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A Study on the Mix Design and Quality Factors of the Combined High Flowing Concrete Using High Belite Cement

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Abstract

This study investigates experimentally into the design factors and quality variations having an effect on the properties of the combined high flowing concrete to be poured in the slurry wall of Inchon LNG in-ground receiving terminal. Especially, high belite cement and lime stone powder as cementitious materials and viscosity agent in order to improve self-compaction and hydration heat are used in this study. Water-cement ratio(W/C), fine aggregate volume ratio(Sr) and coarse aggregate volume ratio(Gv) as design factors of the combined high flowing concrete are applied to determine the optimum mix design proportion. Also quality variations for sensitivity test are selected items as followings. (1) Surface moisture(5cases) and (2) Fineness modulus of fine aggregate(5cases), (3) Concrete temperature(3cases), (4) Specific surface(3cases) and particle size of lime stone powder.

As experimental results, water-cement ratio, fine and coarse aggregate volume ratio are shown as the optimum range 51%, 43% and 53% separately considering site condition of slurry wall. Also quality factors by sensitivity test should be controlled in the following ranges. (1) Surface moisture ±0.67% and (2) Fineness modulus 2.6±0.2 of fine aggregate, (3) Concrete temperature 10~20℃, (4) Specific surface 6,000㎠/g and particle size 9.7±1.0㎛ of lime stone powder. Based on the results of this study, the optimum mix design proportion of the combined high flowing concrete are selected and poured successfully in the slurry wall of LNG in-ground tank.

Keywords: fine and coarse aggregate volume ratio, self-compaction, viscosity, combined high flowing concrete

1. Introduction

Since the high flowing concrete was firstly proposed by Okamura,[1)] many studies including a national project supported by Ministry of Construction & Transportation and some site applications were performed in Korea.[2,3)]

But applications from now could be classified into mock-up test or trial pouring for the high flowing concrete which used binder type as ordinary portland cement plus fly ash, also these cases were limited in a partly portion of the office building without vibrating work. Recently, Korea government has a plan to construct LNG (Liquefied natural gas) in-ground tank in order to supply stably in near Seoul and another large city. Inchon is proved to have the best situation for storage and supply of LNG.

Now, Inchon receiving terminal was already constructed and operated 10tanks of above type and 6tanks of in-ground type having the largest storage capacity about 200,000㎘ in the world have been constructing in regular sequence.

Especially, slurry wall concrete of in-ground type with a large and deep section was planed in pouring by the combined high flowing concrete which had high viscosity, self-compaction and no-segregation without vibrating. The depth and section of the in-ground slurry wall shall be designed and constructed to safety as following functions.

1) Cut off the seepage ground wall to meet the practical drainage quality.
2) Maintain the bottom stability against deep excavation.
3) Against expected loads during construction and completion of work.
4) In-ground slurry wall shall be considered as a temporary structure only.
5) Accordingly, the workability including slump flow and self-compaction, compressive strength shall be verified to be highly reliable.

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Regarding the mix design proportion of the slurry wall concrete, unit binder contents shall be more than 370kg/㎥. And the low-heat cement as a high belite cement shall be used in order to reduce the hydration heat and enhance the high quality of slurry wall concrete. Also, chemical admixtures including high-range water reducing agent, viscosity agent to secure the flowability, consistency and self-compaction shall be used. Therefore, we have to study the high flowing concrete poured in this site condition, evaluate the mix design factors including confined water ratio(βp), water-binder ratio, fine and coarse aggregate volume ratio and select all materials and the optimum mix design proportion by laboratory and actual site test.

The purpose of this study is to confirm the optimum mix design, the properties of fresh and hardened concrete and hydration heat, to analyze the quality factors having an effect on the combined high flowing concrete in actual site.

2. Summary of slurry wall

2.1 Structural summary

The structural summary and construction sequence of Inchon LNG in-ground tank having storage capacity about 200,000kℓ are shown as following Fig. 1 and Fig. 2.

