- Technical Paper -

Manufacture of High flowable, Self Compacting Concrete using Advanced Viscosity Enhancing Agent

Woojin LEE [*1], Jinman HAN [*1], Junchul YOON [*2] and Hyunmin YANG [*3]

ABSTRACT

This study investigates the production of SCC incorporating an AVEA, from trial studies to field applications. The developed SCC with AVEA demonstrated superior performance, achieving a placement rate of up to 60 m³/h - significantly higher than SCC made with conventional admixtures. Field applications confirmed its effectiveness, while cost analysis indicated potential savings of up to 20%. Overall, the findings highlight the enhanced workability, efficiency, and economic benefits of using AVEA in SCC.

Keywords: SCC, Advanced viscosity enhancing agent, Field study, Cost analysis.

1. INTRODUCTION

Self compacting concrete (SCC) was developed in 1988 by Professor Okamura [1], at the University of Tokyo, Japan, primarily for the purpose of pouring and compacting complex sections without mechanical compaction. However, two significant issues have been identified that hinder the widespread use of SCC: the increased cement content and the dependency on the conditions of the viscosity enhancing agent (VEA). The increased cement content causes problems such as higher heat of hydration, increased costs, and environmental concerns. Additionally, the stability of the concrete is affected by the variability in raw materials and the condition of the VEA. To address these challenges, the development of SCC with an advanced VEA has begun. SCC should be flowable, as shown in Table 1, and therefore requires high cement contents such as 500 kg/m^3 to prevent segregation. In this respect, it is difficult to spread normal-strength concrete, which contains cement contents around 400 kg/m^3. Mix design for SCC could be divided into 3 types, powder, VEA and a combination type. Powder type requires sufficient binder contents 500 kg/m^3 or more. VEA type is a method of increasing the artificial viscosity through the use of a VEA, however, material cost is increased since an additional facility is required for VEA. The combination type could reduce the problems of the above two methods, but it is not a fundamental solution.

In this study, AVEA (advanced viscosity enhancing agent) [2] including dissolved viscosity enhancing agents that can be realized the production of self-compacting concrete for normal concrete range without increasing the amount of cement contents.

Table 1 Workability Index for Concrete

Type	Slump	Slump flow	Self-compacting
Workability			
	~210 mm	500~700mm	600~800mm
Compaction	Necessary	Necessary	Not necessary

2. DEVELOPMENT OF ADVANCED VISCOSITY ENHANCING AGENT

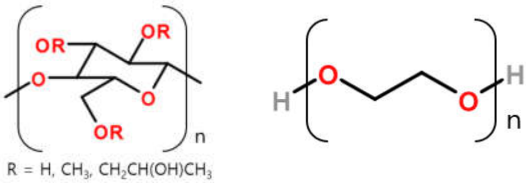
2.1 Background of VEA

VEA is used in various area as additives to increase the adhesiveness of materials and resistance to material separation by changing the viscosity of the liquid. VEA can be divided into natural VEA and synthetic VEA. Typically used VEA is based on cellulose, alkali and associative [3,4,5,6]. Increasing workability and resistance of material separation, reduction of bleeding can be secured by using VEA as a concrete admixture.

Polyethylene oxide (PEO)-based VEA, which is commonly used in concrete before, have the characteristics of securing workability and improving adhesive performance. However, it has to be improved for resistance of material separation. Due to this reason, recently cellulose-based VEA, hydroxypropyl methyl cellulose (HPMC) is used in concrete. The molecular structure of HPMC and PEO, which is shown in Fig. 1, shows that HPMCs viscosity and resistance of material separation is high due to complex molecular structure compare with PEO. However, this causes concrete to be sticky and to be used mainly in bored pile

*1 Principal Professional, Division of Engineering, Samsung C&T
*2 Master's course, Department of Smart City Engineering, Hanyang University
*3 Professor, Division of Smart Convergence Engineering, Hanyang University ERICA

construction for anti-washout underwater concrete. Therefore, many researchers are progressing for middle flow (450~550mm) and high flow (600~700mm) to increase construction efficiency.



