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In-Situ Application of High-Strength Antiwashout Underwater Concrete

Han-Young Moon[1)*] and Yong-Kyu Song[2)]
[1)]*Dept. Civil Engineering, Hanyang University, Seoul, Korea*

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Abstract

Recently, the construction of underwater structures has been gradually increased, but underwater concrete got some problems of quality deterioration and water contamination around cast-in-situ of construction. In addition, massive underwater structures such as LNG tank, underwater concrete structures of large and continuous high-strength subterranean wall under water are being demanded lower heat of hydration. In this paper, the mechanical properties of high-strength antiwashout underwater concrete (HAWC) containing with two kinds of mineral admixtures respectively were investigated. On the basis of these results, the pH value and suspended solids of HAWC manufactured in the mock-up test were 10.0□11.0 and 51 mg/ℓ at 30 minutes later, respectively, initial and final setting time were about 30, 37 hours, and the slump flow was 530±20┬m. In the placement at a speed of 27 m^3/hr, there was no large difference in flowing velocity with or without reinforcing bar, and flowing slope was maintained at horizontal level. Compressive strength and elastic modulus of the cored specimen somewhat decreased as flowing distance was far; however, those of central area showed the highest value.

Keywords : underwater structure, high-strength antiwashout underwater concrete, suspended solids, mock-up test, flowing velocity

1. Introduction

Recently, the progress of underwater concrete has been developed through improved methods of concrete placement, the development of chemical admixtures and the use of supplementary cementitious materials in other words, ground granulated blast-furnace (BFS), silica fume (SF) and fly-ash (FA) etc. Several researchers have reported improvement in washout resistance, in minimization of the environmental contamination, in-place properties of underwater concrete when the concrete incorporates antiwashout admixtures.[2,3,10,11)]

When underwater concrete is placed under water, cement particles in concrete are washed away, which it induces concrete not only to deteriorate uniformity, adhesion to reinforcing bar and joint part but to produce undesirable influence on the environmental and ecological phase by contaminating the quality of water around cast-in-situ of underwater concrete.

So, antiwashout underwater admixture (AWA) is used to enhance the stability of fresh cement matrix, in manufacturing antiwashout underwater concrete. Such admixture is used in self-levelling concrete to intensify resistance to bleeding, segregation (suspended solids & pH), and surface settlement.

Particularly, AWA is increasingly being used in cement matrix products to improve cohesiveness. Hydroxypropyl methyl cellulose (HPMC) derivative is believed to increase the viscosity of mixing water due partially to the adherence of long-chain polymer molecules to the periphery of water molecules, thereby adsorbing and fixing part of the water.[4)]

In recent, the instance of construction applied for underwater concrete structures such as a bridge, the foundation and repair of a bridge is increased according as AWC contributes largely to minimize environmental pollution of construction site and to improve quality of concrete underwater concrete.[5-7)] In addition, massive underwater structures such as underwater concrete structures of extra large and continuous subterranean wall of high-strength underwater or into the sea are being demanded to satisfy with lower heat evolution amount and high-strength.

Therefore, effective FA and BFS among mineral admixtures is used together with AWA and high range water re-

* *Corresponding author*
Tel.: +82-2-2290-0323 Fax : +82-2-2293-9977
E-mail address: moon77@hanyang.ac.kr

ducer not only to decrease heat evolution amount but also to improve the long-term strength, the properties and durability of concrete. The main objective in this paper is to investigate the mechanical properties of HAWC in laboratory and evaluate the possibility of in-situ application of under water construction through the mock-up test.

2. Experimental program

2.1 Materials

2.1.1 Cement

Ordinary portland cement (OPC) was used and FA and BFS were employed for the supplementary cementitious materials in order to improve workability and performance of concrete. The blaine fineness of the cement, FA and BFS were 3,112, 3,270 and 4,380cm^2/g respectively. Chemical compositions and physical properties of cement and mineral admixtures were presented in Table 1.

2.1.2 Aggregates

A well-graded, crushed stone coarse aggregate with nominal particle size of 25mm in laboratory and 20mm in mock-up test respectively and a siliceous washed sea sand with a fineness modulus of 2.83 were used. Physical properties of aggregates were shown in Table 2.

2.1.3 Chemical admixtures

A water-soluble cellulose-based AWA and a melamine-based HRWR had specific gravities of 0.8 and 1.23 respectively. In this study, melamine-based HRWR was used to obtain adequate workability. Chemical compositions and physical properties of chemical admixtures were displayed in Table 3.