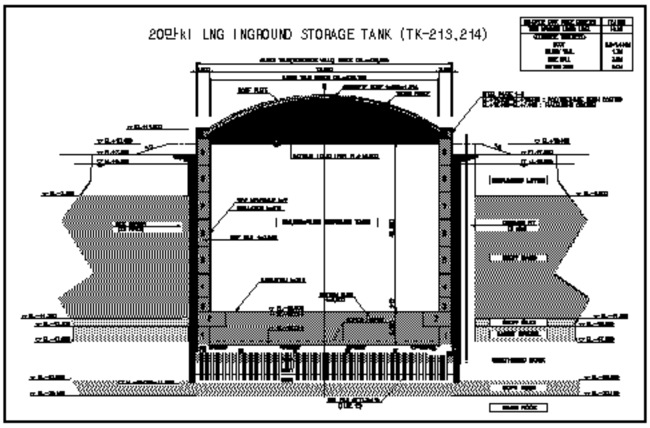

Fig. 1 Structural summary for LNG in-ground tank

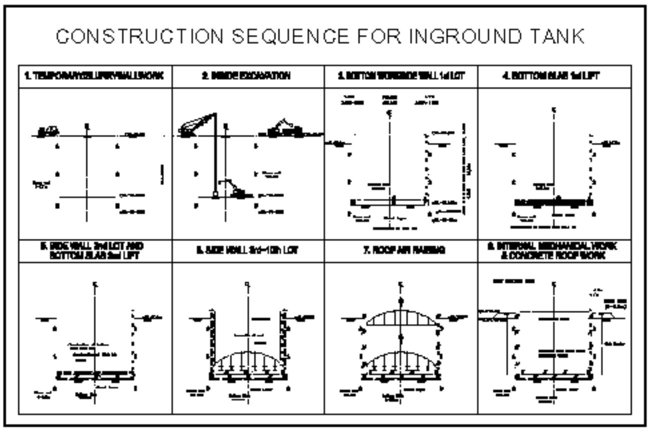

Fig. 2 Construction sequence for LNG in-ground tank

LNG in-ground tank is composed of slurry wall and 3 parts including bottom slab, side wall and roof as a main structure. Slurry wall has a thickness of 1.7m, depth of 72.4~76.4m, inside diameter of 78.58m and 52 elements including 26 elements of the primary panel and 26elements of the secondary panel.

2.2 Flow chart for concrete mix design

Flow chart for the optimum mix design of the concrete slurry wall is shown as following Fig. 3.

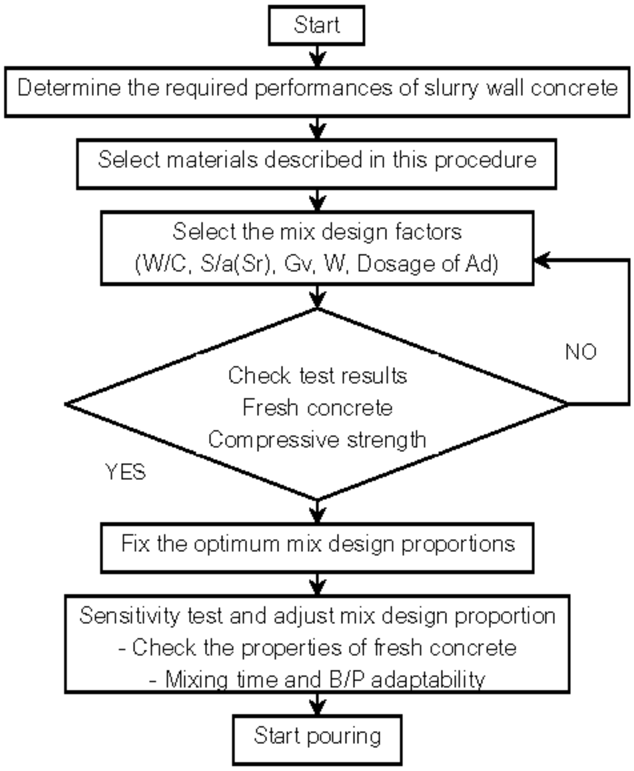

Fig. 3 Flow chart for concrete mix design and testing

2.3 Required performances

Table 1 gives the required performances of the high flowing concrete poured in the slurry wall of in-ground tank. Incidentally, the required performances of the fresh con-

Table 1 Required performances of slurry wall concrete

Items	Target value	Remark
Specified design strength	400 kg/㎠	KS F 2405 91days (∅100x200 ㎜)
Required strength	505 kg/㎠	
Slump flow	65 ± 5 ㎝	JSCE working group for evaluating performance in subcommittee on high flowable concrete "Testing for self-compacting concrete"
50 ㎝ reaching time	7 ± 3 sec	
V-type flowing time	15 ± 5 sec	
Air contents	4 ±1 %	
U-Box height	Min. 300 ㎜	

crete are kept to be preserved until 90 minutes consi-dering mixing of batch plant, transporting, site pouring, and self-compaction in the tremie-pipe.

Increment factor(α) for coefficient of variation(V) and reduction factor(γ) for under water concrete are applied 1.2 and 0.95 separately in the calculation of the required strength at 91days.

2.3 Evaluation methods

Generally, evaluation methods of the high flowing concrete are classified into flowability, self-compaction and segregation resistance in the fresh concrete. Slump flow is to check flowability as a flowing radius and 50㎝ flow reaching time is to evaluate consistency in slump flow test.

Therefore, these items are very important in a view point of the consistency and flow-ability, segregation without vibrating. Also, V-type flowing time shown as following Fig. 4 is to evaluate the flowability and the viscosity. It means that concrete sample having fast flowing time has a low viscosity and high flowability.

U-box height shown as following Fig. 4 is to evaluate self-compaction of the high following concrete by adverse height. It means that concrete sample having high filling height has a good self-compaction but it must have a balance between flowability and viscosity.

2.4 Basic mix conditions

The primary factors affected on the mix design of the high flowing concrete are specified design strength, constituents properties, manufacturing process, test age of compressive strength, flowing inclination, segregation resistance, high compactability, and economical efficiency.

Furthermore, in advance of mixing, concrete mix design is performed to accommodate the established standard considered target strength and workability of concrete after careful analysis and examination of data for the given condition of batch plant manufacturing concrete, the process of transportation, and the properties of materials used.