Hydroxypropyl Methylcellulose (HPMC)

Polyethylene oxide (PEO)

Fig.1 Molecular Structure for VEA

2.2 Development of AVEA

In general, the chemical admixture for SCC uses cellulose-based, powder-type VEA to prevent segregation. However, powder-type require manual handling during material input, which increases the risk to safety due to the reliance on manpower. As a result, AVEA was targeting to make a one type of liquid. Basically, the molecular structure of a HPMC VEA is only composed of a main chain, which is mentioned Fig. 1 When analyzing the microstructure, only the main chain should be increased for viscosity of concrete. It decreases workability and pumpability, and increases the amount of water reducing agent and delay the hardening of concrete, as a result, it affects the compressive strength. To satisfy and optimize this issue, AVEA is developed to supplement this to secure high material separation resistance without increasing viscosity. Therefore, for further improvement of workability the method of increasing the amount of water reducing agent is not being effective. Fig. 2 shows the molecular structure of AVEA, a structure in which PEO is synthesized at both ends of the basic structure of HPMC, so it has the characteristics of both PEO and HPMC, and has the advantages of each VEA in increasing the effect of workability.

HPMC VEA, when dissolved in water, exhibits a thickening effect mainly from binding of a hydrophobic group such as a propyl group [7,8,9]. However, as shown in b) in Fig. 3, the binding distance between molecules is short, and thus a viscosity increase effect occurs, which adversely affects the workability of concrete. AVEA synthesized in this study has remarkable solubility in water, and when dissolved in water as shown in Fig. 3 c), the molecular structure of PEO and HPMC is exist simultaneously, even if the distance between cement particles is not narrowed, cement can hold the particles. In addition, because of the wide distance between the cement particles, it was possible to secure preventing the reduction of the concrete workability due to the increase in viscosity.

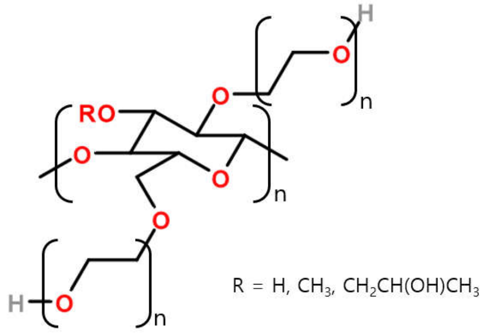


Fig. 2 Molecular Structure for AVEA

Fig. 3 shows the mechanism of enhancing viscosity in concrete when it is used in concrete itself. PEO VEA exists in agglomerated shape, however, when dissolved in water, the molecules spread in a linear shape in water as shown in Fig. 3 a), contributing to the viscosity between cement molecules.

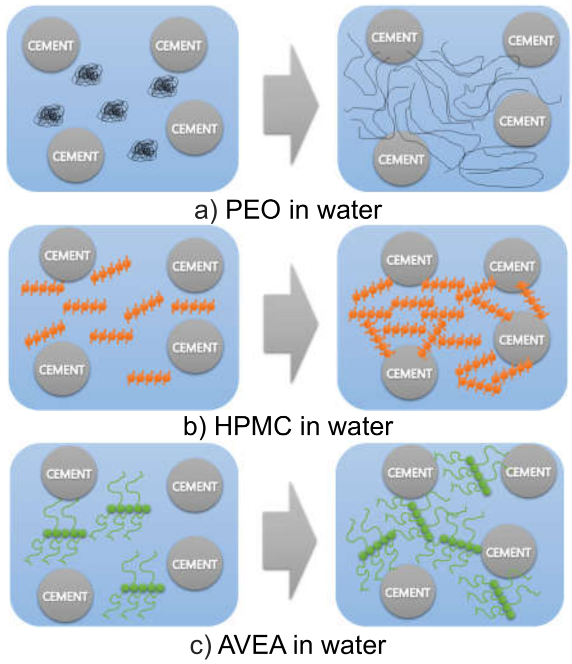


Fig.3 Dissolving Performance in Water for Each VEA

2.3 Comparison of general SCC and SCC used AVEA

SCC technology is reemerged by SDC (Smart Dynamic Concrete) [10] of Germany and Neuro-Crete Neo [11] of Japan. SDC announced that for SCC technology the world's highest level is by using cement contents of minimum 400 kg/m^3. AVEA is developed to target minimum 400 kg/m^3 cement contents and additionally consider universality. SDC must be used with designated raw materials instead of local materials. Neuro-Crete Neo was developed by using a standard material, which cannot be used universally. AVEA could be used with local raw materials conversely, it shown in Table 2.

