Fundamental Properties of Antiwashout Underwater Concrete Mixed with High Reactivity Metakaloin

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Abstract

High reactivity metakaolin (HRM) is a manufactured pozzolan produced by thermal processing of purified kaolinitic clay. Field performance and laboratory research of concrete containing HRM have demonstrated its value for bridge decks, bridge deck overlays, high-strength concrete and masonry products.

This paper discusses laboratory evaluations to assess the physical properties of antiwashout underwater concrete (AWC) containing HRM, such as pH value, suspended solids, slump flow, and compressive strength. There were not much variations of pH value with the changing HRM contents, but suspended solid test showed that the amount of suspended solids of AWC with 10 and 20% of HRM were reduced in comparison with plain. Due to the fast hydration and reaction property of HRM, slump flow was decreased with increasing HRM contents. According to the results of compressive strength test, AWC with 10 and 20% of HRM showed higher strength characteristic than plain at all curing ages.

1. Introduction

With the focus on good quality of concrete structures, supplementary cementitious materials, like a pozzolanic material, 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. Most pozzolans used in the world today are byproducts from other industries, such as coal fly ash, blast furnace slag, or silica fume, and high reactivity metakaolin (HRM) is one of those manufactured pozzolanic mineral admixtures. Many researchers have reported the enhanced performance characteristics of cement-based mortars, concretes and related products containing HRM.

In this study, therefore, an application to the antiwashout underwater concrete and physical properties of HRM, such as pH value, suspended solids, and compressive strength, were evaluated.

2. Materials and mixture proportions

2.1 Materials

KS type I cement (OPC), similar to ASTM type I cement, was used, and a high reactivity metakaolin were employed for the supplementary cementitious materials. They had specific gravities of 3.15, and 2.63 respectively. The blaine's fineness of the cement and HRM were 3,112 and 12,000 cm^2/g respectively. Chemical compositions and physical properties of cement and HRM are shown in table 1.

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Table 1. Chemical compositions and physical properties of cement and HRM

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
HRM	53.00	38.00	2.50	0.02	0.05	-	0.5	2.63	12,000

A well-graded, crushed stone aggregate with maximum particle size of 25mm and a siliceous sand with a fineness modulus of 2.66 were used. The bulk specific gravities of the coarse aggregate and sand were 2.59 and 2.66 respectively, and their absorption values were 0.78 and 0.80% respectively. Physical properties of aggregates are shown in table 2.

Table 2. Physical properties of aggregates

Item / Type	Specific gravity	Absorption (%)	Percentage of solids (%)	F.M.	Abrasion value (%)	Unit weight (kg/m^3)
Fine agg.	2.59	0.80	56.4	2.83	-	1,473
Coarse agg.	2.66	0.78	64.9	6.51	28.6	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

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

2.2 Mixture proportions

The investigated mixtures were prepared with w/cm of 0.5, and HRM was replaced for 10~30%(wt. %). Each concrete is indicated in table 4. The mixtures are referred to as Plain, HRM10, HRM20, and HRM30.

Table 4. Mixture proportions of antiwashout underwater concrete

Item / Type	w/cm (%)	S/a (%)	Air (%)	Unit weight (kg/m^3)					Chemical admixture	
				W	C	HRM	G	S	AWA (W X %)	HRWR (C X %)
Plain	50	42	4±1	210	420	-	951	673	1.20	1.80
HRM10	50	42	4±1	210	378	42	947	671	1.20	1.80
HRM20	50	42	4±1	210	336	84	943	668	1.05	1.90
HRM30	50	42	4±1	210	294	126	939	665	1.00	2.10

3. Results and discussion

3.1 pH value and suspended solids

The measured pH value and suspended solids of antiwashout underwater concrete are given in Fig. 1.

As shown in Fig. 1, suspended solids of AWC mixed with HRM had a tendency to increase with increasing mixing ratio, 10, 20, and 30 %, and each mixture's measurement was 25.5, 34, and 54 mg/l respectively. Unlike other pozzolanic admixtures, such as fly ash and blast furnace slag and they usually show higher amount of suspended solids than OPC, HRM10 and HRM20 showed lower amount characteristic than OPC. In addition, pH value of AWC with HRM was in the range of 11.481~11.876, which was satisfied with under 12, specification of Korean Society of Civil Engineers (KSCE).

3.2 Slump flow

The results of the slump flow are shown in Fig. 2, where each value was the average of two measurements. It can be seen that the slump flow characteristic has decreasing tendency with increasing HRM contents. An assumption can be considered that the high reactivity of HRM caused high rate of hydration of cement paste.

