Fracture Mechanics of Concrete and Concrete Structures -
High Performance, Fiber Reinforced Concrete, Special Loadings and Structural Applications- B. H. Oh, et al. (eds)


# Investigation on characteristics of high fluidity concrete for tunnel lining

O. Choi
*Public Service Team for Disaster Prevention and Safety, KISTEC, Ilsan, Kyonggi, KOREA*

G. B. Kim
*Technology Research Institute, Dongbu Corporation, Seoul, KOREA*

W. Y. Choi & J. G. Jung
*Semyung University, KOREA*

K. M. Lee
*SungKyunKwan University, KOREA*

ABSTRACT: The depth of excavation for railway tunnel is increasing when applied to the tunnel excavation under the pre-existing railways, especially in urban or downtown area. As recently increasing the number of deep and big tunnel, development of new excavation technology, giving little damage to the railways located in the neighborhood, as well as improving the quality of concrete and construction technology, was concerned. In Korea, lining concrete of tunnel is considered to be an ordinary concrete having a slump 150 ± 30 mm until now. However, when applying the ordinary concrete in tunnel lining, it often cause the degradation of performance and quality for construction, and also the second grouting is required in order to fill in the cavitations of the crown of tunnel lining after casting concrete. To solve these problems, high fluidity concrete for tunnel lining have been developed and have proven to be successful in the field of application of tunnel lining. As a part of the research for increasing the flow and viscosity, the manufacturing technology of a high fluidity concrete for tunnel lining is developed and applied after conducting both BP (Batch plant) and field test.

## 1 INTRODUCTION

The depth of excavation for railway tunnel is increasing when applied to the tunnel excavation under the pre-existing railways, especially in urban or downtown area. Moreover, the height and width of tunnel are getting big due to the construction of the double track railway in urban. As recently increasing the number of deep and big tunnel, development of new excavation technology, giving little damage to the railways located in the neighborhood, as well as improving the quality of concrete and construction technology, was concerned. In Korea, lining concrete of tunnel is considered to be an ordinary concrete having a slump 150±30 mm until now. However, when applying the ordinary concrete in tunnel lining, it often cause the degradation of performance and quality for construction, and also the second grouting is required in order to fill in the cavitations of the crown of tunnel lining after casting concrete [1-2]. The problems after casting are the cavitations of the crown of tunnel lining due to the material segregation, incompatibility between supporting system and ground due to the excess vibration of steel formwork and forming the local cracking, and then developing the act of carbonation of concrete, and finally reduce the durability of concrete structure. In order to solve out these problems, conventionally tile and coating of the bottom wall of tunnel lining concrete were applied. But, it isn't fundamental solution, and also it could make another problem in terms of the maintenance. To solve these problems, high fluidity concrete for tunnel lining have been developed and have proven to be successful in the field of application of tunnel lining. High fluidity concrete has no-segregation and no-bleeding with suitable flow and viscosity, and also can be casted in the self-weight of concrete itself without vibration [3-6]. As a part of the research for increasing the flow and viscosity, the manufacturing technology of a high fluidity concrete for tunnel lining is developed and applied after conducting both BP (Batch plant) and field test.

Table 1. Chemical Components and Physical Properties of OPC, LSP and FA.

| Items / Types | $SiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | CaO (%) | $Na_2O$ (%) | $K_2O$ (%) | MgO (%) | $SO_3$ (%) | L.O.I | Density (g/㎤) | Specific Surface Area (㎠/g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OPC | 21.60 | 6.00 | 3.10 | 61.40 | - | - | 3.40 | 2.50 | 0.03 | 3.15 | 3,540 |
| LSP | 11.06 | 4.13 | 1.44 | 43.80 | 0.18 | 1.02 | 1.42 | 0.30 | 35.66 | 2.69 | 4,170 |
| F A | 58.20 | 26.28 | 7.43 | 6.51 | 0.80 | - | 1.10 | 0.30 | 3.20 | 2.18 | 3,550 |

Table 2. Physical properties of aggregates.

| Items / Types | Gmax (mm) | Density ($g/cm^3$) | Absorption (%) | F.M. | Bulk density ($kg/m^3$) |
|---|---|---|---|---|---|
| G | 20 | 2.71 | 1.01 | 7.96 | 1,611 |
| S | - | 2.55 | 2.07 | 2.89 | 1,637 |

## 2 EXPERIMENTAL PROGRAM

### 2.1 *Materials*

#### 2.1.1 *Cement and admixture*

The ordinary Portland cement (OPC) with density of 3.15g/$cm^3$ and fineness of 3,540$cm^2$/g has been used. The admixture of limestone power (LSP) with fineness of 4,170$cm^2$/g and fly ash (FA) has been used to enhance the rheological properties upon mixing with high fluidity concrete. Table 1 shows the chemical components and physical properties of these materials.