Basic mix conditions for the combined high flowing concrete are shown as following Table 2.

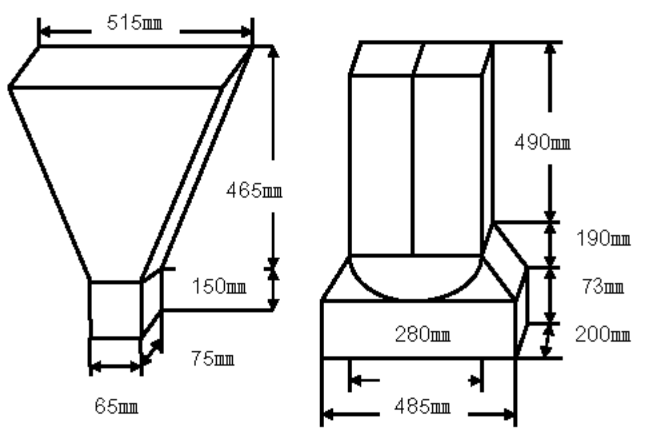

Fig. 4 Test devices for V-type flowing time and U-box height

3. Experimental investigation

3.1 Materials

All materials of the combined high flowing concrete in this study make it a rule to use domestic products including belite cement, fine and coarse aggregates, high-range water reducing agent, viscosity agent and lime stone powder.

3.1.1 Cement

As the high flowing concrete poured in the in-ground slurry wall is demanded to reduce the heat of hydration and enhance long term strength, high belite cement as low heat cement is selected and checked by KS F 5201. Table 3 shows test results for the chemical and physical properties of high belite cement.

3.1.2 Fine and coarse aggregates

Flowability, self-compaction and viscosity of the high flowing concrete are influenced by the properties of the fine and coarse aggregate. To be satisfied with these performances, the fineness modulus, specific gravity, results of sieve analysis test of the fine aggregate are very important factors. Table 4 gives test results of fine and coarse aggregates produced from the source of Bi-Bong(crushed

Table 2 Basic mix conditions

Classifications	Control condition	Remark
Size of coarse aggregate	19 ㎜ max.	KS F 2405 91days (Ø100x200 ㎜)
Water-binder ratio (W/B)	55% max.	
Unit water contents (W)	175 ㎏/㎥ max.	
Unit binder contents (B)	370 ㎏/㎥ min.	
Fine aggregate ratio (S/a)	55% max.	
Dosage of H.R.W.R agent	B×3.5% max.	

Table 3 Chemical and physical properties of belite cement

Specific gravity	Specific surface (㎠/g)	SO_3 (%)	Fe_2O_3 (%)	MgO (%)	C_3S (%)	C_2S (%)	C_3A (%)	Ignition loss(%)
3.22	3,391	1.9	3.6	3.6	28.0	48.0	3.0	1.4

Autoclave expansion (%)	Setting time (hr:min)		Strength (㎏/㎠)		Hydration heat (cal/g)	
	Initial	Final	7days	28days	7days	28days
0.04	6:10	8:50	204	363	52	62

Table 4 Physical properties of aggregates

Type	F.M	Specific gravity	Water absorption (%)	Soundness (%)	Passing 0.08 ㎜ (%)	Unit weight (kg/㎥)
Fine	2.62	2.61	1.16	4.5	1.0	1,628
Coarse	6.69	2.63	0.66	3.7	0.2	1,588

Table 5 Test results of high-range water reducing agent

Water content (%)	Setting time (hr:min)		Compressive strength ratio (%)			Flexural strength ratio (%)		
	Initial	Final	3days	7days	28days	3days	7days	28days
80.0	+25	+25	131	121	119	115	105	105

Table 6 Compatibility between viscosity and H.R.W.R

Kinds	Component	Dosage (kg/㎥)	Compatibility with H.R.W.R
Cellulose	Cellulose ether	0.01~0.6	Poly carbonate melamine sulfonate
Bio-polymer	Polymer	0.5~1.5	Poly carbonate amino sulfonate naphtalene sulfonate
	Poly-saccharide	0.2~0.6	
	Microbe	0.5~1.0	
Acryl	Poly acryl amid	3.0~6.0	Naphtalene sulfonate poly carbonate

Table 7 Chemical and physical properties of L.S.P

Specific gravity	Specific surface (㎠/g)	SiO_2 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Al_2O_3 (%)	Moisture (%)	Ignition Loss (%)
2.61	6,320	1.2	0.2	1.2	53.5	1.1	0.2	42.1

Table 8 Test range of the trial mixing for design factors

Design factor	Test range	Remark
Water-cement ratio(W/C)	47 ~ 55 %	Strength
Coarse aggregate ratio(Gv)	51 ~ 57%	Self-compaction
Fine aggregate ratio(Sr)	41 ~ 45 %	Consistency flowability
Dosage of H.R.W.R	1.0~1.9% (B×%)	

Table 9 Mixing method and time in the laboratory test

Sequence	Mixing method	Mixing time
(1)	Fine aggregate + coarse aggregate	30sec
(2)	Cement + lime stone powder	30sec
(3)	Viscosity agent (powder)	30sec
(4)	Water + H.R.W.R	120sec
(5)	Total mixing time	3min 30sec

stone:19㎜) and Keum-Kang (river sand). Test results for all items are satisfied with KS F 2526 as specification of fine and coarse aggregates.

