A STUDY ON SMARTDYNAMICCONCRETE
(A NEW DIMENSIONAL SCC)

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Abstract:*Today launching the concept of Smart Dynamic Concrete (SDC), a new generation of highly flow able concrete which allows the construction industry to achieve faster and reliable concrete placement, higher concrete durability and improved energy efficiency during the placement process. In today's context, almost 65% of the traditional vibratable concrete classes are between 20 – 32MPa. To convert these strength classes to classical SCC is a big challenge, especially the balance required between stability and fluidity of the concrete mass owing to sensitivity of the mix owing to ever changing scenario in concrete constituents. By default, classical SCC requires high fines content and any SCC specified by the consultant and subsequently produced by the concrete producer is an "overdesign". Add to it the "dry batch" plants pose a challenge for consistency in production. Today, low fines self-consolidating concrete, i.e. < 340 – 380 kg / m3 of cementations content has become a reality for the lower grades of concrete. Low fines yet self-consolidating concrete uses a new state of the art synthetic viscosity modifying agent (VMA Rheomatrix 110) incorporated in special Polycarboxylate ether (PCE) based hyper plasticizer. This low fines, self-consolidating, sustainable solution will help boost productivity and efficiency to help engineers, owners, and concrete producers, realize their respective dreams.*

Low fines SCC (referred to as Smart Dynamic Concrete) realizes a host of benefits - economic (reduction of fines), enduring (durable), ecological (low fines) and ergonomic (almost negligible vibration).

Keywords:*Low-fines SCC, SDC, VMA, Hyperplasticizer, Polycrboxylate ether, Smart Dynamic Concrete.*

INTRODUCTION

The seeds of the present day form of Self Compacting Concrete (SCC) were sown in Japan in the early '80s. While the concept has spread widely across the United States and very recently in the Middle East where single pours as large as 14,000 m^3 have been successfully implemented. This has saved time and money and accelerated the construction process in quite a few areas.

The European guidelines for Self Compacting Concrete (EFNARC May 2005) have mentioned that, in the fresh state, the filling ability and stability of SCC can be defined by four key characteristics, viz., flowability, viscosity (assessed by rate of flow), passing ability and segregation resistance.

In all cases, superplasticizers (in recent times, termed as "hyperplasticizers" are used with or without the aid of viscosity modifying admixtures to obtain the desired degree of flow, deformability and /or segregation resistance. Whether in ready mix, pre cast, underwater applications, SCC has gained widespread acceptance, particularly in European countries for the pre cast industry.

Globally, estimates of quantity of SCC used in ready mix concrete mention 8 – 10% in countries like the US and Middle East; while in the pre cast industry the use could be as high as 40 – 50% .

PRESENT DAY SELF COMPACTING CONCRETE (SCC)

Concrete is quite an unique material and composition of SCC can vary between plants and countries alike even if the fresh and hardened properties are same, in terms of flow / rate of flow and passing ability. As cement and the pozzolanic content could vary in their composition including the crushed / natural fines, the unit water content can also vary appreciably based on normal consistency of cementitious material as well as the water absorption characteristic of the aggregates.

Benefits of SCC accrue to the pre cast industry in terms of tangible (materials cost saving, production increase, superior quality, reduction of patching work) and intangible (process- made-simpler, noise reduction and safe environment).

This is not quite the same for the ready mix concrete producer who does not derive any benefit instantly as his product (SCC) is required to deliver to his customer in the fresh state. Over an above, the strengths delivered are much greater owing to the nature of SCC with its high cementitious content / limestone fillers. The extra cementitious content increases the cost (as in some countries the benefits of using fly ash / slag are not available in commercial terms) and in some pours the heat of hydration is also an issue. Add to this any requirement for re-tempering the SCC would also pose immense problems in terms of stability / robustness of the mix.

The excess of cement content and the extra amount of fines required for SCC requirement compliance and the logistics, add costs to production.

