- Technical Report -

CASE STUDY FOR PUMPING 80 MPa GRADE CONCRETE TO 260 M HEIGHT (CORE CONSTRUCTION OF A HIGH RISING BUILDING IN KOREA)

Dongyeop HAN*1, Min-Cheol HAN*2, and Gyu-Dong KIM*3

ABSTRACT
The aim of this study is to evaluate and analyze the influence of pumping on property changes of concrete. The high-performance concrete with 80 MPa made up of various materials including a high retention type polycarboxylate-based superplasticizer was fabricated and placed to the 260 m height. Test results indicated that different changes in concrete properties were evaluated depending on the pumping height. Based on a rheological analysis, plastic viscosity was significantly decreased, and yield stress was slightly decreased.
Keywords: concrete pumping, high-retention type polycarboxylate-based superplasticizer, high performance concrete

1. INTRODUCTION

Concrete pumping is the most commonly used technique for concrete placement [1–4] in construction. It is essential to the construction of high-rise buildings, and as such, presents some unique challenges. Concrete pumping is the movement of fresh concrete through a steel tube under high pressure. After pumping, concrete properties change depending on the various conditions, pressure applied, pipe characteristics, etc. [5]; hence, much research [5, 6] has been conducted on how and what properties change during and after the pumping process. These studies traditionally use a horizontal concrete pumping test, which is set up in the field. Generally, the influence of pumping on fresh concrete properties is decreasing workability and air content. Since high pressure during the pumping action, moisture in concrete mixture migrates to outside of the concrete mixture and inside of the aggregate.

High-rising buildings are usually constructed with high performance concrete, which contains complex composites of chemical powders and admixtures to achieve high performance. Therefore, in the case of high-rising building construction, high performance concrete is exposed to extreme high-pressure pumping, which causes concrete properties to change afterward as well as normal concrete, and thus it is necessary to check such changes. Characteristics of high performance concrete include less moisture content (low water-to-cement ratio) and high fineness of binders, including various powders [7, 8]. Because of the low water-to-cement ratio, the workability of high performance concrete is very low, and high viscosity due to high portion of powder, especially, high fineness of the binders. Hence the superplasticizer is needed [9] for better concrete pumpability. Therefore, different types of superplasticizer can be an important factor on changing properties of high performance concrete after the pump.

This study used 80 MPa grade high-performance concrete, which was pumped to construct a building over 260 m high so as to evaluate and analyze the influence of pumping on changes in the properties of the concrete depending on the pumping height.

2. FIELD CONDITIONS

Fig. 1 Current condition of the objective high rising building in Seoul, South Korea (the building is under construction)

*1 Post-doc Researcher, Research Institute of Industrial Science, Cheongju University, Ph.D., JCI Member
*2 Ass. Prof. Dept. of Architectural Engineering, Cheongju University, Ph.D.
*3 General Manager, Lotte E & C, M.S.

The object building was a high rising building in South Korea (Fig. 1). Although the object building is under construction, Table 1 summarizes the buildings basic information.

The building core was constructed with concrete pumping. Four mount-type line pumps (pipe diameter: 6 inch (15.2 cm), pump: putzmeister BSA 14000 SHP D) were installed and used depending on the height and floor plan. To achieve the enough pumpability at entire height of the building construction, a pumping pressure was fixed at 22 MPa (220 bar) throughout construction. The pumping pressure was determined based on the horizontal pumping test. As the floors were raised, the designed compressive strength of the concrete changed from 80 MPa up to 44th floor (200 m height) to 70 MPa up to 76th floor (322 m height), and 60 MPa up to 123rd floor (512.4 m height). For all compressive strength ranges, the management age of designed strength was 56 days.

Table 1 Building information

Construction period	2011 – 2016
Site area	87,182.80 m^2
Gross area	807,508 m^2
Floors above ground	123
Floors below ground	6
Building functions	Mixed use (office, hotel, resident, and observation deck)

3. EXPERIMENT

3.1 Experimental Plan

This study's experiment was conducted during actual building construction. Concrete properties were measured every 50 m. Concrete samples were chosen randomly from the ready-mix trucks. Table 2 summarizes the experiment's general plan. Depending on the floor levels, two different compressive strength values were designed: 80 and 70 MPa. For mixing proportions, water-to-binder ratios were 0.225, and 0.25, and sand-to-aggregate ratios were 0.43, and 0.46, for 80, and 70 MPa, respectively. The detail mixing proportions of concrete used are summarized in Table 3. Fresh state property measurements included slump flow, air content, and time taken to reach the 500 mm target flow. Measured rheological properties included plastic viscosity, yield stress, concrete temperature, and chloride content. Hardened property measurements included compressive strength and elastic modulus.