2.2 Mixture proportions

In order to manufacture HAWC, the investigated mixtures were prepared with W/Cm of 0.36 and targeted strength 50MPa through preliminary test, FA and BFS were replaced for 10~30%, 40~60%, respectively. For each concrete was indicated in Table 4.

The mixtures were referred to as Control, FA10, FA20, FA30, BFS40, BFS50, and BFS60. HAWC incorporated high contents of cementitious materials to reduce aggregate weight, thus enriching flow characteristics. The HRWR and AWA dosages for given workability and stabilization must be reduced due to increase in cementitious material content.

It was noted that for the majority of the high-strength mixtures, a large part of the cement was substituted by FA or BFS to decrease the heat of hydration and improve fresh and hardened characteristics of the concrete.

In Table 4, the mixture in the case of HAWC was prepared with W/Cm of 0.37 that was specified strength of 49.1MPa. In particular, cement was replaced by 50% of ground granulated blast furnace slag to decrease the heat of hydration and improve fresh and hardened characteristics of the concrete.

Table 1 Chemical compositions and physical properties of cement and mineral admixtures

Types \ Items	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ig. Loss (%)	Specific gravity	Blaine's fineness (cm^2/g)
OPC	21.95	6.59	2.81	60.10	3.32	2.11	2.58	3.15	3,112
FA	67.70	25.00	2.85	2.00	0.90	-	3.47	2.15	3,270
BFS	34.34	15.76	0.09	42.19	6.81	0.16	-	2.90	4,380

Table 2 Physical properties of aggregates

Types \ Items	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	-	1,563
Coarse agg.	2.66	0.78	64.9	6.51	28.6	1,741

Table 3 Chemical compositions and physical properties of chemical admixtures

Types \ Items	Main composition	Specific gravity	Standard dosage (%)		pH	Appearance
			Water	Cement		
AWA	HPMC	0.8 ±0.1	0.8~1.5	-	-	White powder
HRWR	Melamine	1.23 ±002	-	0.5~3.0	10 ±1	Transparent liquid

Table 4 Mixture proportions of laboratory and mock-up test

	W/Cm =0.36							0.37*
	Control	FA (%)			BFS (%)			
		10	20	30	40	50	60	50
Cement, kg/m³	590	531	472	413	354	295	236	295
Fly ash, kg/m³	–	59	118	177	–	–	–	-
Ground granulated blast furnace slag, kg/m³	–	–	–	–	236	295	354	295
Water, kg/m³	210	210	210	210	210	210	210	220
Coarse aggregate, kg/m³	868	868	841	828	858	856	853	850
Sand, kg/m³	612	603	593	584	605	603	602	604
Melamine-based high range water reducer, C× wt.%	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.0
Cellulose antiwashout admixture, W× wt.%	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.0

* Mixture proportion of mock-up test

2.3 Testing methods

2.3.1 Heat of hydration

Heat of hydration of cement pastes of 0.5 W/Cm was measured till 72 hours at 20℃ with microscopic calorimeter (Tcc-26) manufactured by Tokyorico company that has 100 (Ω) of resistance, 1.995 (V) of heater voltage and 286.562 (J).

2.3.2 Mixing method

The mixtures of concrete were prepared in a forced circulating mixer. The batching sequence consisted of mixing the sand and cementitious materials, then adding 100% of the mixing water with the HRWR. The coarse aggregate was then added during mixing. The powdered AWA was used to mix with cementitious materials prior to addition to concrete. The concrete was mixed for totally 2min.

2.3.3 Suspended solids and pH value

In accordance with underwater dropping test of "quality specification of antiwashout underwater admixture for concrete" of Korean Society of Civil Engineers (KSCE), after filling 80 *ml* distilled water in 1000 *ml* beaker, 500g concrete sample was dropped into beaker which was full of water, suspended 60*ml* of the upper part in 3min. was collected, and suspended solids in 40 *ml* out of that through filter were measured, and the others was used for measuring pH value.

2.3.4 Slump flow

Slump flow is measured in accordance with "slump flow test method of antiwashout underwater concrete" of KSCE. After concrete sample was filled with slump cone and was uniformed, slump cone was lifted in accordance with slump test method of KS F 2402. After lifting slump cone in 5 min. the maximum diameter and in that direction crossed at right angles were measured. Mean value of diameter measured at two points was determined as slump flow.