3.1.3 Chemical admixtures

High-range water reducing agent(H.R.W.R) used in this study is the poly-carbonate base which has the advantage of the compatibility with viscosity agent (poly-saccharide base), the dispersion action and the maintenance time of slump flow in the fresh concrete. Table 5 shows test results of high-range water reducing agent and compatibility between viscosity agent and high-range water reducing agent is shown as following Table 6. Test results for all items were satisfied with ASTM C 494 "F type" as specification Based on Table 6, viscosity agent as the component of poly-saccharide type considering compatibility is selected.

3.1.4 Lime stone powder

To enhance the flowability and consistency of the high flowing concrete, lime stone powder is used as a powder type. And replacement ratio of lime stone powder is selected by test results of the confined water ratio.[4] Table 7 shows test results for properties of lime stone powder. Test results for all items are satisfied with JIS A 5008 as specification of lime stone powder.

3.2 Mix design conditions

3.2.1 Factors and range of mix design

For the fundamental items derived from concrete mix design, the laboratory test using small mixer(pan type-100 liter capacity) is performed. But all items are executed to consider the site condition as the verification for the management of batch plant, manufacture, transportation and pouring concrete for slurry wall.

Factors related with concrete mix design in the laboratory test are as follows.

- Water-cement ratio or Water-binder ratio(W/B)
- Sand-aggregate ratio(S/a) or Sand volume ratio(Sr)
- Coarse aggregate volume ratio(Gv)
- Unit water weight(W)

Table 8 gives test range of the trial mixing for the high flowing concrete in the laboratory test. After tested the trial mixing according to design factors, the optimum mix design condition of the high flowing concrete satisfied with quality requirements specified in Table 1 is selected.

3.2.2 Mixing method

The laboratory trial mixing is executed by mixer of tyranny pan type which have a capacity of 100 liter and 44 r.p.m. Table 9 shows mixing method and mixing time in the laboratory trial mixing.

Concrete mixing is divided into 4steps and total mixing time is 210 seconds considering capacity of mixer load.

3.2.3 Fundamental mix design

After checked various mix design factors to choose the

Table 10 Fundamental mix design condition

W/C (%)	Sr (%)	Unit material weight (kg/㎥)					Ad (B*%)	V.A (B*%)
		Water	Cement	L.S.P	Sand	Gravel		
48~54	41~45	174	341	254	743	789	1.0~1.5	0.16

Table 11 Variation factors for the sensitivity test

Variation items	Range of variation	Remark
Concrete temperature	10, 20, 30℃	Viscosity flow-ability self-compaction
Unit water	W±5 kg, ±10 kg/㎥	
Fineness modulus	2.2 ~ 3.0 (sand)	
Specific surface (LSP)	5,000, 6,000, 8,000 ㎠/g	

optimum mix design condition in preliminary test, the fundamental mix design condition of the high flowing concrete in the laboratory test is proposed as following Table 10.

3.3 Sensitivity test for the variation factors

After selected the optimum mix design condition, the sensitivity test for changing material properties and it's variation as following Table 11 is performed.

The purpose of this sensitivity test is to conform the properties of slurry wall concrete according to change of sand moisture, concrete temperature and quality variation of materials. Through this test, the range of quality control in the production process of the slurry wall concrete can be specified.

4. Results and discussion

4.1 Test results for design factors

4.1.1 Effect of the coarse aggregate volume ratio(Gv)

The coarse aggregate volume ratio in the high flowing concrete has an influence on the V-type flowing time and U-box height evaluated self-compaction and consistency of the fresh concrete. The coarse aggregate volume ratio to evaluate these influence in this study is tested in the range of 51~57%(4cases). Test results for this factor are shown as following Fig.6.

In case of 51%, flowability and viscosity are satisfied with the requirement of the target value, but the self-compactness is not enough. All of flowability, viscosity and self-compaction in case of 53% are satisfied with the requirement of the target value. But, in cases of 55 and 57%, viscosity and self-compaction are not satisfied with the requirement of the target value except slump flow by aggregate arching. From the analysis of test results, it is selected the range of 53% as the optimum coarse aggregate volume ratio.

4.1.2 Effect of the fine aggregate volume ratio(Sr)

The fine aggregate volume ratio to evaluate these influence is tested in the range of 41~45%(5cases) because it has an influence on the consistency of the fresh concrete. Test results for this factor are shown as following Fig.7.

Compared with test results for the fine aggregate volume ratio, the smaller fine aggregate volume ratio become, the more viscosity and segregation resistance increase because binder volume is increased in the same coarse aggregate volume ratio. Therefore, the optimum fine aggregate volume ratio is selected and suggested in the rage of 43±1%.