3.2 Materials

The concrete used contained fly ash and silica fume as a supplementary cementitious materials (SCMs). Ordinary Portland cement used in this concrete is a commercially available product in South Korea. According to the information provided from the manufacturer, density and fineness were 3.15, and 3,390 cm^2/g, respectively. Fly ash and silica fume used were also commercially available products in South Korea. The properties of fly ash and silica fume are shown in Table 4. Since the concrete used was obtained from ready-mixed plant, the information of detail properties of aggregates used is not available. However, for coarse aggregate, limestone was used for higher elastic modulus and less absorption rate than normally used granite aggregate. Chemical admixtures, superplasticizer and an air entrainer were used.

Table 2 Experimental plan

Concrete mixture	Maximum coarse aggregate size (mm)	20
	Designed compressive strength (MPa)	80 (up to 44^{th} floor) 70 (up to 76^{th} floor)
	Target flow (mm)	650
	Target air content (%)	2.0 ± 1.0
Experiment	Measured floors (height)	15 F (68 m)
		19 F (100 m)
		21 F (117 m)
		32 F (150 m)
		43 F (200 m)
		56 F (250 m)
		58 F (259 m)
		59 F (260 m)
	Test at fresh concrete	• Slump flow • Air content • T-500 (time for reaching 500 mm flow) • Rheological properties • Concrete temperature • Chloride content
	Test at hardened concrete	• Compressive strength (7, 28, 56 day) • Elastic modulus (28, 56 day)

Table 3 Mixing proportions

MPa	Unit weight (kg/m^3)						
	W	OPC	FA	SF	S	G	SP
80	152	507	135	34	671	902	10.5
70	155	465	124	31	741	875	10.2

W: water, OPC: ordinary Portland cement, FA: fly ash, SF: silica fume, S: sand, G: gravel, SP: superplasticizer

Table 4 Properties of SCMs

Properties	Density (g/cm^3)	Fineness (cm^3/g)	Ig-loss (%)	SiO_2 (%)
Fly ash	2.22	4,061	3.5	51.2
Silica fume	2.10	200,000	1.50	96.4

The superplasticizer used was a polycarboxylate-based superplasticizer with a density of 1.05 g/cm^3. Polycarboxylate-based superplasticizer works in both electrostatic dispersion and steric dispersion with its backbone and side chains of polymers. Especially, based on the length and density of the side chain of the polymer, high retention type superplasticizer is obtained. In this case, the superplasticizer used was a high slump retention type polycarboxylate-based superplasticizer. Depending on the manufacturing companies, different techniques are applied, but generally, high retention type polycarboxylate-based superplasticizers have longer and denser polymer chains than other types of superplasticizers [10–12]. Especially, according to the Li, et al.'s research [13], depending on the side chain of the polycarboxylate-based superplasticizer, delayed slump loss was observed and furthermore, in the case of high-retention type superplasticizer, slightly increased workability was observed within initial 30 minutes (Fig. 2).

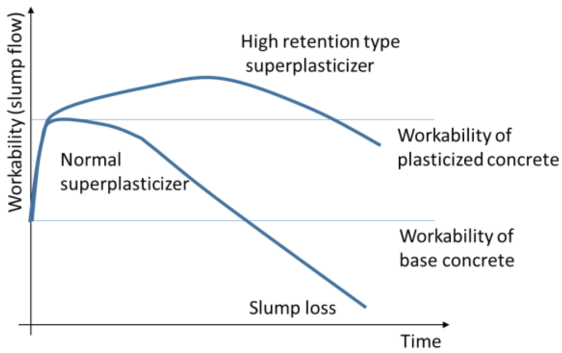

Fig. 2 Concept of workability change using high retention type polycarboxylate-based superplasticizer (Simplified based on Li, et al.'s [12] figure)

The air entrainer used was a synthetic anionic surfactant type with a density of 1.04 g/cm^3. Both chemical admixtures were liquid and mixed at the ready-mixed concrete plant, with truck deliveries scheduled within 60 minutes of the KS F 4009 standard (a ready-mixed concrete standard) [14].