2.3.5 V-type box

V-type box for efflux time represented in Fig. 1 corresponds to the measurement of efflux time when opening after filling concrete in V-type funnel in order to measure the flowability of concrete.[1)]

2.3.6 U-type box

U-type box for head difference shown in Fig. 2 corresponds to the measurement of head difference between left side and right side when lifting compartment after filling concrete in one side in order to investigate the filling property of concrete.[1)]

2.3.7 Compressive strength

After the specimens for HAWC were cast without any consolidation under water by "manufacturing method in water for compressive strength test of antiwashout underwater concrete," of KSCE like Fig. 3, compressive strength underwater specimens is measured in accordance with KS F 2405 and these results were compared with measured strength of specimens normally consolidated in air.

2.4 Mock-up test

The mock-up test form was manufactured as 1.5m, 0.8m and 12m of width, height and length, respectively, to evaluate the properties of the fresh and hardened HAWC as shown in Fig. 3 (a). Tremie was installed at the midpoint of mock-up test form, and in advance water was filled up, and placed concrete would be possible of slipping from the center to the left and right end. As shown in Fig. 3 (b) a reinforcing bar was embedded in one side of mock-up test form,

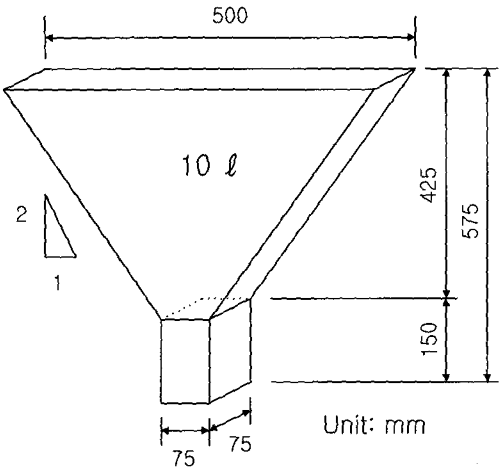


Fig. 1 V-type box

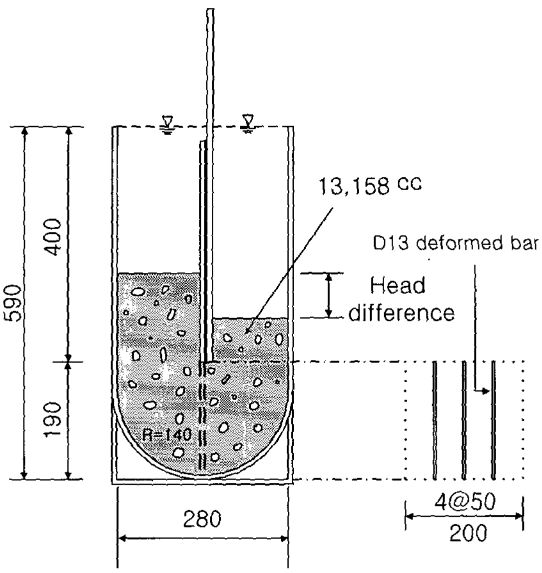


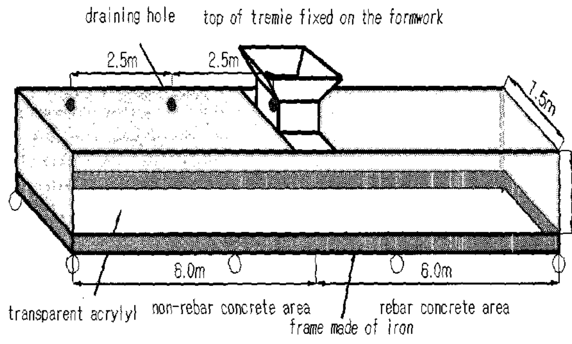
Fig. 2 U-Type box

and was not embedded in other side of it. The front part of it was manufactured by transparent acryl board to observe flowing situation of concrete. The compressive strength and modulus of elasticity of cored specimen in reinforced and non-reinforced area at the age of 14, 28 and 56days were measured respectively after concrete was hardened.

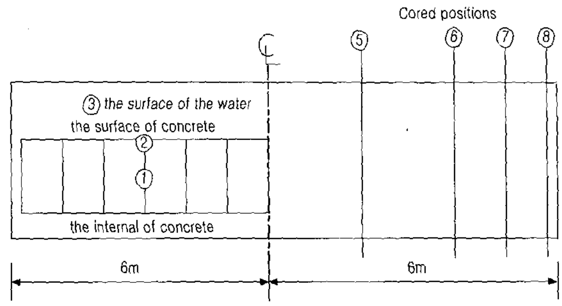
3. Laboratory test results

3.1 Heat of hydration in cement pastes

Antiwashout underwater concrete compared with land-based concrete has following characteristics that unit water content and unit cement content are high enough to obtain workability of concrete for not washing away. When large sized underwater concrete structure or massive underwater concrete foundation and LNG tank are constructed, FA and BFS as supplementary cementitious were used with a view to controlling temperature rise. Therefore, in order to invest