The test results between SDC and AVEA are as follows, the slump flow, the estimation factor of workability, is similar. However, passing performance for rebar based on the U-box test shows a distinct difference between SDC and AVEA. As per European Guidelines for Self Compacting Concrete [12] difference of U-box should be below 30 mm. Test results shows AVEA is 0 mm and SDC is 190 mm difference, shown in Fig. 4.

Table 2 Comparison of Each Technology

Type	Flow type	Passing performance	Universality
SDC	o	x	x
NeuroCrete	o	x	x
AVEA	o	o	o

Slump Flow U-box

SDC

AVEA

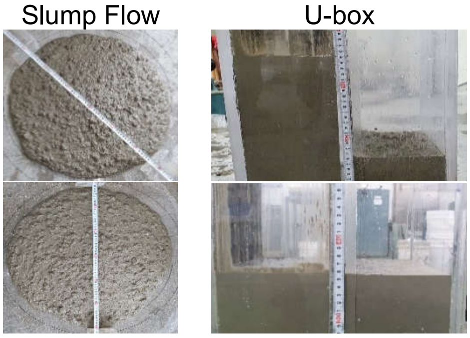


Fig.4 Flowability of SCC mixes

3. FIELD APPLICATION

3.1 Background of VEA

The purpose of this study is to develop and evaluate the performance of AVEA through mockup, pilot test and field application for the normal concrete range. To compare and optimize the AVEA, existing SCC mix design, which was applied in the Yeouido Kookmin bank HQ project, was used as a control group. Total binder concrete contents are 530kg/m^3. Which is the general contents of raw materials for current SCC technology. General experimental factors are applied, polycarboxylate water reducing agent and advanced viscosity enhancing agent for self-compacting concrete. The trial mix was conducted based on technical requirements, slump flow (workability), air contents, time to reach 500 mm (T_{500}), U-Box test (passing performance for rebar) and visual index, which is defined in European Guidelines for Self-Compacting Concrete [5]. Admixture type is shown in Table 3, and all admixtures consists liquid water reducing agent and power type viscosity enhancing agent except AVEA.

3.2 Mockup Test

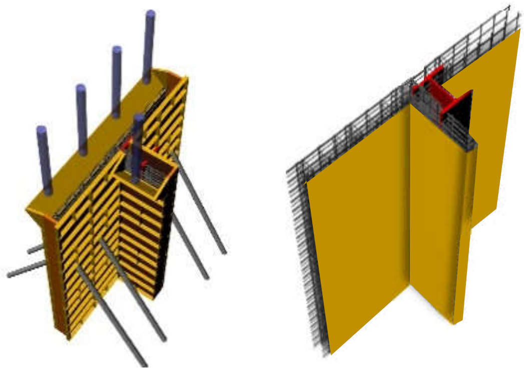
For top-down construction, due to the pre-casting of the floor slab, the inverted casting method is appropriate to be applied since the concrete of the vertical member is changed to a subsequent process. For the inverted casting method, it is necessary to verify the workability and filling performance of concrete through the passing performance test. To clarify this, a mock-up test and

Table 3 Admixture type

Two type (Water reducing agent + viscosity enhancing agent)	One type (Liquid)
	
·Admixture for general SCC	SCC (AVEA)

Table 4 Concrete Mix Design

W/B (%)	S/a (%)	Unit Weight (kg/m^3)				
		Water	OPC	BFS	F/a	AD
36.0	57.5	180	350	100	50	7.0 (SCC*)



