Fundamental Properties of Antiwashout Underwater Concrete Mixed with Mineral Admixtures

Han-Young Moon,* Kook-Jae Shin, Yong-Kyu Song*****

Abstract

This paper discusses laboratory evaluations to assess the physical properties of antiwashout underwater concrete (AWC) containing pozzolanic materials such as fly ash (FA), blast furnace slag (SG) and metakaolin (MK). For the experiments, pH value, suspended solids, slump flow, efflux time and compressive strength were tested. According to the results from compressive strength test, MK10 showed the very high compressive strength characteristic during the entire curing days, but the rate of strength development was decreased as time goes by.

1. Introduction

With the focus on good quality of concrete structures, supplementary cementitious materials, like pozzolanic materials, have gained popularity. In fact, the use of pozzolanic materials in the manufacture of concrete has a long, successful history and their use pre-dates the invention of modern day portland cement by almost 2000 years. Today, most concrete producers worldwide recognize the value of pozzoanic enhancements to their products and where they are available they are becoming a basic, even a routine, concrete ingredient. No exceptions exist in antiwashout underwater concrete field as well. In this study, therefore, an application of pozzolanic materials, such as fly ash, blast furnace slag and metakaolin, to the antiwashout underwater concrete and physical properties of those pozzolans containing AWC was evaluated.

2. Materials and mixture proportions

2.1 Materials

For the basic cementitious material, ordinary portland cement (OPC) was used and fly ash, blast furnace slag and metakaolin were employed for the supplementary cementitious materials. Chemical compositions and physical properties of OPC and those pozzolanic materials are shown in Table 1.

Table 1. Chemical compositions and physical properties of OPC, FA, SG and MK

Item / Type	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ig. loss (%)	Specific gravity	Specific surface (cm^2/g)
OPC	21.95	6.59	2.81	60.10	3.32	2.11	2.58	3.15	3,112
MK	53.00	38.00	2.50	0.02	0.05	-	0.5	2.63	12,000
FA	67.70	25.00	2.85	2.00	0.90	-	3.47	2.15	3,274
SG	32.30	14.80	0.40	44.10	5.50	1.00	1.10	2.80	4,580

* Professor, Department of Civil Engineering, Han Yang University
** Ph. D. Candidate, Department of Civil Engineering, Han Yang University
*** Ph. D. Department of Civil Engineering, Han Yang University

A well-graded, crushed stone aggregate with maximum particle size of 25mm and washed sand with a fineness modulus of 2.66 were used. Physical properties of aggregates are shown in Table 2.

Table 2. Physical properties of aggregates

Type \ Item	Specific gravity	Absorption (%)	Percentage of solids (%)	F.M.	Abrasion value (%)	Unit weight (kg/m^3)
Fine agg.	2.60	0.80	56.8	2.83	-	1,475
Coarse agg.	2.54	0.78	65.4	6.47	28.9	1,741

A liquid-based cellulosic antiwashout underwater admixture (AWA) and a melamine-based high range water reducer (HRWR) had specific gravities of 0.8 and 1.23 respectively. Their properties are shown in Table 3.

Table 3. Chemical compositions and physical properties of chemical admixtures

Type \ Item	Main composition	Specific gravity	Dosage (W or C×%)	pH	Appearance
AWA	HPMC	0.8 ± 0.1	1.0 ~ 1.2	-	White powder
HRWR	Melamine	1.23 ± 002	1.8 ~ 2.1	10 ±1	Transparent liquid

2.2 Mixture proportions

As summarized in Table 4, the investigated mixtures were prepared with w/cm of 0.5, and OPC was partially replaced by MK, FA and SG with the proportions of 10%, 20% and 50% respectively. The mixtures are referred to as Plain, MK10, FA20, and SG50.