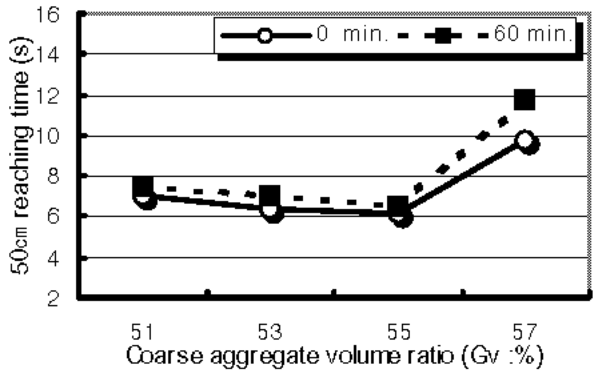

Fig. 6 (a) 50㎝ flow reaching time for Gv

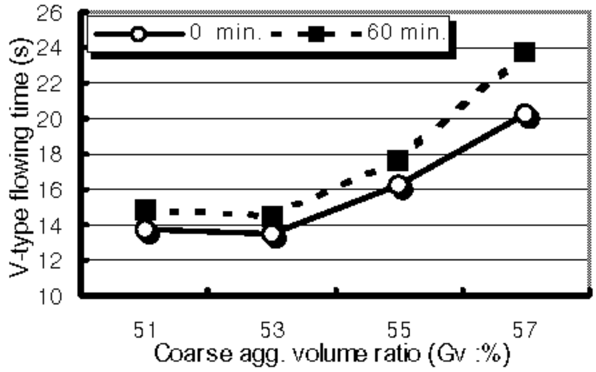

Fig. 6 (b) V-type flowing time for Gv

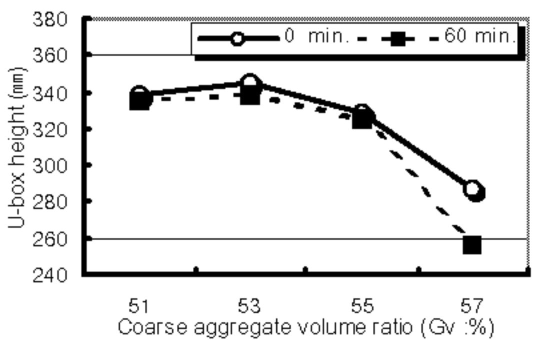

Fig. 6 (c) U-box height for Gv

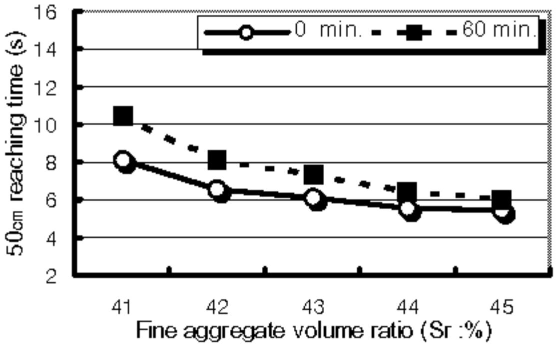

Fig. 7 (a) 50㎝ flow reaching time for Sr

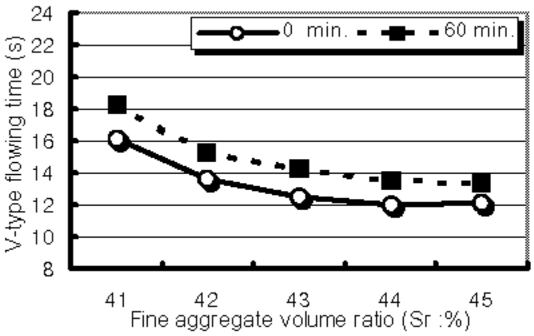

Fig. 7 (b) V-lot flowing time for Sr

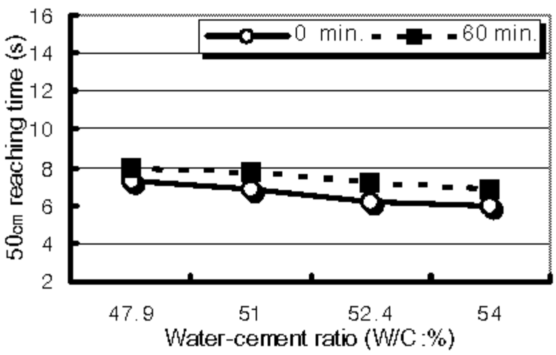

Fig. 8 (a) 50㎝ flow reaching time according to W/C

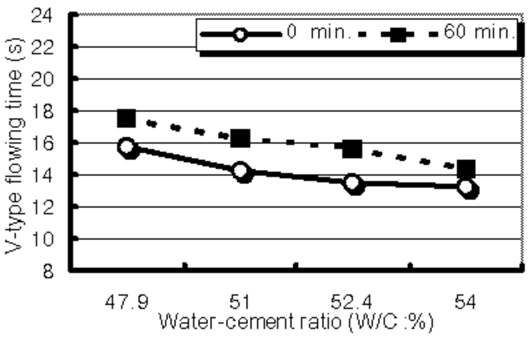

Fig. 8 (b) V-type flowing time according to W/C

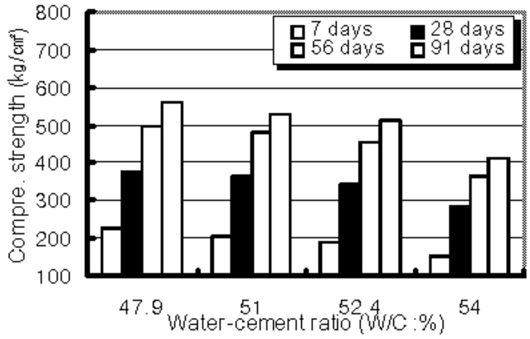

Fig. 9 Development trend of strength for test ages

Table 12 The optimum mix design of slurry wall concrete

W/C (%)	Sr (%)	Gv (%)	Unit material weight (kg/m³)					Ad (B×%)	V.A (B×%)
			Water	Cement	L.S.P	S	G		
51.0	43.0	53.0	174	341	254	743	789	1.25	0.16

