

# Development of high performance concrete and mock up test for mega foundation

S.M. Woo, S.Y. Jun, J.H. Lee

*Lotte Engineering & Construction, Research & Development Institute, Seoul, Korea(South)*

S.H. Cho & J.Y. Bae

*Hanil Cement Co., LTD., Technical Center, Daejeon, Korea(South)*

**ABSTRACT:** Recently, structures become higher, larger and more strengthened. Mega concretes are planned and designed as mega foundations. This trend raises problems of concrete hydration heat and workability during construction. The two major issues of concrete quality in mega foundation construction are the control of hydration heat and improvement of workability. In this study, ternary blended low heat cement was developed to control hydration heat. Self compacting concrete and high performance concrete were also developed to assure concrete quality and workability. In addition, the biggest mock up test locally, 4m×4m×4m size, was performed to verify the performance of developed concrete. Several tests were carried out such as temperature measurement, slump flow test, compressive strength, tensile strength test, and crack investigation in this mock up test. Therefore it is inferred that the developed high performance concrete will be made full use for mega foundation construction.

## 1 GENERAL INSTRUCTIONS

Recently, structures become higher, larger and more strengthened for increasing SOC industry of economical growth and to construct landmark of the cities. And for these reasons the shape of mega foundation became tendency to be a large concrete block.

In October 2007, technical committee of Korean Geotechnical Society established ATC-18 "Mega Foundations", since then, the foundations of abutments and piers of long span bridges and super tall buildings are called Mega foundation and many studies of surface exploration, temporary retaining wall, concrete material development and construction method to construct mega foundation are carried out.(ATC-18 committee 2007)

Since, large mass of concrete deposit is required to Mega foundation construction, there are problems of concrete hydration heat, workability and high strength concrete.

There is some probability of thermal crack due to hydration heat. The probability of thermal crack increases by internal restraint effect, temperature difference of inside and outside of foundation, and external restraint effect, by old concrete or ground.(Kang et al. 1996)

Therefore blended cement(Kim et al. 1999), separate deposit, pipe cooling(Kim et al. 1995, Lee et al. 2002) are attempted to control temperature crack caused by hydration heat of concrete. Furthermore, to deposit concrete in wide area without compaction, concrete must have sufficient self compaction ability and flowability to insure workability. And this is the reason that self compacting concrete with slump flow 600-700mm has to be developed. And also it is necessary to strengthen concrete above 40MPa for most of the Mega foundations which support large weight of long span bridges and super high buildings.

In this study, ternary blended cement was used to control temperature crack. And high performance concrete was developed with application of high strength mix design and ternary blended low heat cement to insure self compaction and high strength. The biggest mock up test locally, 4m×4m×4m size, was performed to verify the performance of developed concrete. Several tests were carried out such as temperature measurement, slump flow test, compressive strength, tensile strength test, and crack investigation in this mock up test. And technical specification is indicated to insure successful construction of Mega foundation.

## 2 CONCRETE DEVELOPMENT FOR MEGA FOUNDATION

### 2.1 Development of blended low heat cement

Generally, blended low heat cement is blended with Portland cement with blast furnace slag and fly ash to lower hydration heat. There are two types of blended low heat cement. One is binary blended low heat cement which is blended Portland cement with one admixture between blast furnace slag and fly ash. Another type is ternary blended low heat cement which is blended Portland cement with both admixtures.

Table 1 shows the quality properties of low-heat cement. To compare binary blended cement with ternary blended, ternary blended has lower relative hydration heat and lower strength in early age but it has good strength in long term. The limit of mixture ratio of fly ash in binary blended cement with fly ash is 30% because of poor strength development. It is expected considerable heat reduction using binary blended cement with mixture ratio over 60% of blast furnace slag but if blast furnace slag ratio is too big disadvantages in durability occur by drying shrinkage and carbonation etc.

Therefore, in this study, ternary blended cement was developed, applying both merits of blast furnace slag and fly ash, to acquire high strength, low heat and durability.

Table 1. Quality properties of low-heat cement (Hanehara 1991).

