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Applications of Smart Dynamic Concrete

Bruno D'Souza[1], Hironobu Yamamiya[2]

[1] *Regional Business Segment Manager, Admixtures, Asia Pacific, BASF South East Asia Pte Limited,*
33 Tuas Avenue 11, Singapore 639090
Phone: +65 6861 6766, Mobile: +65 9487 8471, Fax: +65 6863 0951,
E-Mail: bruno.dsouza@basf.com

[2] *Sales Division Head, Construction Chemicals, Japan, BASF Japan Ltd,*
21/F Mori Tower, Roppongi Hills, 106-6121 6-10-1 Roppongi, Minato-ku, Japan

Phone: +81-3-3796-9742 Mobile: +81-90-1045-0922 Fax: +81-3-3796-9980

E-Mail: hironobu.yamamiya@basf.com

ABSTRACT

The concept of Self Compacting Concrete (SCC) was first developed in Japan in the 1980's. Its use in the precast concrete is quite prevalent in several European countries and the USA. In the ready-mixed concrete industry however, the use of SCC is limited and restricted to specialized projects and applications despite all the benefits it offers. One of the main reasons why SCC is not commonly employed in the ready mixed industry is the higher cost associated with such mixes. SCC mixes require a higher amount of cementitious material in order to achieve pre-defined self-compacting properties. Hence, it is quite easy for lower grade concrete mixes to end up with higher than specified criteria.

With Smart Dynamic Concrete (SDC), a concept introduced to the Asian market in the recent past, it is possible to achieve self-compacting properties using a lower amount of cementitious material without detrimental effects. The production of SDC is made possible by combining an innovative Viscosity Modifying Agent (termed VMA) with a Superplasticizer. This combination of admixtures is capable of delivering a mix that is highly stable and robust. The VMA also enables the concrete producer to achieve self-compacting properties with lower fines and paste contents without the risk of excessive bleeding and tendency to segregate.

As engineers, contractors and ready mixed concrete suppliers continue to learn about the benefits of SDC, the authors wish to discuss their experiences and its application in various projects already executed or underway in several countries. Interest in the use of SDC is rapidly growing because it has the potential to deliver considerable savings to all parties concerned. Moreover, these savings are achieved without compromising the plastic and ultimate properties of concrete making SDC an attractive proposition.

Keywords: viscosity-modifying agent, self-compacting concrete, smart dynamic concrete, rheology

INTRODUCTION

Self-Compacting Concrete (SCC) has undoubtedly been a major advancement in the field of concrete technology. SCC, put to practical use in the early 1990s in Japan, (hereinafter referred to as SCC) has contributed to enhanced quality, durability and rapid construction of concrete structures. Several Guidelines and Recommendations that give practical advice have been published.

The Japanese Society of Civil Engineers "Recommendations for Self Compacting Concrete" foresee 3 types of SCC; thePowder type (P), the Viscosity agent type (V) and the Combination type (C). The powder type is proportioned to give the required self compactability by reducing the water to powder (material < 0.1mm) ratio (W/P) to provide adequate segregation resistance and the superplasticizers and air entraining admixtures give the required deformability and flow. The viscosity type is proportioned to provide self compaction by the use of a viscosity modifying admixture to provide segregation resistance and the superplasticizer and the air entraining admixture are used for obtaining the desired deformability. This type of self compacting concrete is usually used in underwater concreting.

Self Compacting Concrete has gained wide spread use in the precast industry, where its advantages are easily verified and put to a profitable use and to enhance the aesthetics and the durability of the precast elements. It is estimated that world-wide more than 50% of the concrete used for structural precast elements is now self compacting.

But the picture is quite different in the ready mixed concrete industry. Why this big difference?
The usage of SCC in ready mixed concrete has been limited due to several reasons as follows:
- It increases the initial cost since SCC has a higher unit content of powder compared to traditional concrete.
- The sensitivity of SCC to variations in mix proportions can lead to higher production costs. Variations in the moisture content of aggregates, especially of the sand, can significantly influence the stability of SCC.