(a) Shape and size of mock-up



(b) Set-up of thermistor (reinforcing bar area) and cored positions

Fig. 3 Mock-up test form for in-situ application

igate the decrease effect of heat of hydration in cement paste mixed with FA and BFS respectively, heat of hydration after mixing cement paste till 72 hours was shown in Fig. 4. In this Fig. 4, while heat of hydration of ordinary portland cement paste in 24 hrs. elapsed time was about 30 cal/g, the cases of cement paste mixed with FA and BFS were 23 ~ 27 cal/g and 16 ~ 23 cal/g respectively according to replacement ratios. The difference of heat of hydration between only ordinary portland cement paste and cement paste mixed with mineral admixtures was considerably grown in 72 hours elapsed time. It was meaned that C_3A and C_3S influencing hydration of heat in cement were decreased by replacement of mineral admixtures.

3.2 Characteristics of fresh HAWC

3.2.1 Underwater segregation resistance

When concrete is placed underwater construction, cement particles washed away by water erosion is resulted in the deterioration of quality of concrete, and environmental pollution around in-situ area. In hence, it was reported that the resistance to segregation is one of the most fundamental properties of AWC. The methods evaluating and comparing with resistance to segregation are following as: washout loss test, analysis of pH value and suspended solids and compressive strength ratio cast in water/air etc. analysis of pH value and suspended solids are chiefly used as standard