3.3 Tests Methods

The influence of the pumping on concrete properties were evaluated by comparing the properties of fresh concrete before and after pumping. Slump flow, and air content tests were conducted following KS or JIS standards. Concrete temperature and chloride content were measured with a concrete thermometer and chloride meter. The time for reaching a 500 mm slump flow was measured using a slump cone of JIS A 1101. The test method was similar to JIS A 1150, but measurements were taken based on the time it took to reach 500 mm of slump flow rather than using flow stop timing. For rheological properties, plastic viscosity and yield stress were measured with an ICAR rheometer. Using the rheometer, a flow curve was obtained by decreasing shear rate and plastic viscosity. Yield stress was calculated based on the Bingham model [15] as follows:

$$\tau = \tau_y + \mu\dot{\gamma} \tag{1}$$

where, τ, and $\gamma^{\cdot}$ are shear stress, and shear rate, respectively, and τ_y, and μ are yield stress, and plastic viscosity (Bingham viscosity), respectively.

For the hardened concrete properties, compressive strength was measured at 7, 28, and 56 days. The designed compressive strengths were different depending on the building height, and the deadline was 56 days rather than 28 days. The concrete cylinders were produced following JIS A 1132 and the test was performed following JIS A 1108. The elastic modulus of concrete was measured with the same specimens used to measure compressive strength at 28 and 56 days. The strain-stress curve was obtained using the attached strain sensor. The test process followed JIS A 1149.

4. RESULTS AND DISCUSSION

4.1 Fresh concrete Properties

According to former research, pumping causes decreased workability. To prevent this decrease in workability, a high retention, polycarboxylate-based superplasticizer was added for increased or retained slump flow. As shown in Fig. 3, regardless of the pumping height, most slump flow was increased.

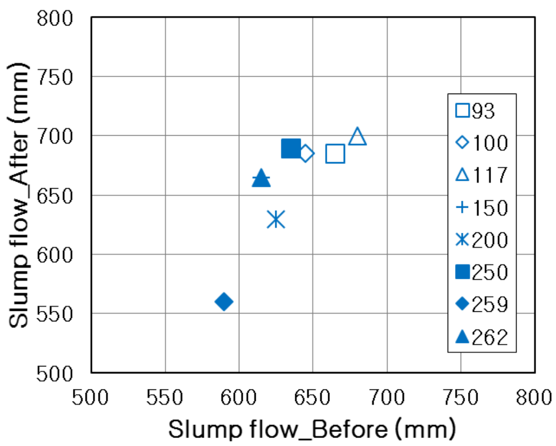

Fig. 3 Influence of pumping on slump flow

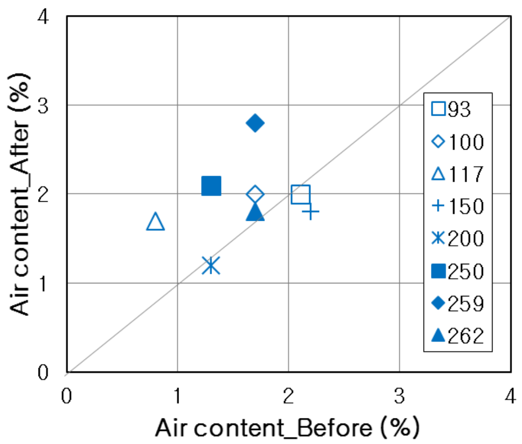

Fig. 4 Influence of pumping on air content

Former research has reported concrete pumping as capable of decreasing air content [5, 6]. As a preventive measure, air content of pumped fresh concrete was also increased as shown in Fig. 4. The reason for decreasing workability and air content after pumping is considered a result of high pressure applied which causes migration of moisture. However, in this case, the high retention type polycarboxylate-based superplasticizer contributed to increased workability and air content even after the high pressure pumping. Meanwhile, there was no clear trend showing a dependence on pumping height of fresh concrete.

To evaluate more properties of fresh concrete in detail, the time it took to reach a 500 mm slump flow (T-500) was measured. This test relates to the viscosity of the fresh concrete before and after the pumping action. As shown in Fig. 5, T-500 values were reduced after pumping.

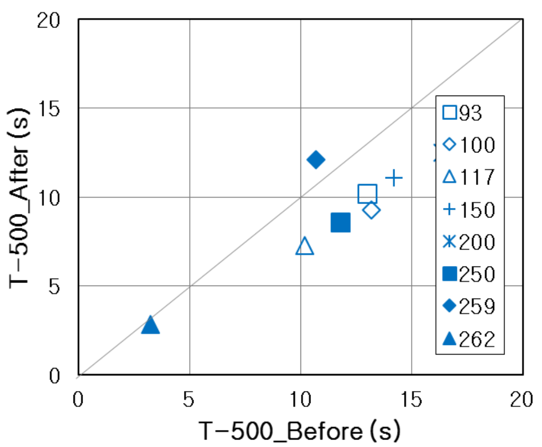

Fig. 5 Influence of pumping on time for reaching 500 mm slump flow (T-500)