Classification	Low-heat blended cement	
	Binary blended	Ternary blended
Hydration heat(28days)	60-80cal/g	45-60cal/g
Adiabatic temperature rise	35-45°C	23-30°C
Temperature dependency (High temp. curing)		
Hydration heat	Large	Small
Str. development	Bad(long-term)	Good

### 2.2 High performance concrete development for Mega foundation

#### 2.2.1 Specific standards of concrete performance

For Mega foundation construction, specific standards are presented in Table 2. It is established that high performance concrete have to acquire high strength over than 40MPa in age 28days, self compaction ability of slump flow with 600-700mm, maximum temperature rise less than 71°C and temperature difference of mass concrete less than 20°C.

Ternary blended cement, developed in this study for Mega foundation of density 2.8 and fineness

3803 grade, was used with admixtures of super plasticizer, air-entraining agent and thickening agent to satisfy slump flow with 600-700mm.

Table 2. Target of high performance concrete for mega foundation.

Item	Target	Remarks
Design strength	40MPa ≤	Age 28 days
W/C	0.3-0.35	150-165kg/m <sup>3</sup> *
Cement contents	400kg/cm <sup>2</sup> ≤	Ternary blended
Slump flow	600-700mm	Proper workability
Air contents	2.5±1.5%	High strength level
Hydration heat	20°C ≥ 71°C ≥	Inside from outside Maximum heat

\* Unit water content

The properties of coarse aggregate, crushed rock from Pocheon, are density in saturated surface dry of 2.61g/cm<sup>3</sup>, water absorption ratio of 0.77%, fineness modulus of 6.57(maximum size 19mm) and for fine aggregate, washed sand from Haeju, density in saturated surface dry was 2.59g/cm<sup>3</sup>, water absorption ratio was 0.68%.

The final mix design of developed high performance low heat concrete is presented in Table 3.

Table 3. High performance concrete mix design (unit: kg/m<sup>3</sup>).

W/C(%)	S/a(%)	C	W	S	G	AD	fck
32.5	50	517	168	813	822	5.69	40MPa

#### 2.2.2 Verification of developed concrete

Adiabatic temperature rise test was performed as Figure 1 to measure hydration heat of developed high performance concrete.



Figure 1. Test process for adiabatic temperature rise of concrete.

Table 4 and Figure 2 present result of adiabatic temperature rise of concrete by placing temperature. At first place, placing temperatures were 10, 20, 30°C, but measured temperatures were 13.2, 18.7, 28.7°C.

Table 4. Test result for adiabatic temperature rise of concrete by placing temperature.

Test	Placing temperature	Test result	
		Maximum rise temperature	Reaction factor
	°C	K(°C)	
KEPRI	10(13.2)	51.995	0.377
	20(18.7)	45.912	0.676
	30(28.7)	41.273	1.009

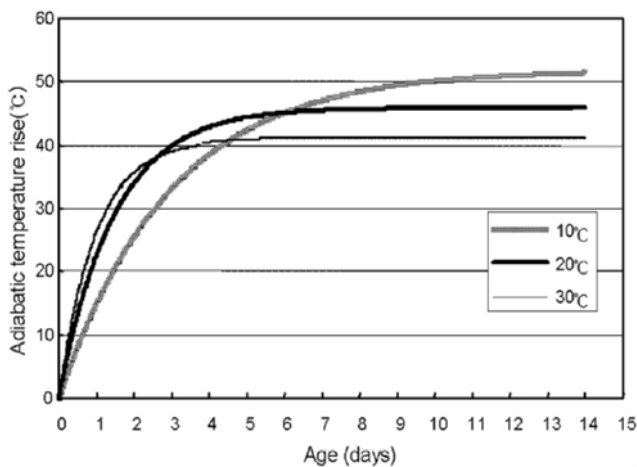


Figure 2. Adiabatic temperature rise curve of concrete by placing temperature.

The higher temperature at placing period decreased maximum adiabatic temperature rise and increased the size of reaction factor. After analyzing the result, using the developed concrete at placing temperature of 10, 20, 30°C, considering placing temperature, maximum adiabatic temperature rise, heat generation and heat reduction by atmosphere, maximum temperature rise of concrete will be less than 71°C remarked in the specification.

Properties of fresh concrete are shown in Table 5. To measure flowability and workability of high performance concrete, several tests were carried out such as air content test, slump flow test, J-ring test, V funnel test, flow time test, L box and U box test.