#### 2.1.2 *Aggregate*

Fine aggregate (hereinafter referred to as "S") used come from Nakdong-river sand and coarse aggregate (hereinafter referred to as "G") with maximum size of 20mm has been used. Table 2 shows the physical properties of the fine and coarse aggregate.

#### 2.1.3 *Chemical admixture*

For securing the high flowability and adjusting the air content, Polycarboxylate superplasticizer (SP) with solid content of 34% (made in Korean company) has been used. The air entraining agent (AE) has been used in order to adjusting the air content. Viscosity Modifying Agent (VMA) and Antifoaming Agent (AA) were used to keep the flowability of concrete over surface moisture of aggregate. Table 3 and 4 show the physical and chemical properties of VMA and AA.

### 2.2 *Concrete Mixing Design & Application of field*

In the method of the powdered, there are some problems on segregation of concrete, control for the quality of concrete, non economic compressive strength, hydraulic heat and shrinkage to obtain the plastic viscosity. In this research, the combined High fluidity concrete mix design was conducted to evaluate on high flowability and mechanical property.

#### 2.2.1 *Concrete Mixing Design*

The proposed concrete mix design in this research is based on Japan Society of Civil Engineers (JSCE) for the second grade performance standards "Specification on High Flowing Self-Compacting Concrete". Concrete mix design was determined with 1.12% of the aggregate filling ratio (hereinafter referred to as "PF"), and 48% of the fine aggregate ratio (S/a), and LSP 30% & FA 20% [7-8]. On powdered and combined of high fluidity concrete, usage of admixture, SP, AE, VMA and AA, are 0.7(xP), 0.15(xP), 0.3(xW) and 20(xVMA)%. Table 5 shows the powdered and combined high fluidity concrete mix design used. Table 6 shows performance evaluation items and ability of the combined high fluidity concrete for second grade performance standards of JSCE [9].

Slump-flow time (sec) up to 500mm and V-funnel flow time were measured for the resistance of the material segregation of high fluidity concrete in accordance with KSCE 2003-1. For compact ability test of high fluidity concrete, after filling concrete into the U-typed box, and lift up, the difference between the filling height and the flowing sample concrete that reached through the reinforcing bar was measured in accordance with KSCE 2003-1. To evaluate on the mechanical property on the concrete compressive strength, the cylindrical mold of ø100×200mm made without compaction. The tests for compressive strength were conducted at 3, 7 and 28 Days in according to KS F 2405.

#### 2.2.2 *Application of field*

The field applied has got traffic congestion and then the dispatch of remicon vehicle has been within 90 minute by taken into accounting rush hour.

Table 3. Physical and chemical properties of viscosity modifying agent.

| Items / Types | Series | Appearance | Solubility | Moisture content (mg/g) | Viscosity (mPa.s) | Ph | Sieve analysis |
|---|---|---|---|---|---|---|---|
| VMA | Poly saccharide | Yellowish powder | Cold water soluble | 95 ˜ 145 | 8,00 ˜ 11,00 | 6.0 ˜ 9.5 | ≤ 30mg/g on 3000 micro |

Table 4. Physical and chemical properties of antifoaming agent.

| Items / Types | Appearance | Color | Ash | Consistency | Apparent density (g/l) | Solubility |
|---|---|---|---|---|---|---|
| A A | powder | white | approx. 33% | free flowing power | approx. 260 | dispersible |

Table 5. Concrete mixing design of the Powdered and Combined high fluidity concrete.

| Types | PF | S/a (%) | W/C (%) | LSP/P (%) | FA/(C+FA) (%) | Unit mass(kg/m³) | | | | | | Water fluctuation (kg/m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | W | P | | | S | G | |
| | | | | | | | C | LSP | FA | | | |
| Powdered /Combined | 1.12 | 48 | 58 | 30 | 20 | 175 | 298 | 64 | 88 | 769 | 864 | 0, ±10, ±20 |

Table 6. Performance evaluation items and ability of the combined high fluidity concrete.

| test type | Slump flow (mm) | 500mm reaching time (sec) | V-funnel flowing time(sec) | U-box height (mm) | Compressive strength(MPa) | |
|---|---|---|---|---|---|---|
| | | | | | Specified design | Required |
| required performance | 650±50 | 7±3 | 15±5 | min.300 | 30 | 24 |

The Site of concrete casting was 40m below the ground and single tunnel. The temperature was about 5℃ when casting concrete and therefore conducted curing by insulating. The width of tunnel is 5.6m single tunnel and casted by pumping like ordinary lining concrete. To verify the applied manufacturetechnology of a high fluidity concrete for tunnel lining, the certified authority for concrete of Korea was conducted.