Invert casting Method Normal casting Method

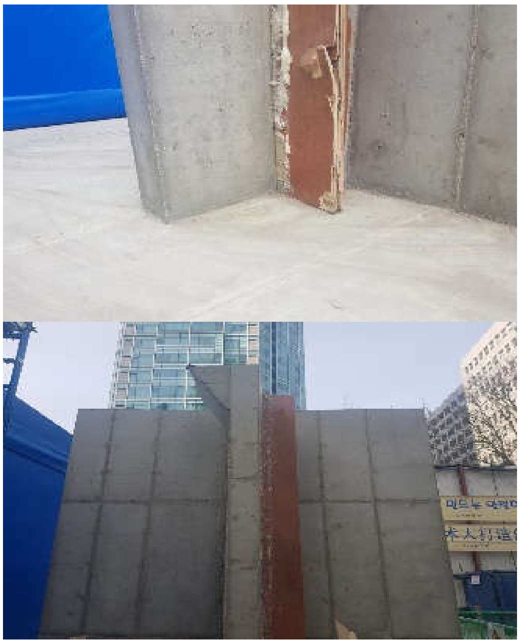
Fig. 5. Mockup Plan

Table 5 Test Results

Concrete (requirement)	Slump Flow (650±50mm)	T500 (≤10sec)	Air Contents (≤5%)	U-box (≤30mm)
25-30-650*	640/660	3.8	5.0	17mm

*25-30-650: Aggregate size-Strength-Workability

Mockup casting

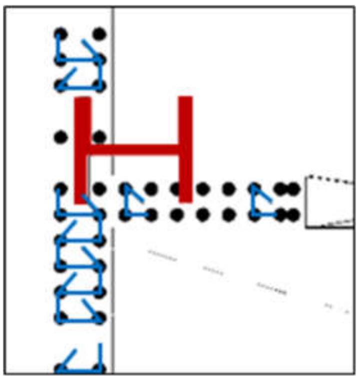


Form striking
Fig. 6 Mockup for Corewall

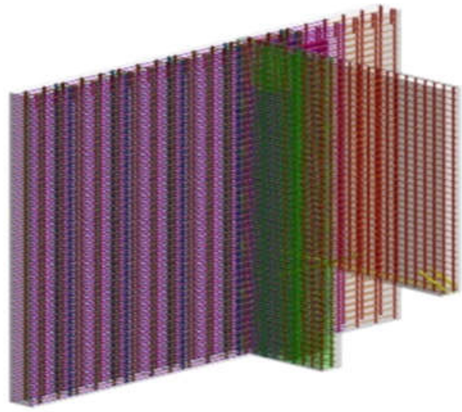
a pilot test were conducted. The mix design of concrete is shown in Table 4 and the mockup plan and casting method is shown in Fig. 5 Ready mixed concrete was cast by concrete pump and form striking was performed the next day after casting. Concrete casting and results are shown in Fig. 6 and Table 5.

3.3 Pilot Test

Performance of AVEA is evaluated through the mockup test and it should be applied on actual structure as a pilot test. Fig. 7 shows the BIM model for the application member, which reflects the arrangement of rebar, which is congested to prevent seismic affect. Similarly, concrete, which is used for mockup test and the quality of actual member, needs to satisfy the requirement. Crack and segregation was not found after the form striking, which is shown in Fig. 8 It shows the proof that quality of concrete is secured. In addition, all concrete work was performed without any compaction and vibration.



Details of rebar



Rebar arrangement
Fig. 7 Drawing and BIM Model of Actual Structure Member

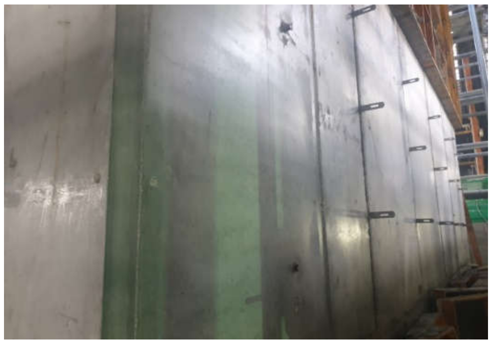


Fig. 8 Actual Structure Member for Pilot Test

Basically, for normal condition 30~40 m^3/h is the casting speed and for developed SCC casting can be perform at 60 m^3/h, which was used AVEA. Following the mockup and pilot test results, SCC with AVEA can achieve fast casting concrete securing reasonable quality.

3.4 Field Application

Field application was performed for column member and wall at Pangyo Alpha-dome Project, April to June, 2020. The materials used in this study are shown in Table 6, and the maximum size of the coarse aggregate was 25 mm, which is the same size for normal grade concrete. As a chemical admixture, a normal polycarboxylate admixture and advanced viscosity enhancing agent for SCC was used, and the mix design for this is shown in Table 7.