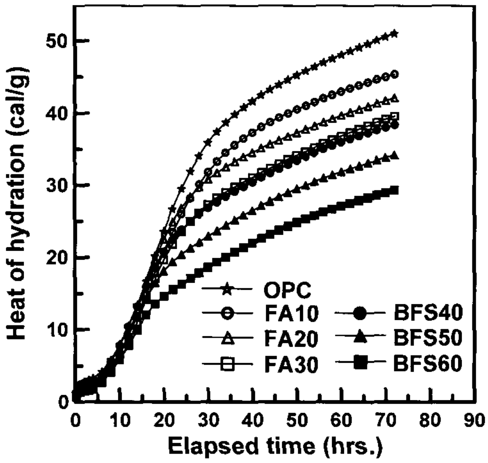


Fig. 4 Heat of hydration in cement pastes

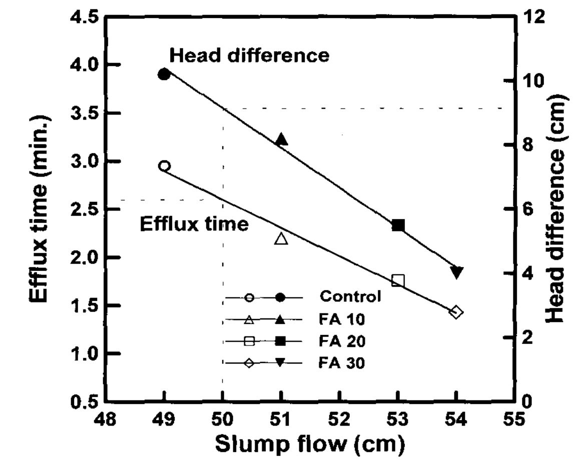


Fig. 6 Workability of HAWC mixed with FA

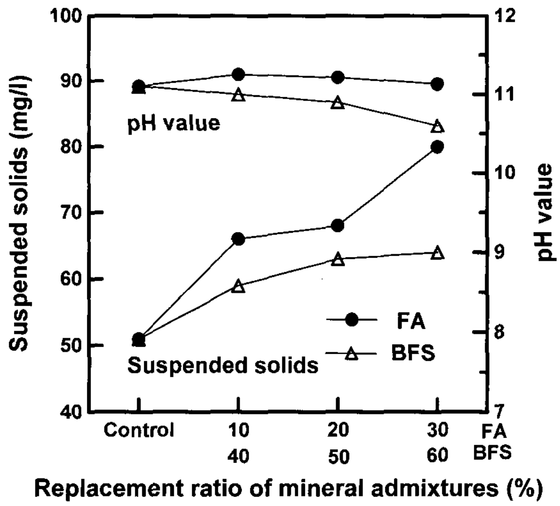


Fig. 5 pH value and suspended solids of HAWC

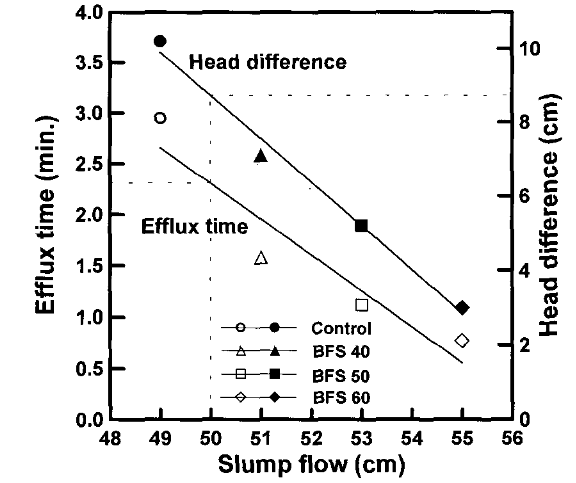


Fig. 7 Workability of HAWC mixed with BFS

among these methods. The measured pH value and suspended solids of HAWC cast after mixing with 2 types of mineral admixtures by each 3 steps in order to investigate the degree of segregation are summarized in Fig. 5. As shown in this picture, suspended solids of HAWC mixed with FA and BFS respectively were increased with increasing mixing ratio and their measurements were 66～80 and 58～63 *mg/ℓ* respectively, compared as suspended solids of HAWC without any mineral admixtures is 50 *mg/ℓ*.

The reason why suspended solids of concrete mixed with mineral admixtures were increased with increasing mixing ratio was due to the occurrence of cement particles loss by adsorption of AWA dissolved in mixing water to mineral admixtures. In particular, the reason that the suspended solids of HAWC with FA were a bit higher than the suspended solids of HAWC with BFS was owing to adsorption of AWA dissolved in mixing water to incomplete combustive particles of FA. In addition, pH value of HAWC with mineral admixtures was in the range of 10.6～11.3 that was satisfied with fewer than 12 of standards of KSCE.

3.2.2 Workability

Besides slump flow, V-type box for efflux time and U-type box for head difference were measured to evaluate workability of HAWC. Interrelation of these measurements was presented in Figs. 6 and 7.

In Fig. 6, while efflux time and head difference of control concrete without mineral admixtures were 3min. and 10cm respectively, HAWC mixed with FA was increased with increasing the replacement ratio, and efflux time and head difference of HAWC mixed with FA represented a linear declining trend according to increasing the replacement ratio. Between these correlation coefficient of efflux time and head difference to slump flow could be known as over all 0.98 that was very good correlation forms

In addition, as Fig. 7, displayed the case of HAWC mixed with BFS, these results showed similar to HAWC mixed with FA, however, correlation coefficient of efflux time and head difference to slump flow showed as 0.89. As above experimental results, efflux time and head difference corresponding to 50cm of slump flow that were defined as the standard of workability estimation of HAWC were presented in Table 5. In Table 5, while efflux time and head difference equivalent to about slump flow of 50 cm in control concrete were 3min. and 10 cm respectively, it was indicated that HAWC mixed with two types of mineral admixtures were 2.3～2.6min. and 8.5～9.2cm respectively. That is to say, the workability of HAWC mixed with two types of FA and BFS compared with that of control concrete without mineral admixtures represented more superior result.

3.3 Mechanical properties of hardened HAWC

After 7 types of HAWC were cured during 91 days, the compressive strength ratio of concrete cast in water to in air was presented in Table 6.

The compressive strength of HAWC with mineral admixtures was a little smaller than that of control concrete without mineral admixtures in the early age according to increasing the mixing ratio of mineral admixtures, however, the former was highly increased in compressive strength compared with the latter due to the pozzolanic reaction and potential hydraulic property of mineral admixtures in the long-term.[9] In particular, it was indicated that compressive strength of HAWC with BFS 60% was got to about 68.5 MPa at the age of 91 days. This value was indicated in much higher than 50MPa of targeted compressive strength.

Table 5 Efflux time and head difference corresponding to 50cm of slump flow

Types \ Items	Slump flow (cm)	Efflux time (min.)	Head difference (cm)
Control concrete	49(100)	3.0(100)	10.2(100)
FA concrete	50(102)	2.6(86.7)	9.2(90.2)
BFS concrete	50(102)	2.3(76.7)	8.5(83.3)

( ) : The ratio of concrete mixed with mineral admixtures to control concrete without mineral admixtures (%)

flexural and tensile strength of AWC at the age of 28 days cast in water and air had a tendency of decreasing with increasing replacement ratio of FA and BFS compared with control concrete without mineral admixtures like land-based concrete. HAWC mixed with mineral admixtures had good coefficients of correlation over 0.96 irrespective of manufacturing method in water and in air. Specially, in the case of HAWC containing FA, flexural and tensile strength to compressive strength of HAWC cast in water were each in the range of 1/7～1/9 and 1/13～1/20 and in the case of HAWC containing BFS, were each in the range of 1/9～1/10 and 1/16～1/22. These results were at the same like the case of land-based concrete. As shown in this Table 6, the compressive strength ratios of HAWC cast in water and air were over 80% without regard to the types and mixing ratio of mineral admixtures and ages of concrete. The measured data were far ahead of over 60% at 7 days, 70% at 28 days, the specification of Korean society of civil engineers.