## 3 RESULTS OF EXPERIMENTAL TEST

### 3.1 *Flowability*

#### 3.1.1 *Flowability & elapsed time*

The values of slump flow of powdered & combined high fluidity concrete is as shown in Figure 1.

In high fluidity concrete mix design, as increase the water content per unit volume of concrete, the powdered & combined high fluidity concrete both increases proportionally. In case of the powdered, slump-flow increases approximately 32 mm as increasing water content per unit volume of concrete 10 kg, on the other hand, in case of the combined, slump-flow increases approximately 21 mm as increasing water content per unit volume of concrete 10 kg. As a result, the powdered is more sensitive than the combined over the change of water content per unit volume of concrete. When pouring high fluidity concrete in site, the combined is better than the powdered in terms of application of the field and construction.

Figure 2 shows the slump flow loss based on the elapsed time for high fluidity concrete, As seen in

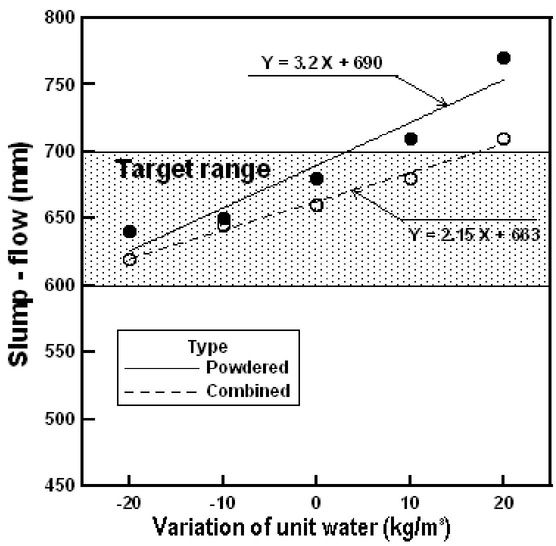


Figure 1. Slump-flow of high fluidity concrete.

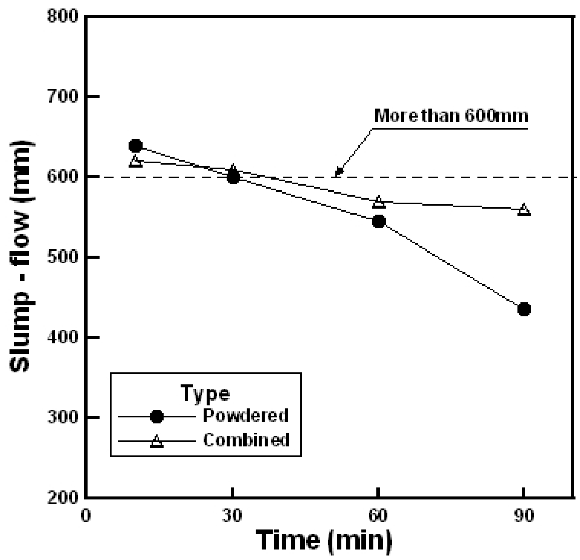


Figure 2. Slump-flow loss.

Figure 2, in case of the powdered, the slump-flow loss is inclined to decrease after 60min. In case of the combined, the graph of the slump-loss is stable after 60min. The initial slump-flow of the combined high fluidity concrete is 40mm lower than the powdered.