Table 4. Mixture proportions of antiwashout underwater concrete

Type \ Item	w/cm (%)	S/a (%)	Air (%)	Unit weight (kg/m^3)							Chemical admixture	
				W	C	G	S	MK	FA	SG	AWA (W X %)	HRWR (C X %)
Plain	50	42	4±1	210	420	938	674	-	-	-	1.20	1.80
MK10	50	42	4±1	210	378	905	671	42	-	-	1.20	1.80
FA20	50	42	4±1	210	336	918	660	-	84	-	1.20	1.80
SG50	50	42	4±1	210	210	924	664	-	-	210	1.20	1.80

3. Results and discussion

3.1 Resistance to segregation

The measured pH value and suspended solids of fresh antiwashout underwater concrete are summarized in Figure. 1. The amounts of suspended solids of fresh AWC mixed with FA and SG, as shown in Figure. 1, showed much higher than the plain, but in case of MK, the result was much lower than the plain. The reason of this result is assumed that the amount of replacement of MK was only 10% while FA and SG was 20% and 50% respectively. Because of non-hydraulic property of pozzolanic materials such as MK, FA and SG, the amount of suspended solids can be highly affected by replacements ratio. In addition, there is another important fact and that is about fast and high rate of hydration property of MK. This fact of MK could help the result of much lower amount of suspended solid than others. Meanwhile, FA contained AWC (FA20) showed the most much amounts of suspended solids among those tested specimens and even higher than SG50. The reason of this result is assumed that the incomplete combustive particles of FA absorbed some of added AWA which gives high viscosity to fresh cement paste. Hence the cementitious particles could be freer in water.

In the meantime, tested pH value of all specimens were in the range of 9.675~10.548, which was satisfied with under 12, specification of Korean Society of Civil Engineers.

3.2 Rheological properties

Generally AWC requires the higher rheological property because of its unique working circumstances, under water, so the consolidation of AWC wouldn't be possible. In this study, for the sake of proper rheological property, HPMC type AWA and melamine type HRWR were used together and additional improved fluidity could expected by partially replaced FA and SG for OPC. Tested all rheological properties are shown in Figure 2. As it can be seen from Figure 2, except MK10, highly advanced slump flow and efflux time (400mm reaching time measured by L-type box test) of FA20 and SG50 can be determined. However, in case of MK10, it can be clearly seen that the fluidity was somewhat inferior to the others, OPC, FA20 and SG50. With this result, an assumption can be considered that the fast and high rate of hydration property of MK, as mentioned above, slowed the fluidity of MK10. Measured slump flow value of MK10, however, was 45.3cm and that is in the range of 45~55cm which is the specification of KSCE for general circumstance. Additional improved rheological properties of FA20 and SG50 are due to globular shape and glassy surface texture of those mineral admixtures.

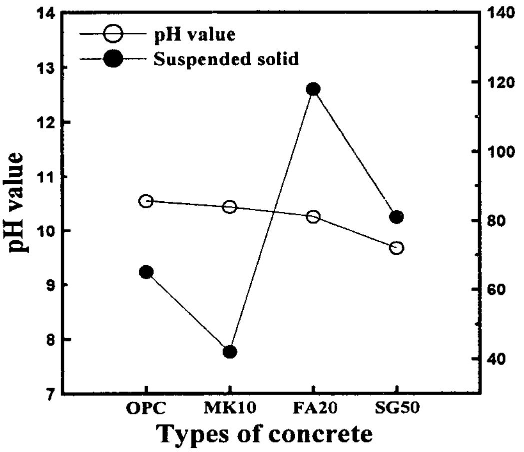

Figure 1 Segregation properties of AWC

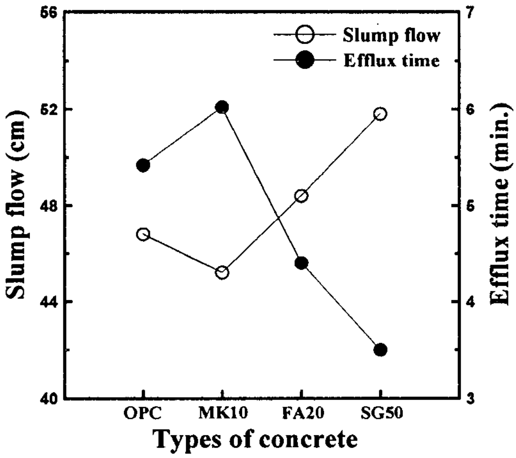

Figure 2 Rheological properties of AWC

3.3 Compressive strength

The measured compressive strengths at different ages are shown in Figure. 3, where each value is the average of three measurements and is expressed with ratio based on compressive strength of plain. As it can be seen from Figure.3, there were two ways of casting method, and in both cases, MK10 showed very high compressive strength ratio at all tested age. Moreover, in case of air conditioned specimens, even though there is a decreasing tendency with increasing curing age while FA20 and SG50 is increasing, the compressive strength ratio at 91 days of curing is still higher than that of plain and the other specimens. This marvellously high compressive strength property of MK is due to its very fast and high hydration characteristic. Differently from MK10, FA20 and SG50 started with much lower compressive strength than the plain at early age. However, by passing 28 days of curing, strength development occurred by steady pozzolanic reaction from FA and SG with potlandite, and