4.1.3 Effect of the water-cement ratio(W/C)

Water-cement ratio has an effect on not only the properties of fresh concrete including flowability, segregation resistance and self-compaction but also strength. The purpose of this test is to determine unit cement contents, dosage of chemical admixtures and replacement ratio of lime stone powder satisfied with the performance of the high flowing concrete. Test results of the fresh concrete for water-cement ratio are shown as following Fig. 8. Compared with test results, all of test results were satisfied with our specification. In cases of fixing another design factors, the more water-cement ratio increased, the larger flowability became and the smaller viscosity became in the fresh concrete. But its difference was very small.

Therefore, it should be selected the optimum mix design proportion after checking compressive strength according to test ages. In specification, design compressive strength is 400㎏/㎠ and required compressive strength is 505 ㎏/㎠(91days). The development trend and compressive strength accor-ding to test ages are shown as following Fig. 9. All of test results except W/C=54% are satisfied with the required strength(505㎏/㎠) at 91days.

Therefore, considered above test results, the optimum mix design proportion of the combined high flowing concrete poured in the slurry wall of LNG in-ground tank are selected as following Table12.

4.2 Sensitivity test results for variation factors

4.2.1 Sensitivity test for moisture variation of sand

The moisture content of sand in actual site is likely to be changeable by weather condition. Therefore, sensitivity test is performed by change water content in the range of unit water(W±5, ±10kg/m³) because countermeasure for moisture variation is needed. Test results of sensitivity for moisture variation are shown as following Fig. 11.

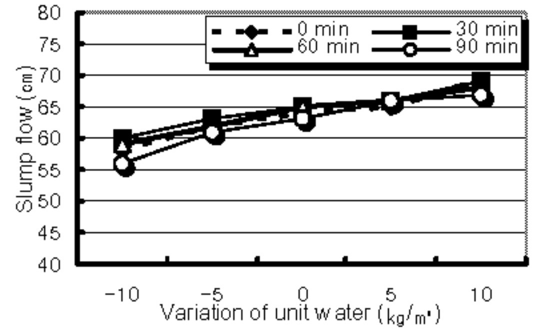

Fig. 11 (a) Slump flow for moisture variation of sand

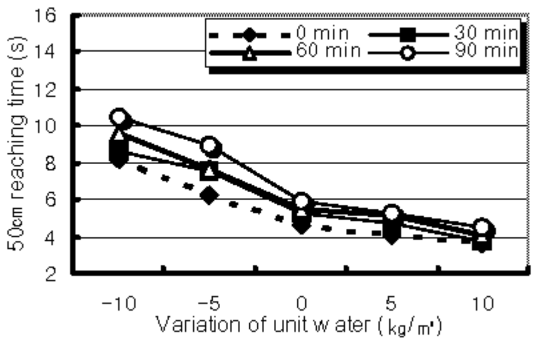

Fig. 11 (b) 50cm flow reaching time for moisture variation

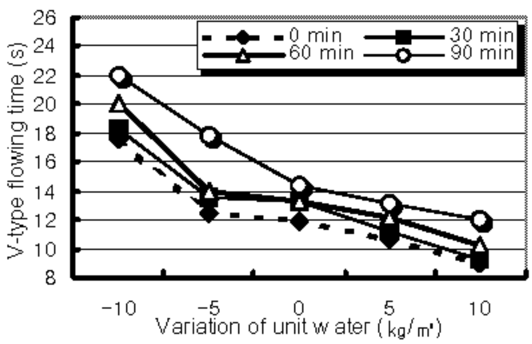

Fig. 11 (c) V-lot flowing time for moisture variation

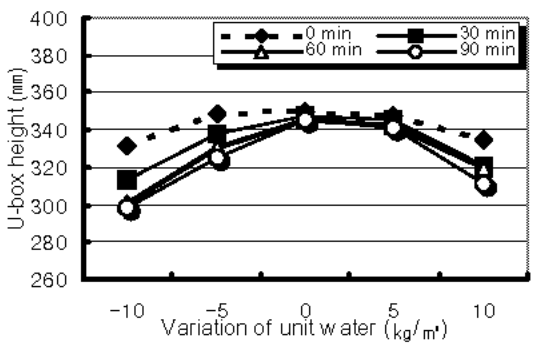

Fig. 11 (d) U-box height for moisture variation

In case of +10kg/m³, even though flowability and self-compactness of the fresh concrete are satisfied with the specification, there are observed low viscosity, segregation between paste and aggregates, and some bleeding. Flowability, self compaction and viscosity of the fresh concrete in case of +5kg/m³ are satisfied with the required performances. In case of -5kg/m³, even though the viscosity is increased a little, flowability and self-compaction are satisfied with the requirement of the target value. In case of 10kg/m³, because viscosity is very high, all of the fresh concrete conditions are not satisfied with the specification.