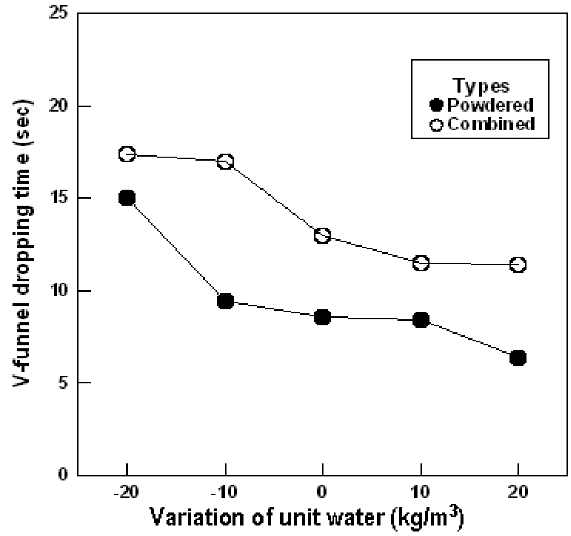


Figure 3. V-funnel dropping time.

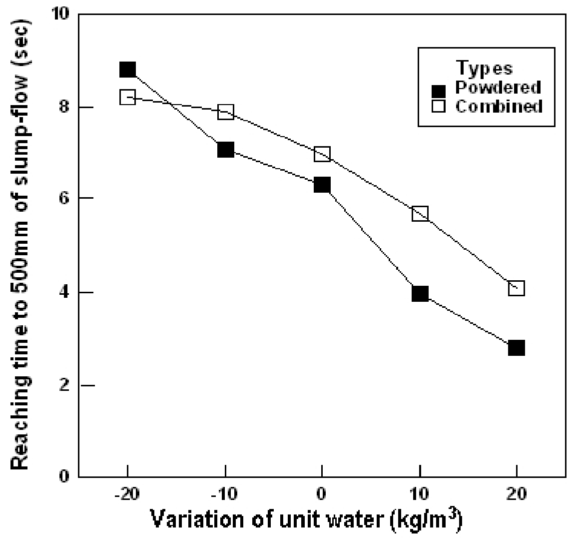


Figure 4. Reaching time to Slump-flow 500 mm.

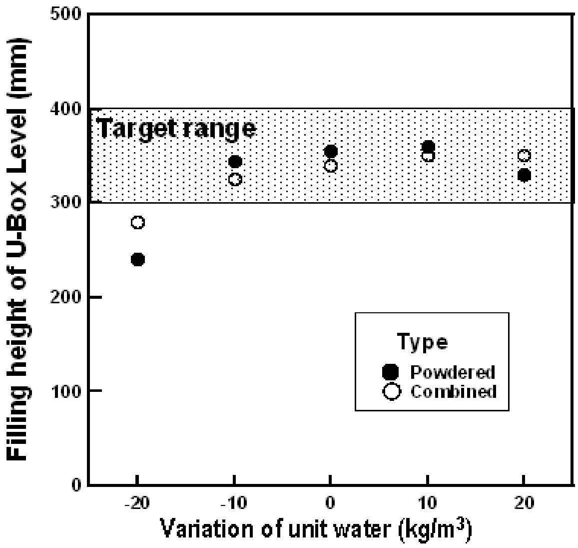


Figure 5. Filling height of U-Box.

The reason for this, the viscosity of the combined is increases as adding VMA, and also sustainable and to prevent the evaporation from inside of concrete, and finally the slump-flow loss is small.

### 3.1.2 *Resistance of material segregation*

In order to solve out the problems of material segregation of the powdered high fluidity concrete, the combined high fluidity concrete was adopted and evaluated. Figure 3 shows the dropping time of V-funnel each level of water content per unit volume of concrete for evaluating of material segregation of no-hardened powdered and combined high fluidity concrete.

As seen in Figure 3, the powdered is only acceptable in case of reducing 20kg of water content per unit volume of concrete, the others are not satisfied in terms of the allowable limitation of dropping time of V-funnel. These results come from material segregation. As increased 10kg water content per unit volume of concrete, the problem of material segregation getting worse. In case of the combined high fluidity concrete, the required performance each level was satisfied, and also even if changed the unit of water, the change of dropping time of V-funnel is not big. It is revealed that the resistance of material segregation of combined high fluidity concrete is superior to the powdered. Figure 4 shows reaching time to slump - flow 500 mm. As a results of Figure 4, the viscosity of the powdered and combined decrease as increased the unit of water. In the powdered, 3 levels (-20, -10, 0kg/$m^3$) were satisfied with the required performance. In the combined, 5 levels (-20, -10, 0, 10, 20kg/$m^3$) were all satisfied. In terms of the reaching time to slump-flow 500 mm over the change of the unit of water, the combined is more stable than the powdered. And, also in terms of the variation of the reaching time to slump-flow 500 mm over the change of the unit of water, the powdered is higher than the combined. There are some problems of material segregation and the difficulties for optimum concrete mix design into the powdered.