Table 6 Technical Data of Raw Materials

Content	Density	Source
OPC	3.15	Asia Cement
Blast furnace slag	2.90	Hanil-Hyundai
Fly ash	2.29	Clean & smart Energy

Table 7 Concrete Mix Design

No	W/B (%)	S/a (%)	Unit Weight (kg/m^3)				
			Water	OPC	BFS	F/a	AD
Mix 1	48.0	54.0	168	245	70	35	3.18 (Normal)
Mix 2	48.0	54.0	168	245	70	35	6.3 (SCC*)

As per the test result shown in Table 8 and Fig. 9, results of mix 2, which used advanced viscosity enhancing agent for SCC, met the requirements. Fig. 10 shows the section drawing for application of SCC with AVEA and casting by top-down construction without compaction due to slab precede method as shown in Fig. 11. 6.8 m height column shown in Fig. 12 and 40 m outer wall shown in Fig. 13, which casted concrete using AVEA. SCC with AVEA allowed hardening of the concrete column without any quality issue.

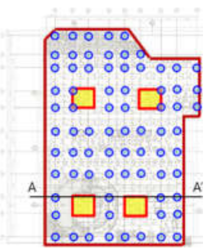
MIX 1

MIX 2

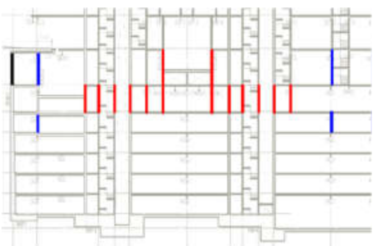
Fig. 9 Flow test observations

Table 8 Test Results

Contents (requirement)	Slump Flow (650±50mm)	T500 (≤10sec)	Air Contents (≤5%)	U-box (≤30mm)
Mix 1	550	18.6	2.4	410mm
Mix 2	630	4.2	2.2	15mm



Plan



Section

Fig. 10 Application Elements for Self-Compacting Concrete

Hole for concreting	Top-down concreting

Fig. 11 Application Elements for Self-Compacting Concrete

Fig. 12 High Surface Quality of Column using SCC

Fig. 13 High Quality Outer Wall after Form Striking

3.5. Analysis for concrete cost

The cost of SCC is increased compared to the normal slump concrete due to workability. Table 9 shows the result from the development and field application of the mixed design regarding cost simulation, mixed design and raw material cost, between the Kookmin Bank HQ case and the SCC mixed design using AVEA. As a result, the cost saving from the value engineering is approximately 20.1% compared to the existing SCC. The main reason for this is the function of AVEA, which makes it possible to produce high-flow and SCC even with a low binder, thus reducing the cost of concrete by reducing the amount of cementitious materials and replacing the high price VEA. In addition, when using the existing VEA, another working process, manually adding powder type VEA, is added. However, AVEA can be used with existing equipment, therefore, productivity should be improved without any cost increase.

Table 9 Cost Analysis of SCC

Contents		Water	OPC	BFS	F/a	Sand	Gravel	AD	Cost
Kook min Bank HQ	kg/m^3	180	350	100	50	931	693	11	72,309
	KRW	54	26,250	4,500	2,000	12,103	9,702	17,700	
SCC (AVEA)	kg/m^3	180	200	120	80	999	694	9.2	57,397
	KRW	54	15,000	5,400	3,200	12,987	9,716	11,040	

4. CONCLUSION

In the construction field, various efforts have been put in to increase the work-life balance and it is affecting the supply of concrete due to the limited time for pouring. Therefore, to secure the quality of concrete and to place concrete within the given time period are tasks to overcome in construction business. In this context, SCC is proposed as a potential solution and has been thoroughly demonstrated through this study.

1) Existing SCC technology is necessary to solve the availability improvement due to high cost and quality risk by segregation as the main issue. SCC using advanced viscosity enhancing agent developed a remarkable material as a resistance of segregation material and cost.
2) It has been proved through experiments and mock-up that it has a performance equal to or higher than that of the existing SCC materials and has low viscosity, which is the core technology of high speed placing, and has been successfully commercialized through field application.
3) Through the cost analysis, it was verified that it is possible to apply high-performance material technology without increasing the cost and expand it to all areas of construction. It will be applied to the big pour of the foundation for basement of P3, a high-tech construction of Pyeongtaek, and it will be recorded as world first big pouring by SCC.

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