Contemporary Engineering Sciences, Vol. 7, 2014, no. 21, 1071 - 1078
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2014.49134

High-Volume SCMs Using Emulsified Refined Cooking Oil (ERCO) for Improving Concrete Durability

Mincheol Han

Department of Architectural Engineering
Cheongju University
Cheongju, South Korea, 360-764

Dongyeop Han

Research Institute of Industrial Sciences
Cheongju University
Cheongju, South Korea, 360-764
(Corresponding Author)

Daehoon Woo

Seon Engineering
Cheongju, South Korea, 360-020

Abstract

The aim of this paper is to evaluate to what extent the addition of emulsified refined cooking oil (ERCO) to high-volume supplementary cementitious materials (SCMs) can improve the durability of concrete. For concrete samples with SCMs made up of 30% fly ash and 60% blast furnace slag, durability tests were based on carbonation, chloride penetration and sulfate resistance levels after various quantities of ERCO were added. The test results showed that the concrete pore system filled with calcium salt produced by the reaction between fatty acid created by the saponification of ERCO and calcium hydroxide in concrete. Because of decreased porosity of the concrete, the durability was increased with decreasing carbonation depth, thereby increasing the resistance to chloride penetration and sulfate attack.

Keywords: emulsified refined cooking oil (ERCO), durability, high-volume SCMs concrete

1.Introduction

Using supplementary cementitious materials (SCMs) is a very common and well-known method used to improve the performance of concrete[1,2]. Furthermore, the recent increased demand for more sustainable materials in the construction industry has drawn attention to concrete manufacturing as one of the primary sources of pollution. The function of SCMs is to replace a portion of the clinker used to make Portland cement and thereby reduce the amount of CO_2 emitted during the blast furnace stage of concrete production.

For this reason, SCMs in concrete are essential to reducing the harm caused by the Portland cement production which is the primary ingredient of all concrete; hence, research continues to flourish in an effort to respond to that need[3,4]. Researchers have tried to increase the amount of replacement SCMs in concrete mixture, introducing unprecedented high-volume SCMs [5,6]. Most SCMs are the byproducts of burning coal (fly ash), operating blast furnaces (slag), and manufacturing silicon or ferro-silicon metal (silica fume); thus, they are often referred to as migrating contaminants.

When fly ash is used as an SCM, calcium hydroxide is consumed and the pH of concrete is decreased by the chemical reaction of SCMs. Because of this decreased pH, the concrete containing SCMs have the drawback of faster carbonation[7]. Additionally, for durability of concrete, permeability is a very important factor. Since most chemical attacks are from the outer environment, increasing permeability of concrete is critical.

According to established research by the authors[8], reducing autogenous shrinkage of low water-to-cement ratio concrete was observed when the concrete mixture contained ERCO. From this research, evaluations were based on experiments where the pore system of concrete was filled with soap particles produced by saponification with ERCO.

Therefore, in this paper, based on the pore-filling effect of ERCO in concrete mixture, the studies were conducted to evaluate the improvement of durability of high volume SCM concrete due to ERCO addition compared to other factors such as decreased permeability.

2. Experimental Plan

2.1 Design of Experiment

The design of experiment in this paper is shown in Table 1, and the mix proportion of the concrete is summarized in Table 2. Based on a water-to-binder ratio of 50%, the mix proportions were designed to satisfy target slump of 180 ± 25 mm, and target air content of 4.5 ± 1.5 %. As a binder, based on the control mixture without SCMs replacement, two different conditions of replacing SCMs were prepared representing a 30% fly ash replacement and 60% slag replacement by weight of cement. ERCO replaced the mixing water by weight of binder from 0.25 to 1.0%.