A RMC does not get direct benefit in their production process, and they have to sell the properties of SCC to their customer. Generally, when a ready mixed concrete producer has to supply a self compacting concrete they deliver much higher strengths than ordered. This is due the high fines content necessary for achieving the particular properties of SCC. These fines are usually provided by cement and pozzolanic materials or limestone filler that are readily available at the plant. The excess of cement content and the extra amount of fines required for SCC requirement compliance and the logistics, add costs to production. The reduction of the total fines content and of cement content would lead to a decrease in the unit cost of the concrete, as long as the self compaction is maintained. SCC, outside pre-cast industry, is used for conditions, where high reinforcement density is used and high strengths are required. The use of SCC usually goes through designer specifications, when reliability of designed characteristics and durability have to be assured in the concrete structure. The high fines content SCC have a higher plastic viscosity and are suitable for structures which are heavily reinforced, that is they have more than 350 kg/m3 of steel as per JSCE Recommendation.

The lower fines content SCC are characterised by a higher yield value and a lower plastic viscosity and are suitable for lightly reinforced structures where the amount of reinforcement is less than 100 kg/m3 and classified as Rank 3 in the JSCE Recommendations. This type of concrete is typical of structures where concrete of strength class C25 and C30 is used and this forms the major part equivalent to 325 million cubic meters or 88% approximately of the ready mixed concrete produced in European Union. Therefore, if the diffusion of self-compacting concrete is to be increased, it is in this sector where the industry should focus its resources to find an innovative approach.

LOW FINES CONTENT SELF-COMPACTING CONCRETE

With conventional SCC technology the ready mixed concrete producer has to supply a concrete with high fines content. These fines are usually provided by cement and pozzolanic materials that are readily available at the plant. Fluctuations in the properties of the fresh SCC caused by the variations in the materials used are adjusted by varying the fines content and the superplasticizer dosage. The excess cement content and the extra amount of fines required for the SCC and the logistics involved (extra silos, extended mixing time, stricter quality control of the materials, etc.) add to the production costs and hence, the margins. The reduction of the total fines content and the reduction of cement content would lead to a decrease in the unit cost of the concrete, as long as the self compacting properties are maintained.

THE TARGET PERFORMANCE

For this purpose a project to develop SCC mixes with fines content (material passing 0.1 mm sieve) of not more than 380 kg/m3 and possibly reduce it to 350 kg/m3 so as to be used in normal ready mixed concrete in place of concrete strength class 25-35 MPa was initiated. The need for extra fillers (100 to 150 kg/m3) is to be eliminated or reduced, as is its cost. A Viscosity Modifying Admixture (VMA) should maintain the homogeneity of the SCC and increase its robustness, without affecting the flows significantly (low yield value) and enhances plastic viscosity. The cement content in the mix is determined on the strength class or the exposure conditions for durability and the W/C. The remaining fines are provided by a filler. In the course of the project it became clear that conventional VMAs do not deliver the needed robustness in application against variations in w/c-ratio. A new type of VMA was developed.

Accordingly, we developed a new Air Entraining Agent (AEA) and a Superplasticizer formulated with a polymerized Viscosity Enhancing Agent. The proposed Smart Dynamic Concrete (hereinafter referred to as SDC) admixture incorporating new technology can economically upgrade concrete with nominal strengths of 20-36 MPa to high fluidity concrete with self-compacting properties, including segregation resistance, cohesion and stable rheology.

Nowadays, sustainable contribution to society is required in construction projects in Japan and other countries around the world including those with emerging economies. In view of the total construction cost considering shortening work periods, CO_2 reductions, longer service life of structures and improvement of worker safety, it is accepted that SCC is extremely necessary and effective.

Having recognized the benefits discussed above, some designers, contractors and owners chose to apply and use SDC in their projects. Some important projects executed in Japan and India are discussed in the following sections.