At the result of air content test, after 1 hour, air content appeared to decrease, but it was satisfied that the range was in  $2.5 \pm 1.5\%$  remarked in specification.

At the flow test, fresh concrete flowed through the bars of J-ring without material separation. Slump flow range was, in general, 600-700mm and the gap between slump flow and J-ring flow was about less

than 50mm, it would be able to pass re-bars without additional compaction.

Table 5. Properties of fresh concrete.

No.	Air content		Slump flow		J-Ring flow	
	%		mm		mm	
	0min	60min	0min	60min	0min	60min
1	2.9	2.4	685	690	660	660
2	2.2	2.1	675	690	645	610
3	2.3	2.2	645	635	635	615

No.	L box flow	V funnel flow	U box intervals
	sec	sec	mm
1	12.69	21.10	12
2	16.47	22.19	24
3	15.67	21.98	23

At the L box test, reaching 500mm time period was average 14.94sec with high flowability, and there was no sign of material separation after passing the re-bars installed in the L box. At the V funnel test, the time period when the concrete, nearly 10liters of, completely flow out through the hole at the bottom of V funnel, was average 21.75sec. At U box test, the gap of the height of both sides of concrete was average 19.7mm and it is satisfied to have good performance of self-leveling.

From the results, developed high performance concrete was concluded to have high flowability and workability enough to be able to apply in large scale construction without additional compaction.

To understand the strength development of developed high performance concrete, strength test was performed. The results of strength test are presented in Figure 4. The strengths at age of 7days were measured highly, 37.1MPa (compressive), 3.2MPa (tensile). At the age of 28days, the strengths were measured higher to be sufficient to Mega foundation, 55.2MPa (compressive), 4.2MPa (tensile).



Figure 3. J-Ring test of fresh concrete.

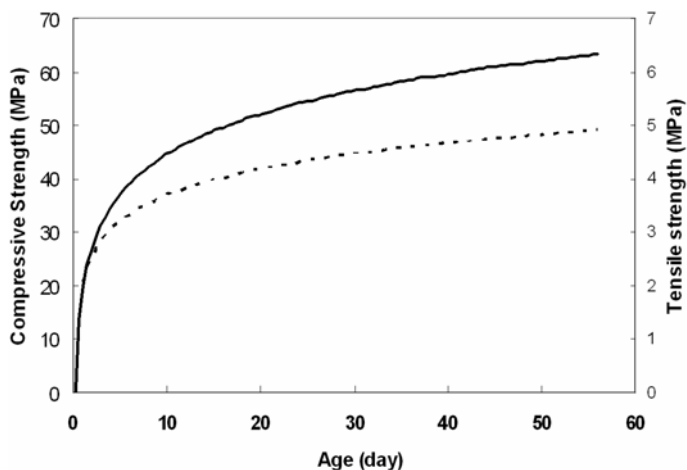


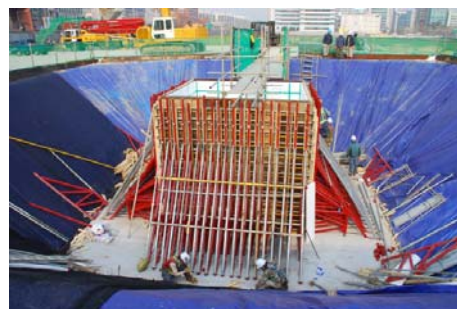
Figure 4. The results of compressive and tensile strength test.

### 3 MOCK UP TEST

#### 3.1 Mock up test

For successful construction of Mega foundation, it is necessary to develop the most suitable and the best concrete and to select the construction method corresponding to field condition. It is necessary to execute Mock up test to find out conformance of selected concrete and construction method. And the biggest mock up test locally, 4m×4m×4m size, was performed to verify field applicability of developed concrete. Developed high performance concrete was placed into the Mock up specimen to estimate self compaction ability of concrete of 600-700mm slump flow. Temperature sensors were set up to estimate low heat measuring maximum temperature, that should be less than 71°C, and temperature difference between inside and outside, which should be less than 20°C. From strength test of cored specimen, compressive strength was estimated for target strength of 40MPa.