### 3.1.3 *Evaluation of compactability*

U-Box test was performed to measure compactability and the percentage of pass in the area of rebars in the high fluidity concrete. Figure 5 shows the results of the filling height of U-Box tests each level in the case of both the powdered and the combined high fluidity concrete. As seen in Figure 5, both the powdered and combined were out of the target range in the level 1 (-20kg/$m^3$). The other levels except level 1 were within the target range as you can see in the Figure 5. Comparing with the filling height of U-Box, the performance of filling in the powdered is rather high than that of the combined.

### 3.2 *Compressive strength*

After hardening concrete, to evaluate the mechanical performance of high fluidity concrete, the compressive strength was obtained at the age of concrete 3, 7 and 28 Days for the powdered and combined. Figure 6 shows the compressive strength of the powdered high fluidity concrete at the stage of each level. The designed compressive strength at the age of 28 Day is 30 MPa. As seen in Figure 6, in case of the powdered, only 3 levels (-20, -10 and 0kg/m³) were above the designed compressive strength. In the powdered, range of compressive strength is large according to the change of water content per unit volume of concrete. The fluctuations of the compressive strength in the powdered was -30%~124% at the maximum and minimum water content per unit volume of concrete. In the field, the change of the surface moisture of aggregate is very severe. It is difficult to obtain the acceptable compressive strength in case of using the powdered.

In case of the combined, range of water content per unit volume of concrete, that satisfied the designed strength, was 4 levels (-20, -10, 0 and 10kg/m³). Comparing with the powdered, concrete mix design of the combined is a reasonable way. In the combined, range of compressive strength is less wide than the powdered according to the change of water content per unit volume of concrete. The fluctuations of the compressive strength in the combined was 13%~113% at the maximum and minimum water content per unit volume of concrete (20 and -20kg/m³). Average compressive strength of the combined is 20% higher than that of the powdered. If the control of surface moisture of aggregate were poor in the field, it is recommended that the combined high fluidity concrete were used. Figure 7 shows compressive strength of the combined high fluidity concrete at the each age.

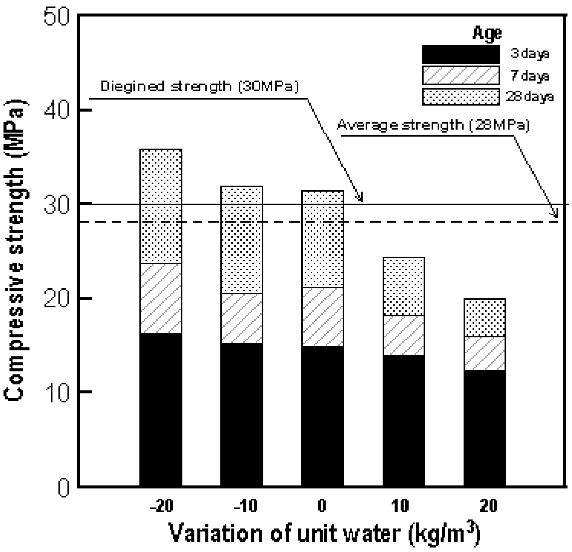


Figure 6. Compressive strength of the powdered high fluidity concrete.

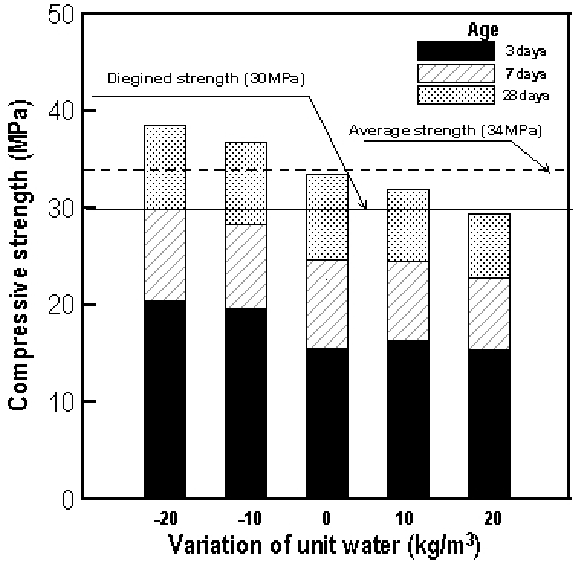


Figure 7. Compressive strength of the combined high fluidity concrete.