Table 1. Experimental plan

Test factors			Levels
Mix Proportions	W/B		0.50
	Target slump (mm)		180 ± 25
	Target air contents (%)		4.5 ± 1.0
	SCMs replacement (%)	OPC[1)]	100
		OPC : BS[2)]	40 : 60
		OPC : FA[3)]	70 : 30
	ERCO dosages (%)		0, 0.25, 0.5, 1
Tests	Hardened concrete		Compressive strength Accelerated carbonation Resistance to chloride attack Resistance to sulfate attack Mercury intrusion penetration (MIP)

1) Ordinary Portland cement, 2) Blast furnace slag, 3) Fly ash

2.2 Materials

Cement used in this paper was the most common Type 1 Portland cement manufactured in South Korea. Based on the information from the manufacturer, density was 3.15 g/cm^3 and Blaine's air permeability reading was 3,390 cm^2/g. Fine aggregate was mixed with the ratio of 6:4 for natural sand and crushed sand. Coarse aggregate was granite obtained from Hwasung in South Korea. Fly ash and blast furnace slag were obtained from thermal power plants in South Korea and the physical and chemical properties are shown in Table 3. For the chemical admixtures, polycarboxylate-based superplasticizer (SP) was used. The SP used was a commercially available product from South Korea. Air entraining agent was an anion type from South Korea. ERCO was made by combining wasted cooking oil and synthetic emulsion to achieve better performance of mixing with water. The physical properties of ERCO are shown in Table 4. Emulsifying of waste cooking oil was conducted with mixer by replacing waste cooking oil to synthetic emulsion by 10%.

Table 2. Mixture proportions of concrete

Mixtures	W/B	S/a	ERCO dosage (%)	AE/B (%)	SP/B (%)	Unit weight (kg/m^3)				
						C	S	G	FA	BS
OPC-0	0.50	0.46	0	0.042	1.0	360	108	215	802	960
OPC-0.25			0.25	0.042	1.0					
OPC-0.5			0.50	0.060	1.1					
OPC-1			1.00	0.090	1.1					
FA30-0			0	0.042	0.9	252	108	215	775	101
FA30-0.25			0.25	0.042	0.9					
FA30-0.5			0.50	0.060	1.0					
FA30-1			1.00	0.090	1.0					
BS60-0			0	0.042	1.0	144	108	215	795	951
BS60-0.25			0.25	0.042	1.0					
BS60-0.5			0.50	0.060	1.1					
BS60-1			1.00	0.090	1.1					

Table 3. Physical and chemical properties of SCMs used

	Density (g/cm^3)	Blaine (cm^2/g)	L.O.I. (%)	Moisture content (%)	Chemical composition (%)			
					CaO	SiO_2	MgO	SO_3
Fly ash	2.20	3,850	2.50	0.10	3.33	59.59	1.68	0.44
Slag	2.90	4,254	1.91	0.23	42.50	34.20	5.26	1.95

Table 4. Physical properties of ERCO

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

2.3 Test Methods

Concrete was mixed with a pan type mixer, and the mixing protocol was dry mixing with cement powder, aggregates, and SCMs at a low speed of 20 rpm for 30 seconds. After introducing the mixing water, initial mixing began at a mid-speed of 30 rpm for 60 seconds until a final high speed of 60 rpm was initiated and continued for 90 seconds after adding superplasticizer. For hardened concrete properties, compressive strength was measured at designated ages with ISO 1920-4:2005, and an accelerated carbonation test was performed following ASTM C876. The resistance for sulfate attack and chloride penetration were performed following ASTM C1012 and ISO 1920-11:2013, respectively. The pore conditions were measured with mercury intrusion porosimetry (MIP) at designed ages.

3. Results and Discussion

3.1 Compressive Strength Depending on ERCO Dosage

As shown in Figure 1, when fly ash (FA) and blast furnace slag (BS) were used in concrete mixtures, decreased compressive strengths at 3 days were observed regardless of the dosage of ERCO. However, the compressive strength of the concrete mixtures with FA and BS was recovered at 180 days. Also, there was no adverse effect on compressive strength with ERCO in concrete for the setting times or data checks performed at 3, 7, 28, and 180 days, respectively.

