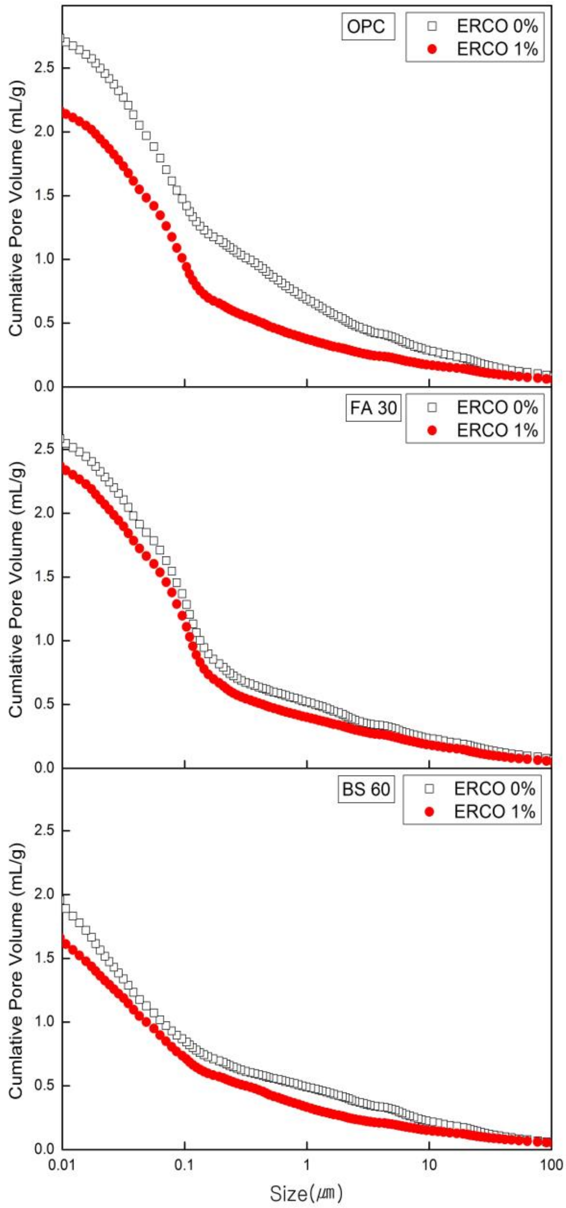

Fig. 7 Pore distributions with ERCO dosages

5. CONCLUSIONS

This study intended to investigate experimentally the effect of ERCO on the physical properties and carbonation reduction of high volume admixture concrete incorporating 30% of fly ash and 60% of blast furnace slag. The following conclusions can be drawn.

1) The slump and air content tended to decrease with larger amount of ERCO. This loss of fluidity could be explained by the large viscosity of ERCO, the adsorption of the AE agent and the water dispersion action.

2) The compressive strength of the concrete with ERCO appeared to be slightly

lower than that of OPC concrete. This loss of the strength due to ERCO could be explained by the fact that the fat component of ERCO degraded the hydration of cement.

3) The use of ERCO provided remarkable carbonation mitigation effect compared to the OPC mix. This could be attributed to the mitigation of carbonation by the filling of the capillary pores inside concrete by ERCO. Moreover, the mixes using FA30 and BS60 with ERCO mix ratio of 1 % showed nearly identical carbonation to that of the mix using only OPC.

Consequently, the use of ERCO resulted in slight losses of the slump, air content and compressive strength but appeared to provide outstanding carbonation mitigation effect compared to the plain mix and was verified to be very effective in improving the durability of concretes with large contents in admixture substitutes.

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