Hence, if one were to consider in terms of reducing total fines content and cement content without compromising on the properties of SCC, ready mix industry as well as the specifiers could benefit on larger scale instead of restricting use of normal SCC in cases of high congestion of reinforcement (in critical sections like columns-beams, girders / inaccessible areas) As in most cases across the globe, 80 – 85% of the ready mix concrete volume consists of 25 – 35 MPa concrete. Hence if we were to focus innovations in SCC, this is the sector which makes it most attractive.

EVOLUTION OF LOW FINES SCC

As highlighted earlier in this paper, traditionally, SCC has to be supplied by any ready mix producer with high cementitious + fines content. Any variations in the properties of fresh SCC are adjusted by changes effected in the fines content as well the superplasticizer and / or viscosity modifying agent.

It is to be borne in mind that in normal SCC applications, the logistics involved is quite significant – vigilance in quality control at plant and pouring point, extra storage bins / silos. This adds to the concrete production costs apart from the minimum cementitious content (approx. 440 – 450 kg/m3), which is quite high and the extra quantity of fines (like limestone fillers).

In the concept of low fines Self Compacting Concrete (SMART DYNAMIC CONSTRUCTION- SDC) the objective is to achieve all fresh and hardened properties of SCC by reduction of total cementitious and /or fines content which would lead to an economical SCC.

PROJECT INITIATION

A research initiative was made to develop SCC mixes with total cementitious content of < 400kg/m3 with an aim to reduce it probably to a level which can be used practically for ready mix concrete applications like 25 – 35 MPa. The following were taken into consideration:

To maintain homogeneity of the mix (stable SCC), a Viscosity Modifying Admixture (VMA) was used and, at the same time, to increase its robustness, without affecting the flows significantly (low yield value) and enhancing the plastic viscosity.

Based on the grade of concrete, type of exposure and the durability factors, the cement content of the SCC (low fines) was chosen.The remaining fines are provided by a compatible filler.

During the course of the trials, it became evident that regular / conventional VMAs do not deliver the much desired robustness in application against variations in w/c-ratio. To suit this requirement, a new type of VMA was developed.

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BEHAVIOUR OF LOW FINES SCC (SDC)

The rheology of Fluid concrete may be defined by two main parameters –

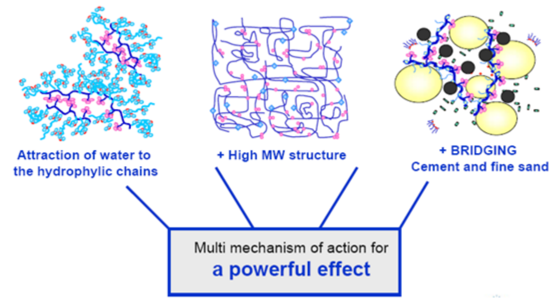
1. The yield value that measures the resistance to motion from the still condition, and

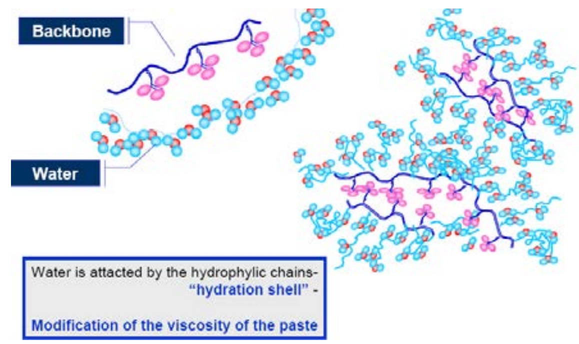
2. the plastic viscosity that measures the resistance to increase the motion speed.

Concrete with high yield value are stiff and offer significant resistance to movement, while those with high plastic viscosity are fluid and move very slowly. If plastic viscosity is too low it is very fluid but incapable to maintain particles of cement and sand in suspension and leads to a severe segregation and bleeding.