Case Study 1 (Japan)

Project information:
· Project name: Superstructure work of Expressway at a river bridge (Kurosakigawa bridge)
· Contractee / Contractor: MLIT Hokuriku Regional Development Bureau / TEKKEN Corp.
· Type: Rigid-frame box-girder bridge with 3 spans
· Design: Bridge length is 168m (span: 44.5m+76m+44.5m)
· Design strength of concrete: $40N/mm^2$

The main reasons why SDC was selected for this work were its construction speed and improved compaction properties. Total volume of concrete placed was 1,000 m^3.
Tables 1 and 2 show the properties of materials used for SDC and mix proportion respectively. High-early-strength Portland cement was used for the purpose of shortening work periods by enhancement of early strength development. Mountain sand and gravel were utilized by the ready-mixed concrete plants as aggregate. Water-cement ratio was 0.40 in order to satisfy the design strength and the unit water content was $170kg/m^3$. In order to improve compaction, the volume of coarse aggregate was determined to be 310 litres. The target slump flow and air content were

determined to be 60cm and 4.5%. The specification was met by adjusting the dosage of the unique admixture for SDC and AEA.

Table 1 ─ Material Properties

Material	Property
High-early-strength portland cement	Density: 3.14 g/cm^3
Mountain sand	Density(Saturated surface-dry condition): 2.52 g/cm^3
Gravel	Density(Saturated surface-dry condition): 2.61 g/cm^3

Table 2 ─ Mix proportion of SDC

W/C	s/a	Unit content (kg/m^3)			
		Water	Cement	Fine aggregate	Coarse aggregate
0.40	0.522	170	425	855	810

2. Fresh property

Table 3 shows the fresh property of SDC. The slump flow of 63.0 cm was obtained when using the unique admixture for SDC at a dosage of Cx1.5%. Time (T_{500}) to reach 500mm flow was 3.0 seconds in that case. It is faster than that of existing Self-Compacting Concrete in Japan, around 10 seconds, and exhibited very low viscosity. Additionally, the concrete had better segregation resistance by visual observation as shown in the Photo 1. Height of U-Box test (R2) was over 300mm as shown in the Photo 2.

Table 3 ─ Fresh property of SDC

Superplasticizer	AE Agent	Slump flow	Air content	T_{500}	Time to stop	Concrete temp.	Height of U-Box (R2)
Cx1.5%	Cx0.002%	62.0cm	4.6%	3.0sec.	24.5sec.	16.0 deg C	340mm

Photo 1 ─ Visual observation of fresh property of SDC

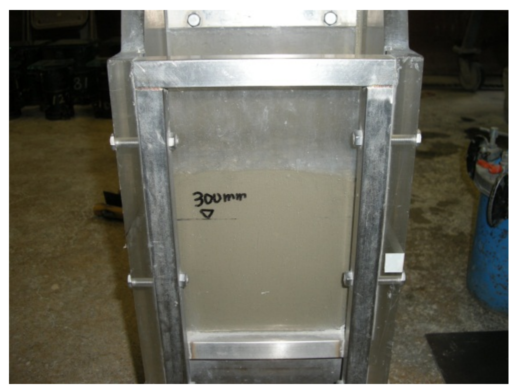

Photo 2 ─ Result of U-Box test (R2)

3. Project summary

SDC was used for the main girder of the superstructure work. Previously ordinary concrete of 12 or 15cm slump was cast. Since SDC has excellent fluidity and compaction, it obtained excellent finishability as shown in Photos 3 to 5 even in some cases where reinforcement arrangement was congested.

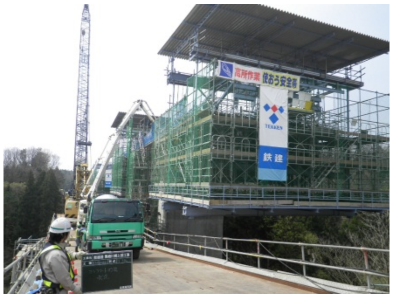

Photo 3 ─ SDC placed by pumping

Photo 4 ─ Placing (cover shot)