To install Mock up specimen, excavation was proceeded in size of 10m×10m (bottom) and 18m×18m (top). Formworks were designed and installed considering side pressure of self compacting concrete. And 50mm thick heat insulator was installed inside of formworks for insulate curing decreasing temperature reduction between inside and outside. Temperature measuring system was built and temperature sensors were installed to measure temperature inside of Mock up specimen. Several tests such as air content test, slump flow test, J-ring test, V funnel test, L box test, etc. were carried out at ready mixed concrete factory and placing site. After concrete deposit, the top of mock up specimen was finished with 50mm thick heat insulator for insulate curing. Concrete cylinder specimen was made for concrete strength test.



(a) Formwork



(b) Concrete placement



(c) Adiabatic curing

Figure 5. Mock up test of 4m×4m×4m concrete structure.

#### 3.2 Mock up test results and consideration

##### 3.2.1 Flowability test results

Concrete is placed after certain time period experiencing transfer by a truck and pump by a pumpcar. During this period material properties of concrete do change. Therefore, concrete flowability was checked two times, right after its manufacture at the factory and when it was pumped out at the placing site. Flowability test results are arranged in Table 6. Slump flow looks to decrease but the gap is small enough to neglect and to estimate that there is no change of flowability. J-Ring flow has decreased, this means that flowability through re-bars has decreased. Results of air content test made no odds.

Table 6. Variation of fresh concrete's properties.

	Slump flow	J-Ring	Air content	L box flow	V funnel flow
	mm	mm	%	sec	sec
Pumping					
Before	645	635	2.4	12.4	21.9
After	635	595	2.3	16.5	34.5



At L box test and V funnel test, 500mm reaching time period has both extended that the resistance of material separation between cement paste and aggregate has decreased.

Additionally, to examine the elapsed time change of concrete, slump flow was tested at the elapsed time of 150minutes. As a result, there was a 150mm loss of slump flow. This means that developed high performance concrete have to be placed within 2hours maximum after manufacture at the factory to maintain its flowability and self compaction ability.

### 3.2.2 Results of concrete hydration heat measurement

Concrete temperature was measured for 90days at 15 locations to check hydration heat. For the first 4days temperature was checked every 1minute, for next 6 days every hour, for next 18days every 4hours and for next 12days every 8hours and finally for next 50days it was measured daily. The location of thermal sensors is shown in Figure 6.

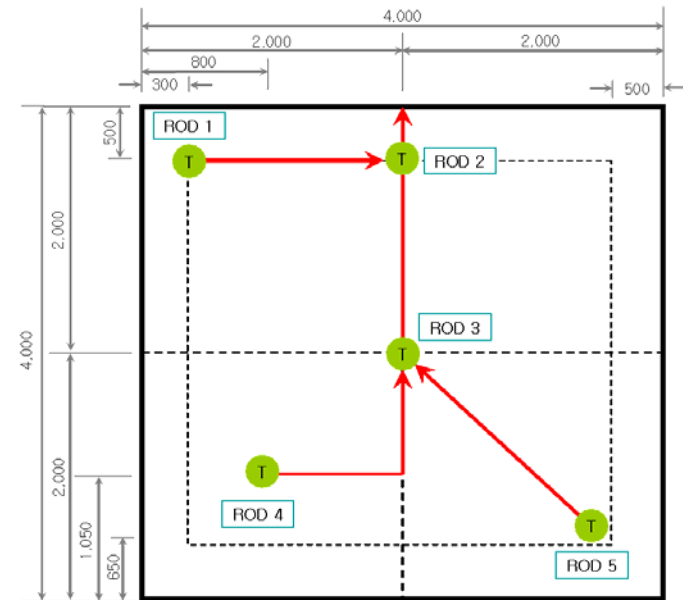


Figure 6. Location of thermal sensors.

There are 3 sensors installed at each location. Vertically, sensors are located at 30cm under the top, the center and 30cm above the bottom to measure the variation of temperature at each location. Results of variation of concrete temperature are shown in Figures 7-11. The measurement proceeded for 90days, or 2160hours, but the graph shows variation of temperature within 900hours. In Figures 7-11, temperature drop shows the period when insulation curing was ended, caused by removing insulation material and formwork after 14days curing. It is noticed that temperature of the upper side is higher than the center.