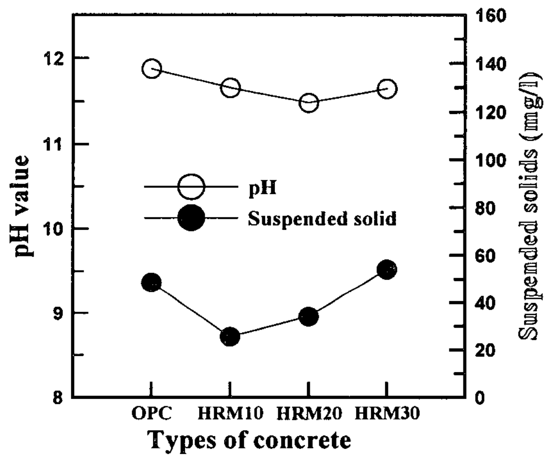

Fig. 1 pH value of AWC

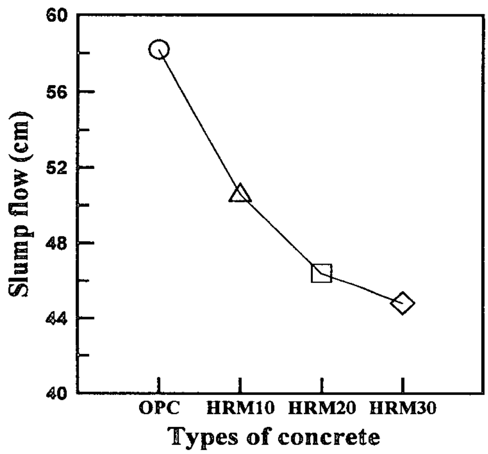

Fig. 2 Slump flow of AWC

3.3 Compressive strength

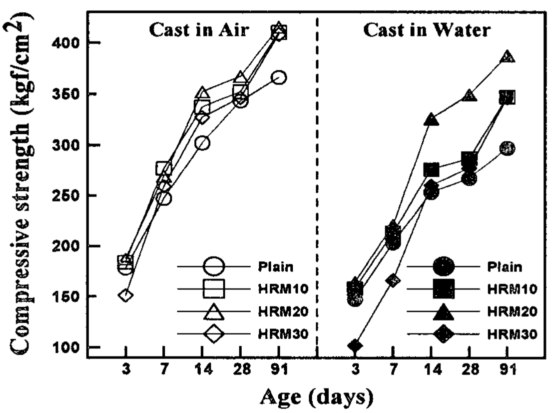

Fig. 3 Compressive strength of AWC

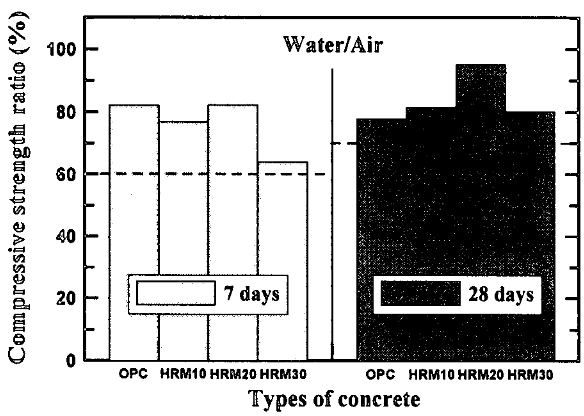

Fig. 4 Compressive strength ratio of AWC

The measured compressive strength at different ages are shown in Fig. 3, where each value was the average of three measurements. As shown in Fig.3, there were two ways of casting method, and in both cases, HRM10 and HRM20 had higher compressive strength than the plain at all tested ages from 3 to 91 days. Differently from above, HRM30 started with lower compressive strength than the plain at early age, but by passing 3 (air placing condition) and 7 (under water placing condition) days of curing, strength compensation occurred rapidly due to the pozzolanic reaction of HRM with potlandite. Eventually, at the age of 91 days, compressive strength of HRM30 recorded 11.5 and 16.5% higher than that of plain respectively.

Comparing the different pozzolanic materials, such as fly ash and blast furnace slag which are generally known to have slower hydration property, compressive strength development phenomenon showed that the rate of pozzolanic reaction of HRM is greater than that of other pozzolans, and even faster than silica fume which shows quite fast reaction characteristic.

From Fig. 3, a particular characteristic of HRM within AWC could be detected that until 14 days of curing, significant strength development was occurred, but after that of critical time, strength development was slowed. It may be regarded as the end of pozzolanic reaction. It is important to note that, however, although the rate of HRM reaction becomes slower after prolonged curing, there was still a considerable increase of compressive strength from 28 to 91 days.

Fig. 4 shows the compressive strength ratio of specimens placed under water contrast with in air placed specimens at the age of 7 and 28 days. The result showed that the mixtures were far ahead of 60% at 7 days, 70% at 28 days, specification of Korean society of civil engineers (KSCE).

4. Conclusion

(1) Suspended solids of AWC mixed with HRM had a tendency to increase with increasing mixing ratio, 10, 20, and 30 %, and each mix's measurement was 25.5, 34, and 54 mg/l respectively. The pH value of all mixtures is in the range of 11.5 ~ 11.9 that is satisfied with quality criteria of KSCE.

(2) Because of the high reactivity of HRM, slump flow characteristic has decreasing tendency with increasing HRM contents.

(3) Due to the faster rate of pozzolanic reaction characteristic, HRM10 and HRM20 had higher compressive strength than the plain at all tested ages from 3 to 91 days. With the quality criteria from KSCE about compressive strength ratio at the age of 7 and 28 days, all mixtures were satisfied.

(4) A general overall conclusion would be that the incorporation of high reactivity metakaolin leads improved quality and performance to antiwashout underwater concrete, with the amount of 10 to 20% of replacements. Further comprehensive investigations, however, should be performed to cover the effect of different percentages of HRM as cement replacement and different w/cm on concrete properties.

References

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