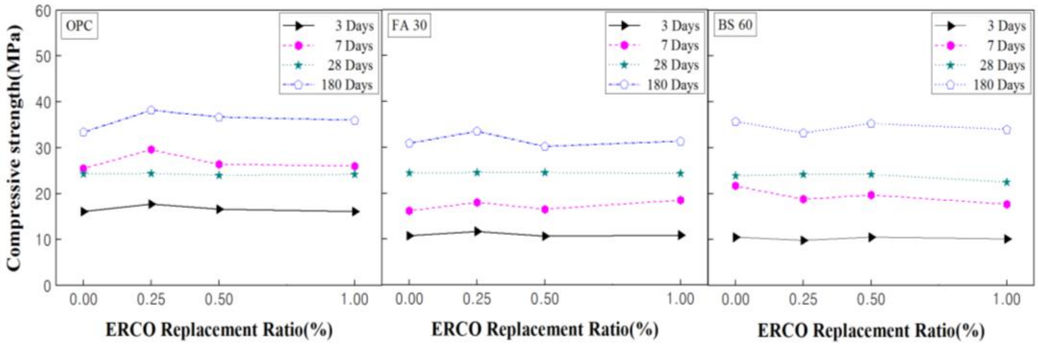

Figure 1. Influence of ERCO replacement ratio on compressive strength depending on the ages

3.2 Carbonation Resistance with ERCO Dosages

Figure 2 provides the influence of the ERCO dosage and SCMs on the carbonation depth of concrete depending on ages. For different SCMs, the carbonation depth increased with BS and FA in concrete mixtures. However, as the dosage of ERCO increased, the carbonation depth decreased; therefore, after13weeks, the concrete with 1.00% ERCO showed a lower carbonation depth that was approximately 2.5–3 mm lower than the concrete without ERCO treatment. The improved performance of carbonation resistance was considered a result of the pore-filled effect of ERCO in the concrete mixture and blocking CO_2 against the concrete surface.

3.3 Resistance to Chloride Penetration Depending on ERCO Dosages

Figure 3 presents the effect of ERCO dosage using different SCMs to measure chloride penetration of concrete depending on ages. BS provided lower chloride penetration depth than that noted in the other two cases. With ERCO in concrete, regardless SCMs, the chloride penetration depth decreased as the ERCO dosage increased. Therefore, similar to the carbonation depth result, the chloride depth decrease was considered a result of the pore-filling effect of ERCO's fatty acid.

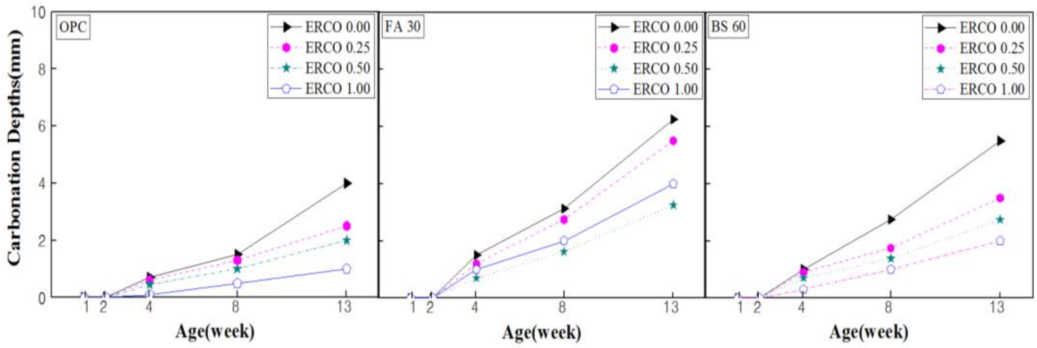

Figure 2. Influence of ERCO dosage on carbonation depth of concrete with different SCMs