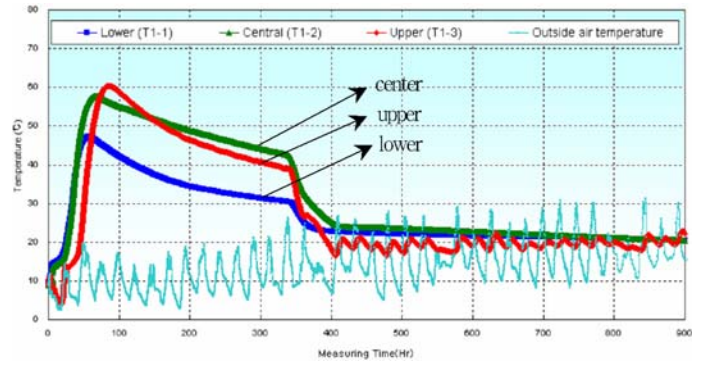


Figure 7. Variation of concrete temperature at rod1.

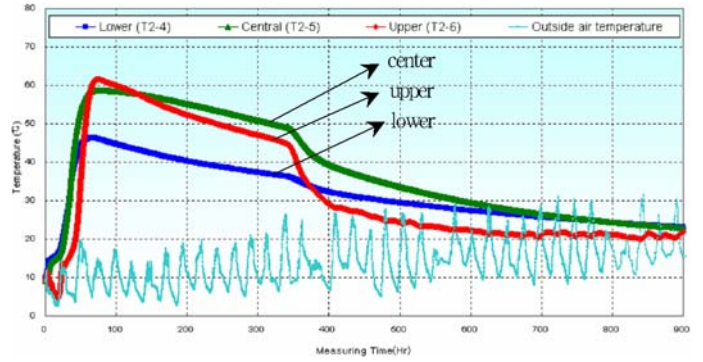


Figure 8. Variation of concrete temperature at rod2.

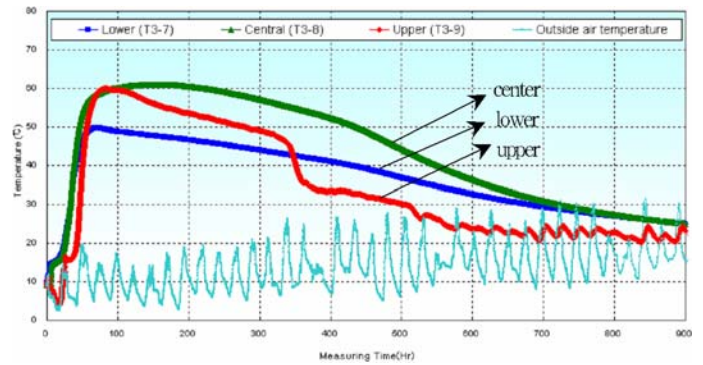


Figure 9. Variation of concrete temperature at rod3.

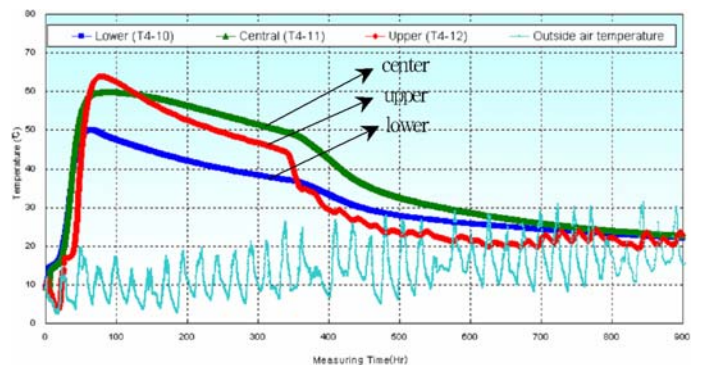


Figure 10. Variation of concrete temperature at rod4.

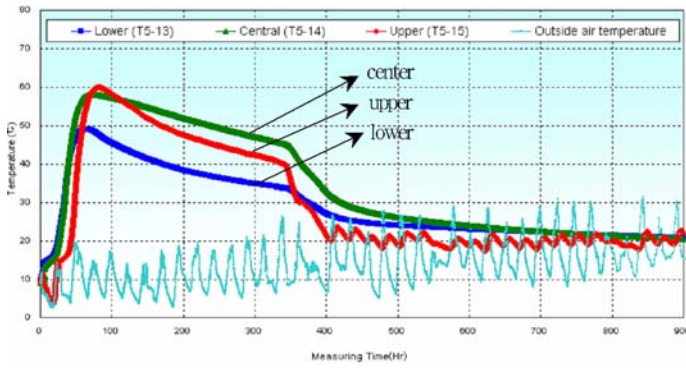


Figure 11. Variation of concrete temperature at rod5.