4. Mock-up test for in-situ application

4.1 Quality of HAWC

Table 7 showed the slump flow value, concrete temperature, pH value, suspended solids and air content of HAWC. These results were satisfied with "quality specification of antiwashout underwater admixture for concrete" of KSCE that was established in 1995. The results of suspended solids and pH value of sample acquired every 10 min. at the 0, 2.5 and 5.0m from placement position were presented in Fig. 8. In this Figure while pH value became 6.5 after rightly placing in mock-up test body irrespective of measured position, it was in the range of 10.0 - 11.0 in 30min. elapsed time. The reason was why it took 30 min. to reach the upper end and the position of acquired sample was located in the height of 65 cm from the bed.

Table 6 Mechanical properties of HAWC cast in water and air

Types \ Age(days)	Compressive strength (MPa)					Flexural strength**	Tensile strength**
	3	7	28	56	91		
Control concrete	29.7/35.1* (85)	40.3/42.3 (95)	52.4/54.2 (97)	57.0/59.5 (96)	59.8/62.0 (96)	6.6/7.4 (89)	3.9/4.0 (97)
FA10	27.9/30.8 (91)	34.1/37.2 (92)	47.9/49.6 (96)	55.4/58.3 (95)	60.3/62.7 (96)	6.4/6.8 (94)	3.4/3.7 (92)
FA20	23.3/27.2 (86)	31.3/33.6 (93)	47.5/48.9 (97)	56.1/59.3 (95)	61.5/63.8 (96)	5.9/6.4 (92)	3.1/3.3 (94)
FA30	21.4/25.6 (84)	29.5/31.4 (94)	46.7/47.8 (97)	56.7/60.1 (94)	62.7/64.8 (97)	5.2/5.4 (96)	2.3/2.8 (85)
BFS40	22.3/25.2 (89)	32.0/35.5 (90)	51.8/53.1 (97)	59.5/62.0 (96)	62.5/65.2 (96)	6.2/6.6 (94)	3.3/3.5 (94)
BFS50	17.2/21.2 (81)	29.6/34.6 (86)	51.3/52.5 (98)	61.7/63.7 (97)	65.2/67.2 (97)	5.8/6.1 (95)	2.8/3.2 (87)
BFS60	14.3/15.8 (90)	28.1/31.9 (88)	51.0/52.1 (98)	63.5/65.1 (97)	66.4/68.5 (97)	5.0/5.2 (96)	2.2/2.9 (79)

* Compressive strength of HAWC cast in water/ compressive strength of HAWC cast in air

** Flexural and tensile strength at 28 days

( ) : Compressive strength ratio of HAWC cast in water/ compressive strength of HAWC cast in air (%)

Table 7 Quality of HAWC

Type \ Items	Elapsed time (min.)	Slump flow (cm)	Air content (%)	Concrete temp. (□)	pH value	Setting time (hr.)	Suspended sol. (mg/ℓ)
Mock-up test	0	53.5	2.5	15	10.5	30 : 37	38
	90	51.5	2.4	14	10.8	-	39