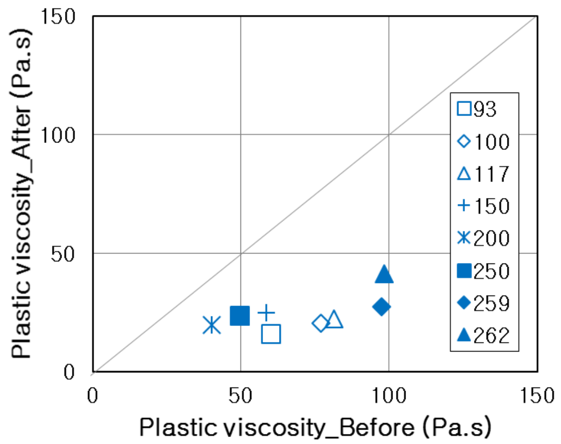

Fig. 6 Influence of pumping on plastic viscosity

Similarly, plastic viscosity decreased (Fig. 6). This was especially true of plastic viscosity values, which decreased with similar values regardless of the initial plastic viscosity values. However, neither T-500 values nor viscosity were affected by pumping height, and no such trend can be reported.

The influence of pumping on yield stress is shown in Fig. 7. As shown in the figure, generally, similar or decreased yield stress were observed after the pumping. Comparing the slump flow data, although decreased yield stress was related with increased slump flow data, no correlationship between slump flow and yield stress was observed. Also, there is no relationship between yield stress and pumping height.

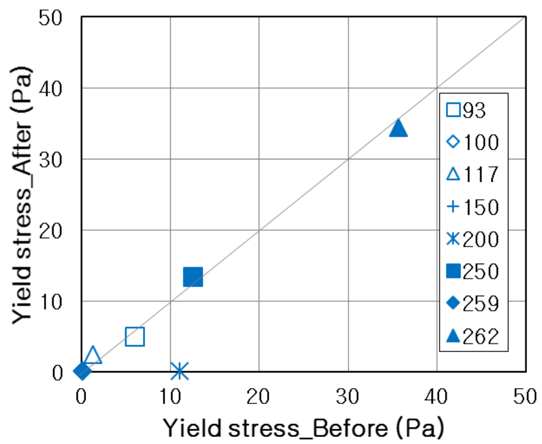

Fig. 7 Influence of pumping on yield stress

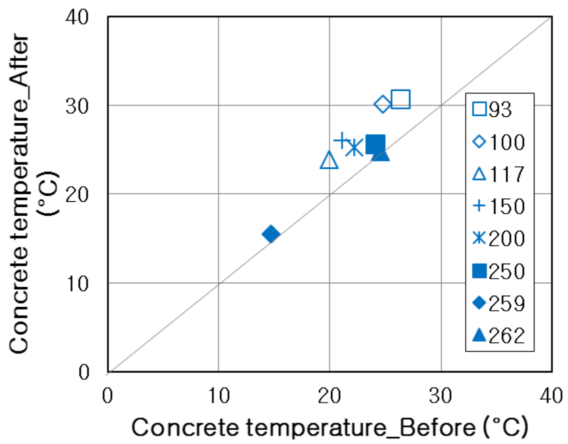

Fig. 8 Influence of pumping on concrete temperature

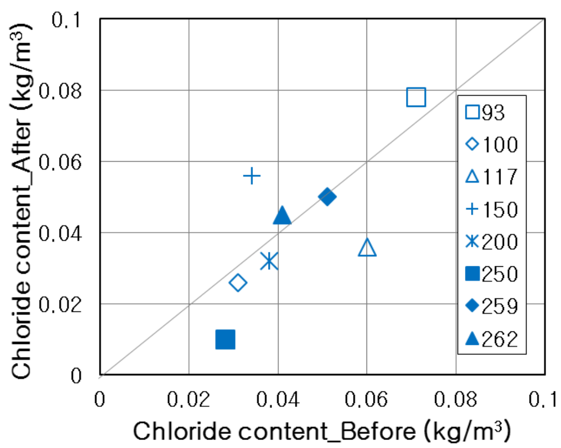

Fig. 9 Influence of pumping on chloride content

Concrete temperature (Fig. 8) increased after pumping, and chloride content (Fig. 9) was slightly decreased but leveled out after pumping. The increased temperature was natural because of the friction of the pipe during the pumping action. The changed amount of chloride content is considered insignificant.