To reproduce large scale concrete deposit at field, concrete deposit proceeded as slow as possible. And when the deposit concrete reached the point of 3/4 of 4m high Mock up, concrete deposit was stopped for several hours to check material separation on the concrete surface. At the moment when concrete deposit was paused, it is estimated that some heat had been lost enough to effect temperature rise at the center, while adiabatic curing had insulate heat transfer of upper side of Mock up. Results of variation of concrete temperature are arranged in Table 7.

Table 7. Summary of hydration heat measurement (unit: °C).

Target	Measurement					
	Rod1	Rod2	Rod3	Rod4	Rod5	
Tmax	71	60.04	61.48	60.97	63.99	59.94
ΔT	20	14.62	14.98	13.95	14.43	13.68

The test results satisfied the specification that maximum temperature is less than 71°C and temperature difference between inside and outside is less than 20°C.

### 3.2.3 Concrete strength test results

Many core cylinders were extracted from Mock up specimen to check concrete strength development. Core cylinders were extracted vertically at age 16, 28, 56, 91days after concrete deposit. 3 core cylinders, at each location shown in Figure 12, were extracted to ensure objectivity of the data. Compressive strength test result is shown in Figure 13. In the strength development curve, it is clear that the compressive strength has already exceeded the target strength of 40MPa after 16days from deposit. Therefore, the compressive strength of developed concrete placed in Mock up satisfies the required strength. And strength test results of the concrete cylinders which were made at the field are shown in Figure 14. The strength of field cylinders also exceeded the target strength of 40MPa at the point of age 16days.

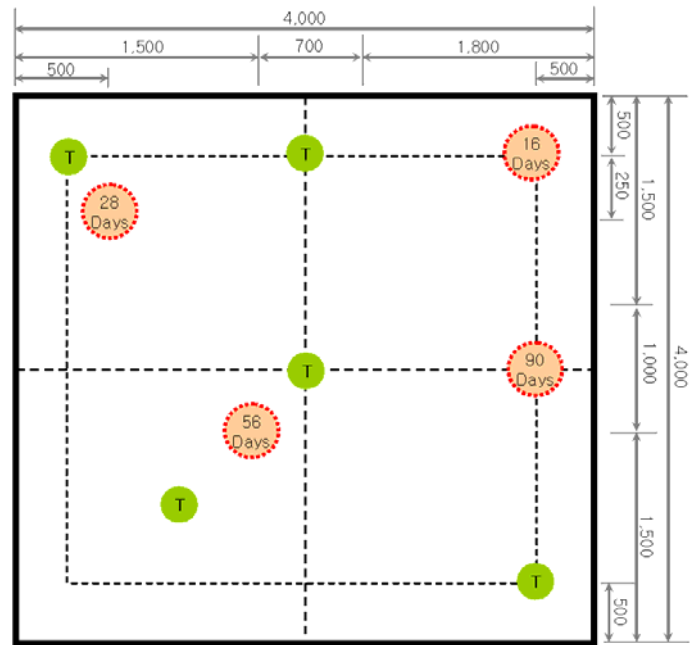


Figure 12. Location of core sampling.

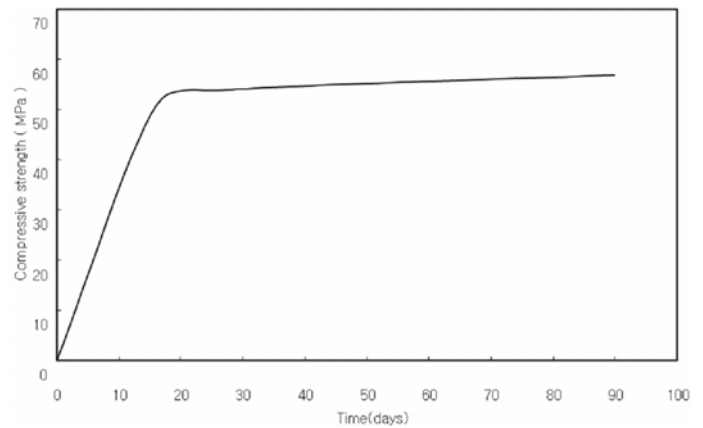


Figure 13. Compressive strength of core sample.