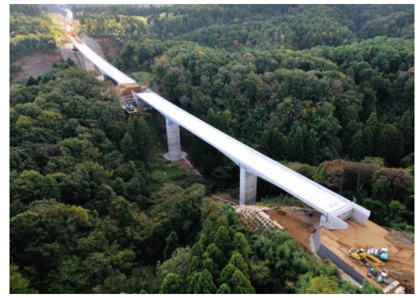

Photo 5 ─ Finishing (cover shot)

<u>Case Study 2 (Japan)</u>

Project information:
· Project name: Daini-Hamada Dam construction
· Contractee / Contractor: Kajima/Goyo/Imai JV
· Type: Set-up an inspection gallery in the dam
· Design strength of concrete: 40N/mm^2

Originally, powder-type SCC containing limestone powder was proposed to be used. However, limestone powder could not be used due to limitations of the production facility of RMC plant. Accordingly, SDC was applied to achieve better Self-Compacting property. Total concrete volume placed was 1,200 m^3.
Tables 4 and 5 show the material properties of SDC and the mix proportion respectively. Water-cement ratio was maintained at 0.40 to satisfy the design strength. And unit water content was 170kg/m^3. In order to improve compaction, the volume of coarse aggregate was determined to be 300 litres. The target slump flow and air content were determined to be 63.0cm and 4.6%.

Table 4 ─ Material Properties

Material	Property
Ordinary portland cement	Density: 3.16 g/cm^3
Blended sand(mountain, river and crushed)	Density(Saturated surface-dry condition): 2.62 g/cm^3
Andesite crushed stone	Density(Saturated surface-dry condition): 2.81 g/cm^3

Table 5 ─ Mix proportion of SDC

W/C	s/a	Unit content (kg/m^3)			
		Water	Cement	Fine aggregate	Coarse aggregate
0.378	0.522	170	450	858	842

2. Fresh property
Table 6 shows the fresh properties of SDC. The slump flow of 63.0 cm and time (T_{500}) to reach 500mm flow of 4.5 sec. were obtained respectively when using the SDC admixture at a dosage of Cx1.4%. Low viscosity Self-Compacting Concrete was obtained while it showed better segregation resistance by visual observation both, at the concrete plant and the site.

Table 6 ─ Fresh property of SDC

Superplasticizer	AE agent	Slump flow	Air content	T_{500}	Time to stop	Concrete temp.
Cx1.4%	Cx0.001%	63.0cm	4.6%	4.5sec.	37.4sec.	21.3 deg C

3. Project summary
SDC was used for the set-up of the inspection gallery in the dam. It exhibited very good workability and obtained excellent finishability as shown in the Photos 6 to 8.


Photo 6 ─ Placing SDC by kibble

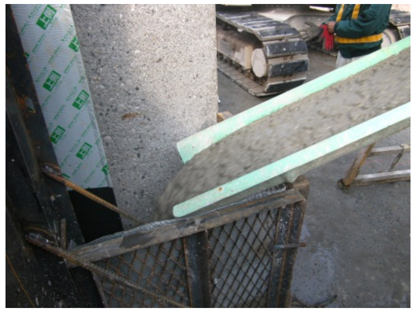
Photo 7 ─ Placing by chute


Photo 8 ─ Finished surface

Case Study 3 (India)

1. Project information:
· Project name: Slum Clearance
· Contractee / Contractor: Karnataka Slum Clearance Board / DEC Infrastructure & Projects (India) Pvt Ltd
· Type: Construction of Low Cost Housing
· Design strength of concrete: 20 MPa

Design, build and transfer of 3866 ground plus three floors dwelling units and 1200 ground floor dwelling units with comprehensive developments for the underprivileged urban population in the identified slums was undertaken by the Karnataka Slum Clearance Board (KSCB) in 2010. The dwellings are based on conventional framed structures with shear wall design, monolithically constructed using 20 MPa concrete. KSCB wanted houses to be constructed at a faster rate since they had to demolish the existing old houses and provide shelter to the affected slum dwellers at temporary locations and then shift them back to the new dwellings. For undertaking such mass housing works, it is necessary to utilize cost effective and innovative technologies capable of fast track construction and yet deliver good quality and durable structures. Once again SDC was the ideal choice for the project because of the unique properties and benefits it has to offer. SDC was poured into 100mm wide specially designed modular formwork. In this construction methodology, the walls and slabs are cast in one operation at site, instead of the traditional column and beam construction. The SDC mix was cohesive with no segregation and bleeding despite a low binder content of only 360 kg/m^3 and a consistent slump flow of 550mm. Almost 100,000 m3 of SDC is estimated to be used over the construction period of the project.