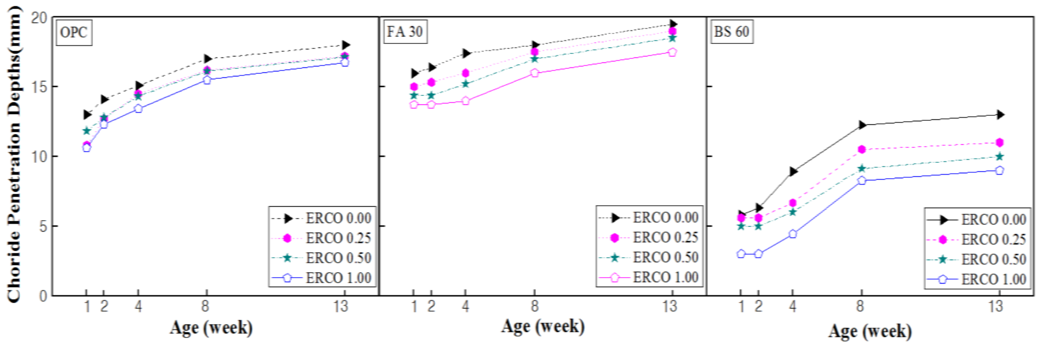

Figure 3. Influence of ERCO dosage on chloride penetration depth of concrete with different SCMs

3.4 Resistance to Sulfate Attack Depending on ERCO Dosages

The influence of ERCO dosage and different SCMs on the degree of sulfate attack on concrete depending on age is shown in Figure 4. In this case, there was no significant effect of ERCO on sulfate attack resistance of concrete. Based on this finding, the fatty acid from ERCO was determined not to have a noteworthy effect on the sulfate attack on concrete.

3.5 Porosity of Concrete Depending on ERCO Dosages

Figure 5 provides the results of MIP measurement with cumulative pore volume. As shown in the figure, generally, replacing ERCO decreases pore volumes in concrete systems. This confirms the validity of the pore-filling effect of ERCO with calcium salt by chemical reaction between fatty acid and calcium hydroxide. Furthermore, this is why the pore volume is lower for the concrete with fly ash consuming calcium hydroxide when considering its pozzolanic reaction. Class F has less than 10% CaO (Calcium Oxide) and Class C has more than 20% CaO. The CaO content for the fly ash used in this experiment was 3%. The LOI content was 2.50%. The CaO and LOI (loss on ignition referring to loss of carbon which remains in the ash) controls the pozzolanic reaction. This experiment used Class F fly ash, which is the predominant ash worldwide. For blast furnace slag, the original pore volume was lower than the other SCMs. This is considered the result of high-volume replacement of slag which has a smaller particle size. Meanwhile, ERCO still decreased the pore volume in concrete with BS.

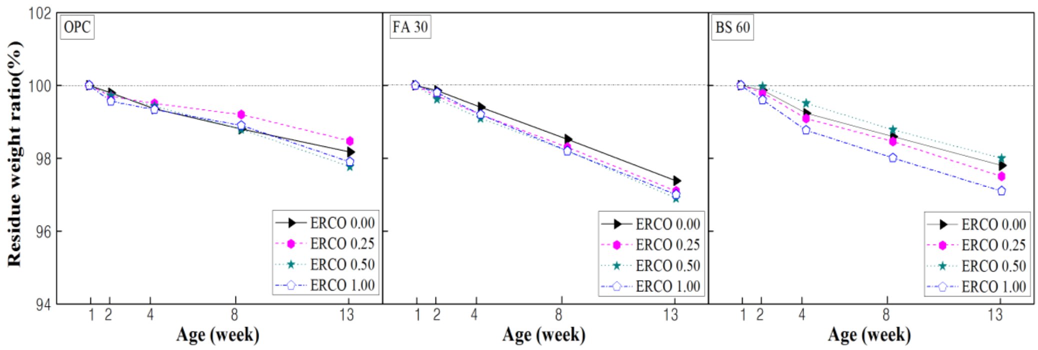

Figure 4. Influence of ERCO dosage on sulfate attack resistance of concrete with different SCMs