In general, all fresh concrete properties created an increased workability after the pumping, which differs from the findings of some research. In this study, the reasons of increased workability after the pumping action can be considered with three factors: 1) high-retention type polycarboxylate-based superplasticizer was used for the concrete, which is considered a major factor accounting for the improved differences in workability as compared to reports of other researchers conducting similar studies [5, 6]. In the case of high retention type polycarboxylate-based superplasticizer, the workability is reported that slightly increased workability within initial 30 minutes. Additionally, 2) as a high performance concrete with very high volume of binder maximize the performance of the superplasticizer. Finally, 3) most studies on decreased workability after the pumping suggested migration of moisture to the outside of the concrete or inside of aggregate. Hence, limestone as a coarse aggregate of the concrete also contributed increased workability with its less absorption rate.

4.2 Hardened Concrete Properties

Fig. 10 shows the Influence of pumping on compressive strength. Compressive strength increased after pumping in all cases regardless of age. Because of the different designed compressive strength values, some different compressive strength values were observed in the figure, while all compressive strength values satisfied designed compressive strength at 56 days. The elastic moduli were not influenced as much as other properties (Fig. 11). However, slightly increased elastic moduli were observed after the pumping action. Based on the mechanical properties of hardened concrete, it was determined that although the mechanical properties of concrete changed after pumping, no significant adverse effect was observed. Mechanical properties improved some after pumping, but not enough to show a direct correlation to the improved workability of fresh concrete.

5. CONCLUSIONS

This study evaluated the influence of concrete pumping on the changing properties of the high performance concrete for a high rising building's core construction. Although researchers worldwide have reported negative effects such as decreased workability and decreased air content after concrete pumping, this study showed improvements in these properties based on the use of an 80 MPa grade high performance concrete incorporating a high-retention polycarbo- xylate-based superplasticizer analyzed after pumping through post testing. Changes in the properties of concrete poured during the construction of the objective building core were tested after the pumping action and those changes are summarized as follows:

(1) After pumping, concrete slump flow and air content increased. This result sharply contrasts with results of former research which reported decreasing workability and air content [5, 6]. The reason for this better outcome is thought to lie in various materials consist high performance concrete including the high-retention polycarboxylate-based superplasticizer, and limestone of coarse aggregate with very low absorption rate used in this building construction.

(2) Rheological analysis also supports increased workability. The plastic viscosity and T-500 values were decreased and reduced, respectively, and yield stress was also decreased after the pumping.

(3) Although these changing fresh properties were encouraging, mechanical properties of the hardened concrete increased but the change of properties was not significant.

The limitation of this study is detail analysis of the workability change after the pumping actions. Therefore, as a future research, the influence of pumping pressure on the changing properties of high performance concrete including high-retention polycarboxylate-based superplasticizer should be conducted.

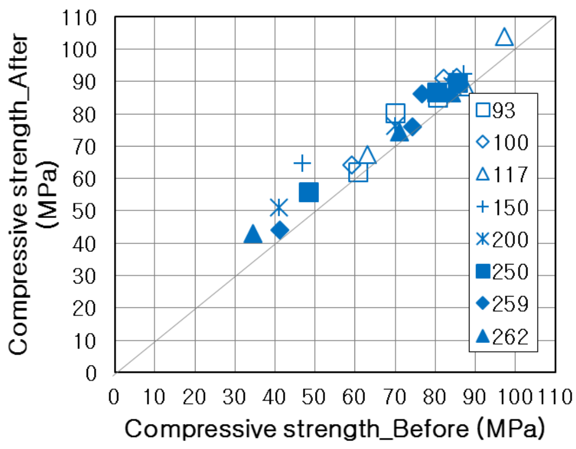

Fig. 10 Influence of pumping on compressive strength of concrete

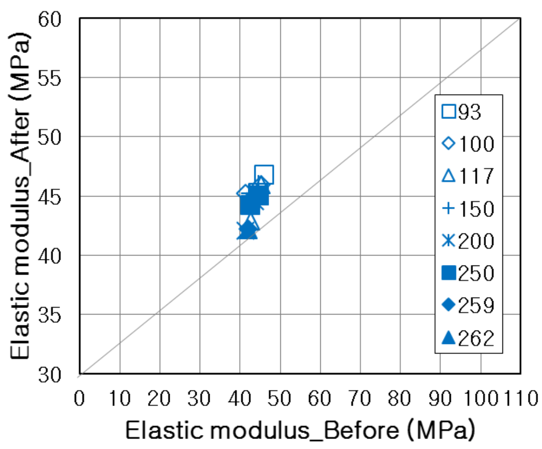

Fig. 11 Influence of pumping on elastic modulus of concrete

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