### 3.3 *Evaluation of application of field*

#### 3.3.1 *Batch Plant*

To apply the combined high fluidity concrete for tunnel lining concrete, field concrete mix design was performed with aggregate which used in practical field construction. The process of mix design was visually checked through the monitor and adjusted without fluctuation. No time to delay to get the site and pouring time in the site are considered. In the field, the length of concrete-conveying pipe was reduced for pouring of concrete. To prevent bent of pipe, the shape of pipe was "ㄷ" shape which is connected from ground to underground, and straight to the formwork in the underground, and from the formwork in the underground to the top of the steel formwork. Remicon truck can move to the underground for pouring. Remicon truck waits on the ground until finishing pouring previous one. Tunnel lining formwork provided with apparatus for exhausting air in order to filling inside. Due to the characteristics of SP, if the time of pouring were longer than expected, as increasing the viscosity, that causes the plugging. It is recommended that the time from batch plant mix to pouring is within 2 hours.

Table 8. In-situ the combined high fluidity concrete.

| Order / Items | 2 | 8 | Range |
|---|---|---|---|
| Slump flow (mm) | 680 | 640 | ± 20 |
| Air (%) | 3.4 | 4.4 | ± 0.5 |

#### 3.3.2 *Performance Evaluation*

The combined high fluidity concrete applied tested air content and flowability before pouring. The tests for strength and durability were conducted after pouring. The casting of lining form was nine times totally. The test of flowability was conducted two times just before casting. The results of test were meets to the JSCE 2 class in Japanese specification. The variation of slump flow and air content were ± 20mm and ±0.5%. Table 7 shows the values of the flowability performance before casting.

## 4 CONCLUSIONS

1) As a result of measuring flowability and compressive strength for the powdered and combined high fluidity concrete according to different water content per unit volume of concrete, the powdered high fluidity concrete was sensitive to the change of water content per unit volume of concrete, and also the compressive strength was rather less than the design strength. When applied high fluidity concrete for tunnel lining, the combined is suitable for the practical field construction.

2) The plugging is due to the retarded time of casting. The concrete-conveying pipe plugged as increasing viscosity of concrete. It is therefore recommended that the time of casting should be within 2 hours with no vibration and no tapping.

3) The variation of slump flow and air content for the combined high fluidity concrete were ± 20mm and ±0.5%. The above values were satisfying performance criteria.

## REFERENCES


1. Choi, Y. W., Choi, W., Kim, B. K., and Jung, J, G. "Flowability and Strength Properties of High Flowing Self-Compacting Concrete Using for Tunnel Lining," Korea Concrete Institute, Vol. 2, Issue 2. 2008, pp. 145~152.
2. Choi, Y, W., Kim, Y, J., Chol, W., and Jung, J, G. "Flowability Properties of Self-compacting Concrete for Tunnel lining," Journal of The Korean Society of Civil Engineers, Vol A ,2006, pp. 2531~2534.
3. Choi, Y, W., Kim, Y, J., Chol, W. "The Quality Properties of Self-Compacting Concrete Mixed with Tailing from the Sangdong Tungsten Mine," Korea Concrete Institute, Vol. 18, No. 6, 2006, pp. 777~783.
4. Bosiljkov, V.B. "SCC mixes With poorly graded aggregate and high volume of limestone filler," Cement and Concrete Research, Vol. 33, January 2, 2003, pp. 1279~1286.
5. Domone, P. L. "Self-compacting concrete: An analysis of 11 years of case studies," *Cement and Concrete Composite*, Vol. 28, Issue 11, 2006, pp. 197~208.
6. Sahmaran, M. Yurtseven, A., and Yaman, I. O "Workability of hybrid fiber reinforced self-compacting concrete," Building and Environment, Vol. 40, Issue 12, 2005, pp. 1672~1677.
7. Su, N., Hsu, K. C., and Chai, H. W. "A Simple Mix Design Method for Self-Compacting Concrete," Cement and Concrete Research 31, 2001, pp. 1799~1807.
8. Choi, Y. W., Kim, Y. J., Shin, H. C., and Moon., H. Y. "An experimental research on the fluidity and mechanical properties of high-strength lightweight self-compacting concrete," *Cement and Concrete Research*, Vol. 36, Issue 9, 2006, pp.1595~1602.
9. 吳相均,"高流動ユソクリートのレオロヅー評價および流動設計,"東京大學, 1999