Table 7 ─ Mix proportion of SDC

W/B	s/a	Unit content (kg/m^3)			
		Water	Cement+Slag	Fine aggregate	Coarse aggregate
0.472	0.516	170	180+180	940	880

Table 8 ─ Fresh property of SDC

Superplasticizer	AE agent	Slump flow	Air content	T_{500}	Time to stop	Concrete temp.
Binderx0.8%	Nil	55.0cm	2.5%	6-9sec	21sec	31.5 deg C

3. Summary of work
For the ready mixed concrete supplier, SDC provided a consistent mix with little loss of workability or slump flow at the point of discharge. These factors resulted in less re-tempering of concrete and therefore, fewer rejections of non-conforming loads being delivered to the job site. From the contractor's perspective, SDC required minimal to no vibration due to its self -compacting properties, thereby resulting in lower energy and manpower utilization. Demoulding was done in just 16 hours and faster rotation of the formwork or in other words, shorter cycle times resulted in overall cost savings and more importantly, earlier completion times. Also, through the use of SDC, a good surface finish with no honeycombing and voids was made possible. Hence, the repair costs of concrete members cast with SDC were maintained at a low level. Similarly, the need for plastering of exposed faces as is

common practice in most parts of the country prior to painting was deemed to be unnecessary.

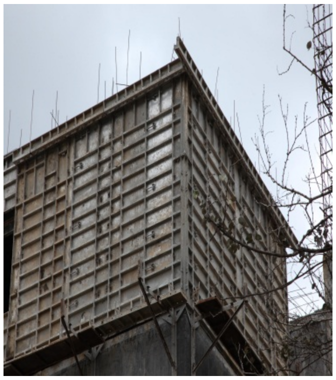

Photo 9 – Modular Formwork

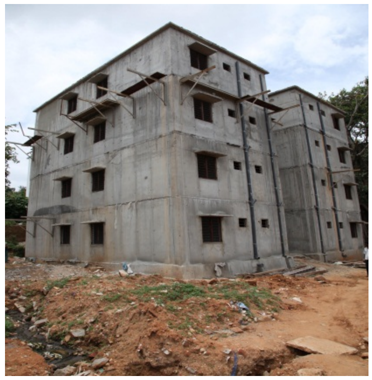

Photo 10 – Cast-in situ SDC

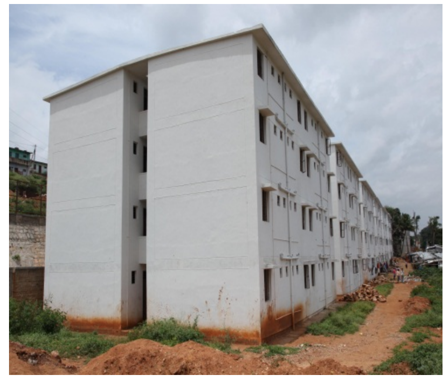

Photo 11 – Completed dwellings

Conclusions

An innovative concept utilizing a viscosity modifying agent (VMA) combined with an appropriate polycarboxylate ether (PCE) based Superplasticizer facilitates the production of Smart Dynamic Concrete (SDC) with self-compacting properties despite relatively low fines content and cost.

The rheology, anti-segregation, cohesive and stable properties imparted by the unique admixture provide SDC with adequate robustness even with minor variations in materials and mix design composition.

The use of SDC can be extended to “everyday” concrete in the ready-mixed and precast concrete industries.

SDC reduces the carbon footprint of concrete and the construction processes because of the lower cementitious content, less energy, lower in-place costs, better finishability and enhanced durability.

SDC is an attractive proposition for designers, contractors and owners because it is economically viable without compromising aspects such as the durability of structures.

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