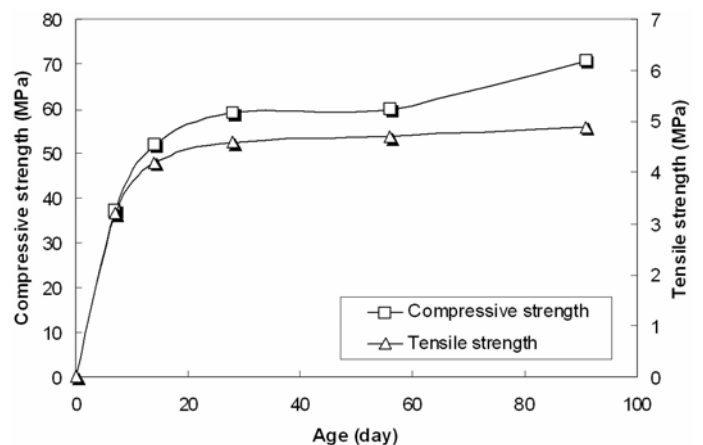


Figure 14. Strength test results of field sample.

## 4 CONCLUSIONS

In this study, appropriate concrete materials were presented developing high performance concrete which used ternary blended cement. And technical specification is indicated for high performance concrete which has low heat to minimize the probability of crack from hydration heat, self compaction ability to enhance workability and high strength to support large weight of the structures. Conclusion is stated as following.

For Mega foundation construction, specific standards are established that high performance concrete have to acquire high strength over than 40MPa in age 28days, self compaction ability of slump flow with 600-700mm, maximum temperature rise less than 71°C and temperature difference of mass concrete less than 20°C.

To satisfy the specification of low heat, maximum temperature rise less than 71°C and temperature difference of mass concrete less than 20°C, ternary blended cement was developed applying both merits of blast furnace slag and fly ash. And to verify its performance adiabatic temperature rise test was performed. In the results, at deposit temperature of 10, 20, 30°C, maximum temperature rise were 51.995, 45.912, 41.273°C so that it would be obviously less than 71°C at practical deposit.

To estimate flowability and workability of high performance concrete, several tests were carried out such as air content test, slump flow test, J-ring test, V funnel test, flow time test, L box and U box test. In the results, developed concrete showed high flowability and workability without additional compaction.

The biggest mock up test locally, 4m×4m×4m size, was performed to verify the performance of developed concrete for Mega foundation.

Mock up test was performed using developed high performance concrete and temperature variation was measured from the thermal sensors. Field tests of concrete flowability was performed, strength test was performed collecting concrete cylinder molds and cored specimen of Mock up. And verify that developed concrete is appropriate for Mega foundation construction.

It is concluded that developed high performance low heat concrete and concrete specification, in this study, are applicable to future standard of field management for Mega foundation construction, design and concrete deposit.

## REFERENCES

- ATC-18(Mega Foundations) committee. 2007. *ATC-18 establishment commemoration workshop*. Korean Geotechnical Society; 53-77.
- Hanehara, S. & Tobinai, K. 1991. Low-heat cement. *Journal of Cement and Concrete*, No. 535; 12-24.
- Kang, S.H. et al. 1996. Evaluation on the External Restraint Stress in Mass Concrete. *Journal of the Korea Concrete Institute*, Vol. 8, No. 5; 111-122.
- Kim, J.K. et al. 1995. Thermal Analysis of the Heat of Hydration in Concrete with Considering Heat Reduction Techniques. *Journal of the Korea Concrete Institute*, Vol. 7, No. 6; 176-185.
- Kim, S.C. et al. 1999. Evaluation of Thermal Characteristics in Association with Cement Types in Massive Concrete Structure. *Journal of the Korea Concrete Institute*, Vol. 11, No. 6; 3-12.
- Lee, J.H. et al. 2002. Study on Thermal Crack Control Using Pipe-Cooling in Massive Concrete Foundation of Urban Bridge. *Proceedings of the Korea Concrete Institute*, Vol. 14, No. 1; 41-46.