Therefore, the moisture variation of sand in site should be controlled within the range of ±5kg/m³(±0.67%).

4.2.2 Sensitivity test for F.M variation of sand

The sensitivity test for fineness modulus of the fine aggregate is to evaluate an effect on the properties of the fresh concrete including segregation resistance, flow-ability and viscosity of high flowing concrete. The sensitivity test for fineness modulus in the range of 2.2~3.0(5cases) is performed and test results of sensitivity test are shown as following Fig. 12.

Compared results of sensitivity test for the fineness modulus variation of the fine aggregate, the more fineness modulus increased, the higher viscosity of the fresh concrete became. But, all of test results were satisfied with our

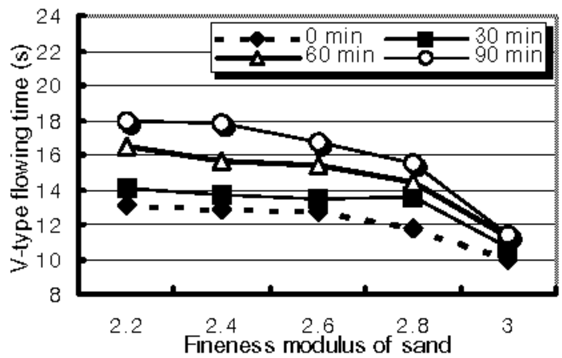

Fig. 12 (a) V-lot flowing time for fineness modulus of sand

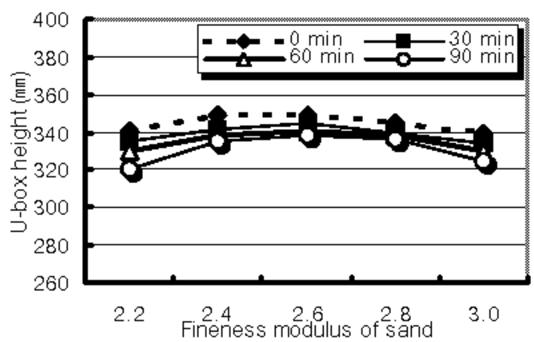

Fig. 12 (b) U-box height for fineness modulus

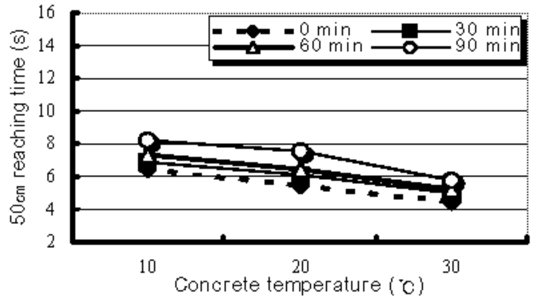

Fig. 13 (a) 50㎝ reaching time for concrete temperature

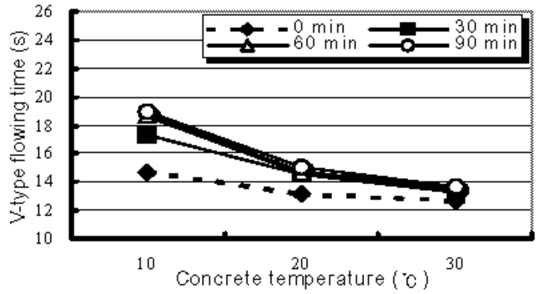

Fig. 13 (b) V-lot flowing time for concrete temperature

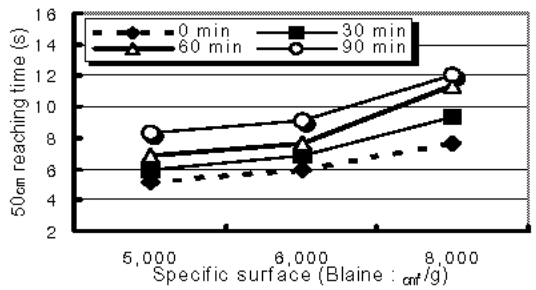

Fig. 14 (a) 50㎝ reaching time for specific surface of L.S.P

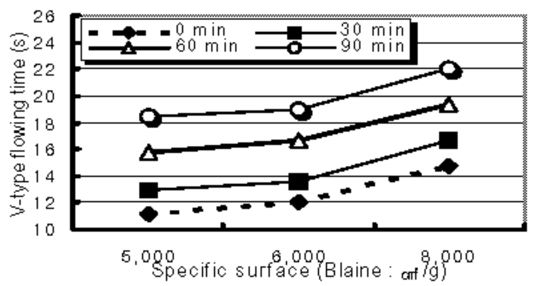

Fig. 14 (b) V-lot flowing time for specific surface of L.S.P

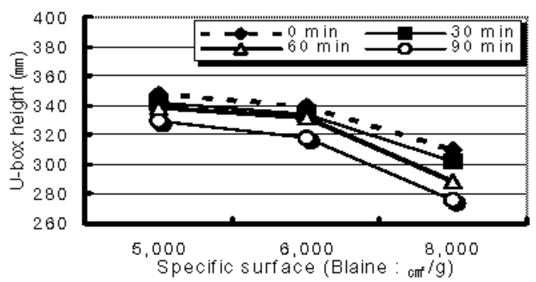

Fig. 14 (c) U-box height for specific surface of L.S.P

specification because of being used viscosity agent in order to maintain the required viscosity on the high flowing concrete. Based on these results, viscosity is high in case of fineness modulus 2.2 but is low in case of 3.0.