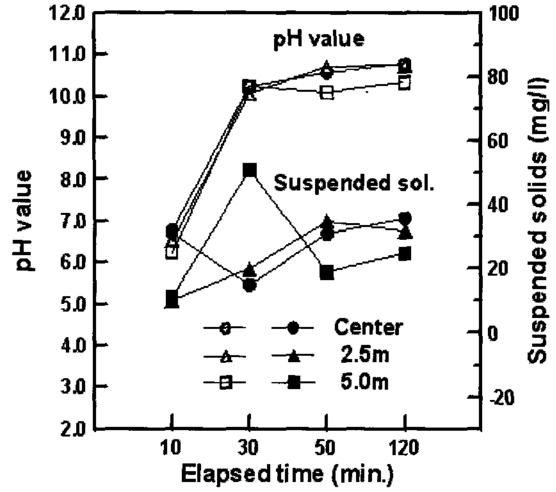


Fig. 8 pH Value and suspended solids of HAWC over elapsed time

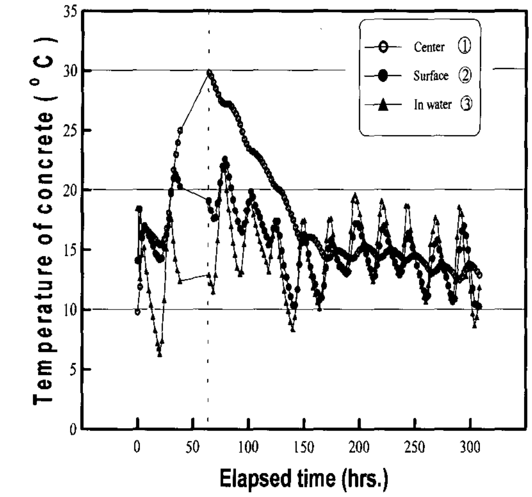


Fig. 9 Temperature of HAWC over elapsed time

On the other hand, if experiment results of suspended solids were converted as 500g concrete sample to 800*ml* water that is specified in KSCE, it would be shown as 51 mg/ℓ in 30min elapsed time and it showed 36, 32 and 25 mg/ℓ at 0, 2.5 and 5.0m from placement position in 120 min. elapsed time respectively. These values were by much smaller than 150mg/ℓ of "quality specification of antiwashout underwater admixture for concrete" of KSCE. After sample of HAWC was acquired from ready-mixed concrete truck, setting time was measured by molded specimen put in 15*l* water tank. Initial and final setting times were about 30 and 37 hours as shown in Table 7. In this mock-up test considerable retardation of setting time was attributed to delaying effect of AWA and low atmospheric temperature.

Therefore, in the case of applying for in-situ area similar to this mock-up test conditions, an operator have to construct underwater structures after enough to investigate in the consideration of atmospheric temperature and water temperature that will have a bad influence upon the quality of concrete.

4.2 Workability of HAWC

HAWC that was 53±2cm of slump flow was produced in the ready-mixed concrete batch plant and it was placed in the midpoint of mock-up test body with tremie as the 27 m^3/hr. of velocity. The flowing situation of HAWC under water was observed. It was indicated that the first produced HAWC kept going so horizontal level that concrete slope could be hardly measured after 5min. and the second produced high-strength underwater concrete still kept so horizontal level that could be scarcely measured after 28min.

At this time both reinforcing bar area and non-reinforcing bar area in the mock-up test body had no big difference in the flowing velocity phase, that is to say, reinforcing bar area kept going good workability according to elapsed time.

4.3 Temperature of HAWC

Fig. 9 showed the results of temperature of HAWC over elapsed time after thermistor set up internal concrete (①), concrete surface (②) and in water surface (③) in order to measure concrete temperature. In this Fig. 9, the temperature of HAWC in incipient stage after placement had a tendency to keep decreasing until 24 hours after placing due to retardation of hydration caused by low atmospheric temperature and cold water, but reached the 32.2℃ of highest peak in 54 hours because of increase in heat of hydration.

4.4 Mechanical properties of HAWC

Table 8 represented compressive strength and modulus of elasticity over flowing distance 0, 2, 4, 5 and 6 m from the center of the mock-up test body, placement position, at the

Table 8 Compressive strength and modulus of elasticity of HAWC

Types \ Items	Area	Distance from placement position (m)	Age (days) 14	28	56
Compressive strength* (MPa)	Center	0	34.1	44.0	58.9
	Non-reinforcing bar area	2 (⑤)	33.6	39.5	57.7
		4 (⑥)	33.1	37.5	53.2
		5 (⑦)	30.9	36.4	51.7
		6 (⑧)	28.9	35.3	52.7
	Reinforcing bar area	2 (⑤)	35.5	40.6	53.9
		4 (⑥)	34.8	37.8	56.3
		5 (⑦)	31.8	38.6	56.2
		6 (⑧)	28.7	39.4	54.5
Modulus of elasticity (×10^4 MPa)	Center	0	2.09	2.37	2.73
	Non-reinforcing bar area	2 (⑤)	2.08	2.22	2.57
		4 (⑥)	1.99	2.26	2.69
		5 (⑦)	2.00	2.25	2.67
		6 (⑧)	2.01	2.23	2.58
	Reinforcing bar area	2 (⑤)	2.10	2.34	2.63
		4 (⑥)	2.04	2.29	2.52
		5 (⑦)	1.94	2.26	2.62
		6 (⑧)	1.84	2.22	2.84