eventually, at the age of 91 days, compressive strength of FA20 and SG50 recorded 6.7 and 12.4% (cast in air) and 0.8 and 7.9% (cast in water) higher than that of plain respectively.
Fig. 4 shows the compressive strength ratio of specimens placed under water versus in air placed specimens at the age of 7 and 28 days. As it can be seen from figure, all tested specimens were satisfied with the specification of Korean society of civil engineers which is over **60%** at **7** days and over **70%** at **28** days.

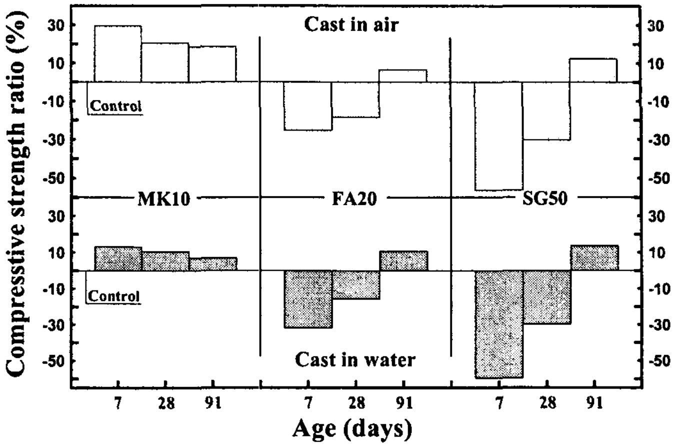

Figure 3 Compressive strength ratio of AWC

4. Conclusion

(1) The amounts of suspended solids of fresh AWC mixed with FA and SG showed much higher than the plain, but in case of MK, the result was lower than the plain. However, every measured value was satisfied with the specification of KSCE with the value of under 150mg/l.
(2) Rheological property was greatly improved by partially replacing FA and SG for OPC, but because of fast and high rate of hydration property of MK, the fluidity of MK10 was slowed.
(3) Due to the faster rate of hydration property, MK10 showed very high compressive strength characteristic through the whole curing age. FA20 and SG50 started with much lower compressive strength than the plain, but with the steady pozzolanic reaction, their compressive strength overcame the plain's of it, at 91 days of curing.
(4) A general overall conclusion would be that the incorporation of mineral admixtures leads improved quality and performance to antiwashout underwater concrete, but more caution on fluidity of MK contained AWC should be paid.

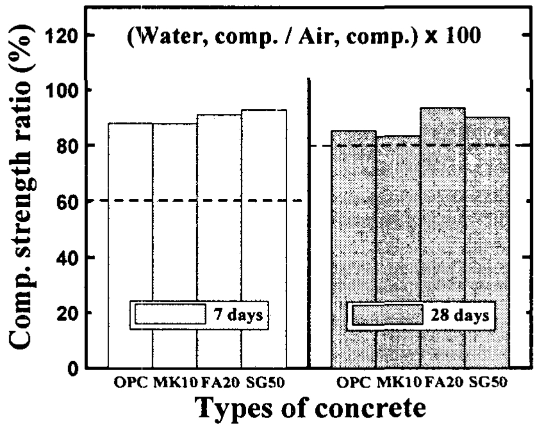

Figure 4 Compressive strength ratio at 7 and 28 days of curing

References

1. H.Y. Moon, K.J. Shin, C.S. Lee., Journal of the KCI, Vol.14, No.3, pp. 409~419, 2002
2. C.-S. Poon, L. Lam, S.C. Kou, Y.-L. Wong, Ron Wong, Cement and Concrete Research, Vol. 31, pp. 1301~1306, 2001
3. S. wild and J.M. Khatib, Cement and Concrete Research, Vol. 27, No. 1, pp. 137~146, 1997
4. Khayat K. H. and Sonebi, M., ACI Material Journal, Vol. 98, No. 4, pp. 289~295, 2001