Therefore, the fineness modulus of the fine aggregate in site should be controlled in the range of 2.6±0.2 to maintain the high quality of the combined high flowing concrete.

4.2.3 Sensitivity test for concrete temperature

The sensitivity test for temperature variation is to evaluate an effect on the properties of fresh concrete including segregation resistance, flowability and viscosity of the high flowing concrete by pouring seasons. For this purpose, the sensitivity test for temperature variation of the fresh concrete in the range of 10, 20 and 30℃ is carried out and test results of sensitivity test are shown as following Fig. 13.

Compared results of sensitivity test for temperature variation of the fresh concrete, all of test results were satisfied with the specification. But, the lower initial concrete temperature became, the more viscosity of the fresh concrete increased. It has effect on the sensitivity for temperature of viscosity agent.

Especially, because concrete pouring work in actual site will be performed in the cold weather, temperature of the fresh concrete should be controlled in the range of 10~20℃ by boiling water system considering viscosity of the combined high flowing concrete.

4.2.4 Sensitivity test for specific surface of L.S.P

The sensitivity test for specific surface of lime stone powder(L.S.P) is to evaluate an effect on the properties of fresh concrete. For this purpose, the sensitivity test for specific surface of L.S.P in the range of 5,000, 6,000 and 8,000㎠/g as blain is executed and test results of sensitivity test are shown as following Fig. 14.

In case of 5,000㎠/g, even though flowability and self-compactness of the fresh concrete are satisfied with the specification, there are observed low viscosity. Also, flowability, self-compaction and viscosity of the fresh concrete in case of 8,000㎠/g are not satisfied with the required performance because of high viscosity. But, flowability and self-compaction in case of 6,000㎠/g are satisfied with the requirement of the target value.

Also, based on the average particle size of lime stone powder, the smaller average particle became, the better flowability improved but the higher viscosity became.

Therefore, the specific surface of lime stone powder is selected powder type of 6,000㎠/g as blain(C-140) and should be controlled average particle size of lime stone powder within 9.7±1.0㎛ range.

Table 13 The optimum mix design of slurry wall concrete

Type	W/C (%)	Sr (%)	Adiabatic temperature			Bleeding (㎤/㎠-hr)	Setting time	
			K(℃)	α	β		Initial	Final
Slag	41.0	47	49.9	0.62	2.05	0.18 – 7.5	16:30	19:20
Belite	51.0	43	30.8	0.42	1.17	0.14 – 8.0	18:40	22:30
O.P.C	53.0	47	49.1	0.64	2.75	0.27 – 7.0	-	-

4.3 Others

Test results for setting time, bleeding and adiabatic temperature raising of the optimum concrete mix proportion as the above mentioned Table 12 and another high flowing concrete including slag cement and ordinary portland cement as binder type are shown as following Table 13.

The combined high flowing concrete used in belite cement and lime stone powder as cementitious materials can be improved various properties of the fresh and hardened concrete.

Slurry wall works of #215, 216-TK are finished with success. After excavation of inner part, all the engineers are surprised at the concrete surface of slurry wall. It appeared no single crack and no-segregation of concrete matrix.[5)]

5. Conclusions

The purpose of this study is to confirm the optimum mix proportion of the combined high flowing concrete by mix design factors and to analyze an effect on the properties of the fresh concrete by changing quality factors before actual site application. Followings are conclusions based on results obtained from this study.

1) Belite cement and lime stone powder was proved to be effective cementitious material of the combined high flowing concrete because these materials can be reduced hydration heat and improved the properties of fresh condition including the confined water ratio(βp), flowability, segregation resistance and self-compaction.
2) Considering compatibility between high-range water reducing agent and viscosity agent, chemical admixtures based on poly-carbonate and poly-saccharide are selected and used the combined high flowing concrete.
3) Considering site condition and properties of fresh concrete, the optimum volumetric ratio of fine and coarse aggregates is selected in the range of 43±1% and 53% separately. To be satisfied with the required strength, water-cement ratio is selected in the range of 51% and replacement ratio of lime stone powder is determined 42.7%.
4) In actual site construction, because materials and site condition are likely to be changeable, variation factors should be kept and controlled in the following ranges : Surface moisture (±0.67%), Fineness modulus of fine aggregate (2.6±0.2), Concrete temperature (10~20℃), Specific surface (6,000㎠/g) and particle size (9.7±1.0㎛) of lime stone powder.

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