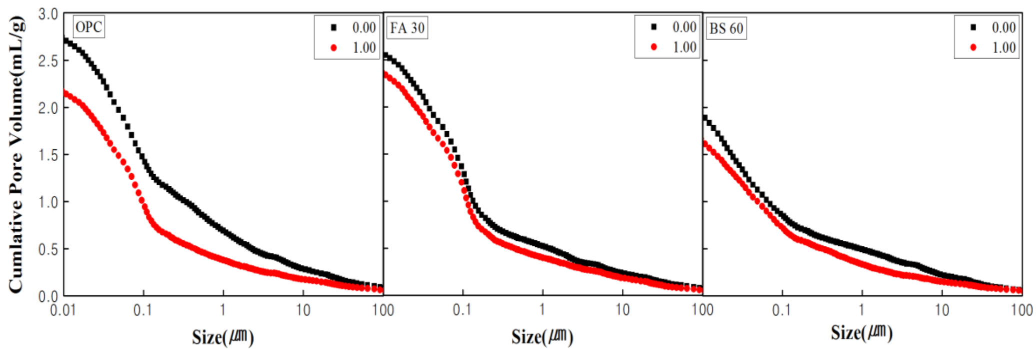

Figure 5. Influence of ERCO dosage on pore system of concrete

4. Conclusions

In this paper, the results of various durability tests were reported including resistance to carbonation, sulfate attack and chloride penetration of concrete with a high-volume of SCMs based on different amounts of added ERCO dosages. From a series of experiments, the following conclusions were drawn: 1) Concrete mixture with fly ash (FA) or blast furnace slag (BS) showed a lower compressive strength at an early stage (3-10 days), while the compressive strength was recovered after 180 days. This is considered a result of pozzolanic reaction or slag’s additional hydration—not because of ERCO in the concrete mixture. Thus, the compressive strength of concrete was not affected by the various dosages of ERCO. 2) From a series of tests on concrete durability, ERCO in concrete mixture increased carbonation resistance and decreased chloride penetrating depth of concrete. This was due to soap particles (from reaction of ERCO with calcium hydroxide) filling the concrete pores thereby reducing the permeability of concrete. 3) From the MIP test, it was shown the decreased volume of pore when the concrete contained ERCO. In addition, the influence of decreasing pore volume with ERCO was decreased when the concrete contained SCMs. However, still ERCO decreases the volume of pore in concrete system. Therefore, ERCO in concrete system was shown to decrease the pore volume of concrete and thus improve durability against outer environmental factors.

Acknowledgements. This study was supported by Ministry of Education, Science and Technology for the supporting outstanding researcher in local university under grant #NRF-2012R1A1A4A01018971.

References

[1] S. Mindess, J. Young, D. Darwin, Concrete, 2002.

[2] P. Mehta, J. Monteiro, Concrete: Microstructure, Properties, and Materials, 2013.

[3] P. Mehta, Global Concrete Industry Sustainability-Tools for moving forward to cut carbon emissions, Concr. Int. 31 (2009) 45.

[4] V. Malhotra, Role of supplementary cementing materials in reducing greenhouse gas emissions, Infrastruct. Regen. Rehabil. Improv. Qual. Life through Better Constr. Int. Conf. (1999) 27–42.

[5] G. Li, Properties of high-volume fly ash concrete incorporating nano-SiO 2, Cem. Concr. Res. 34 (2004) 1043–1049.

[6] R. Feldman, G. Carette, V. Malhotra, Studies on mechanics of development of physical and mechanical properties of high-volume fly ash-cement pastes, Cem. Concr. Compos. 12 (1990) 245–251.

[7] K. Sisomphon, L. Franke, Carbonation rates of concretes containing high volume of pozzolanic materials, Cem. Concr. Res. 37 (2007) 1647–1653.

[8] S. Han, Autogenous Shrinkage of high Strength Mortar Using Emulsified Waste Cooking Oil, Cheongju University, Cheongju, 2011.

Received: August 2, 2014