*: Average value of 3 core specimens

age of 14, 28 and 56 days after mock-up test of HAWC was carried out. Fig. 10 showed compressive strength of HAWC was increased with increasing ages and showed the highest value in the placement position, however, compressive strength of cored specimen at 28 days was smaller than specified strength 49.1MPa. Compressive strength of cored specimen at 56 days exceeded specified strength due to pozzolanic reaction and latent hydraulic property of ground granulated blast furnace slag. In addition, compressive strength was inclined to decrease with increasing flowing distance from placement position regardless existence of reinforcing bar. The reason was that water dilution of cement matrix and material segregation of concrete was occurred by water erosion. Modulus of elasticity of cored specimen over flowing distance was shown in Fig. 11. It was likely that modulus of elasticity had a little bit tendency to decrease with increase of flowing distance without regard to the existence of reinforcing bar. Although the compressive strength at the age of 28 days was about 44.2 MPa, modulus of elasticity was proved no more than the range of 2.2~2.4 × 10^4MPa.

5. Conclusions

From the analyses of experiment results, the replacement of mineral admixtures such as FA and BFS improved the fresh and hardened properties of antiwashout underwater

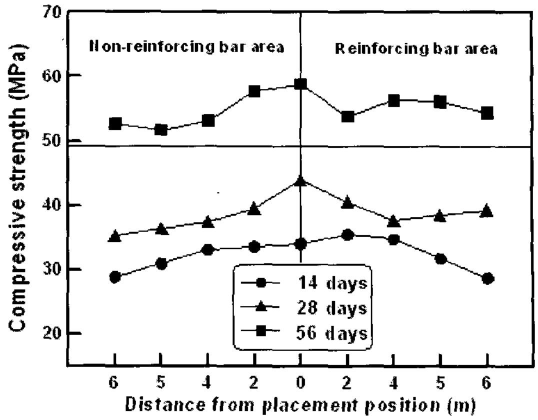


Fig. 10 Compressive strength of HAWC over flowing distance

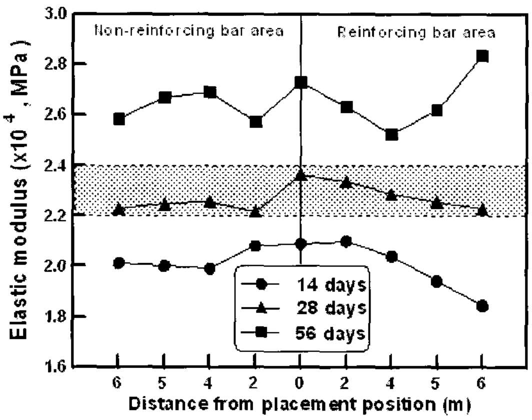


Fig. 11 Modulus of elasticity of HAWC over flowing distance concrete.

1) Suspended solids of HAWC mixed with FA and BFS respectively were increased with increasing the mixing ratio of mineral admixtures compared with those of control concrete, but their values were satisfied with specification of KSCE. Slump flow of HAWC mixed with FA and BFS respectively was improved according to increasing replacement ratio of mineral admixtures. Therefore, it was shown that mineral admixtures such as FA and BFS were very effective in improving flowability and workability.
2) The measured compressive strength of HAWC mixed with BFS was smaller than that of control concrete without any mineral admixtures in the early age in proportion to increasing the mixing ratio of mineral admixtures, but the former was highly increased in strength compared with the latter due to pozzolanic reaction and latent hydraulic property of mineral admixtures in the long-term.
3) From the observation of flowing condition of high-strength antiwashout underwater concrete with 53±2cm of slump flow and $27m^3$/hr of placing velocity, both reinforcing bar area and non-reinforcing bar area had no difference in flowing velocity of concrete, that is to say,

reinforcing bar area kept going good workability according to elapsed time.

4) Compressive strength was increased with increasing ages and showed the highest value in placement position, however, compressive strength of cored specimen at 28 days was smaller than 49.1MPa of specified strength. Compressive strength of cored specimen at 56 days exceeded specified strength due to pozzolanic reaction and latent hydraulic property of BFS.

Consequently, in the case of practically applying for in-situ area similar to this mock-up test conditions, an operator have to construct underwater structures after enough to investigate in the consideration of atmospheric temperature and water temperature that have a bad influence upon the quality of concrete. However, pH value, suspended solids, workability, mechanical properties was satisfactory for standard specification of KSCE. High-strength antiwashout underwater concrete could be applied for in-situ construction underwater structures through laboratory test and mock-up test.

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