A stable concrete needs to have yield value and plastic viscosity within the orange area but its behaviour does not yet comply with SCC requirement. This is only achieved in the red area where the behaviour not only complies with SCC requirements – passing, flowing and filling but is highly stable.

The typical conditions are obtained in a conventional SCC by compensating with a high quantity of cementitious fines whereas in SDC it is achieved by the use of a special VMA





The special VMA designed for the low fines SCC (SDC) vastly improves the concrete stability and robustness, through "bridging" The long molecular chain links the cement and fine aggregate particles. Through their functional groups, they act as "flexible glue" in a sort of co-matrix that binds particles floating in suspension. This mechanism allows obtaining a stable concrete paste even with less fine particles, in a very fluid system. This special VMA is therefore capable to turn a segregating concrete into a stable one and makes it very robust. One of the primary target of this research was to introduce an interesting aspect of this new

VMA technology – i.e. able to maintain the concrete in the stability area even after adding water (e.g. 10 litres/m3 of concrete, corresponding to a variation of 4% in mixing water). This is the key for its robust behavior.

DESIGN PARAMETERS

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For the test programme some important parameters were fixed:

- Total fines content < 375 kg/m3.
- Slump flow : 600 - 670 mm Time for t500 < 12 seconds Appearance : no bleeding.
- Flow (spread) retention was fixed at 90 minutes considering that this would be satisfactory for ready mix concrete applications

The time of efflux through the V Funnel was a topic of discussion with insufficient data available for low fines self-compacting concrete (SDC). Also the proposed VMA should be "user friendly" and have a reasonable dosage rate. That is to say it may be dosed normally and not modify the mixing cycle significantly. Also, keeping in tune to the mega trends of modern day construction, the system must work with the majority of the cements, aggregates and superplasticisers combinations and should remain stable even with a variation of the water content of ± 10 l/m3. In short, the low fines self compacting concrete (SDC) must be "robust".

INITIAL FINDINGS

Available VMAs in market and cited in literature were chosen along with a number of synthesised new VMAs. A concrete mix with cement content of 350 kg/m3 was chosen using cement of the same type over all the mixes. The following parameters were measured:

- Slump Flow (yield value)
- T_{500} and V-Funnel time(plastic viscosity)

Material details:

a) Cement – CEM II 42.5 A/L

b) Aggregates - were in SSD (saturated, surface dry) condition and contained no material passing the 0.1 mm sieve. The maximum size of the aggregate was 20 mm.

c)Total water content = 185 litres/m3.

d) Admixture – Poly Carboxylate Ether (PCE) superplasticiser at a dosage rate of 0.8% was employed.

e) The VMA were dosed as a percentage of the fines content and added to the mix as the last component after the superplasticiser.

A FEW OBSERVATIONS

We observed that in quite a number of cases we got satisfactory results of slump flow

(65 + 2 cm) and V Funnel time (14 + 6 seconds) with 350 kg/m3 of fines content.

In certain cements though there is a good flow initially, after some time, the mortar separates out and settlement of coarse aggregates is observed. In such cases where the VMA dosage is increased to stabilise the concrete, the mix becomes ultra cohesive and the slump flow decreases considerably. In such cases, if superplasticiser dosage or the water content is increased to improve the slump flow, the mortar again tends to separate out. At this stage we need to see if we can make some adjustments in the VMA, so that the concrete should have a sufficiently low yield point to make the concrete flow rapidly and then have adequate plastic viscosity to prevent segregation. That is to say, it should

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maintain homogeneity without affecting the slump flow. Ideally, it should show thixotropic behaviour when at rest.

Another important point to consider is the robustness of the whole system. It should maintain homogeneity even with about 10 l/m3 of excess water in the mix.

TAILOR MADE VISCOSITY MODIFYING ADMIXTURE

Generally, the VMA tested stabilizes the mix by increasing significantly the yield value and less the plastic viscosity (Figure 4). A yield value < 10 Pa is negligible. VMA that increased the plastic viscosity did not provide enough stabilization to get a stable mix. Mixes with plastic viscosity > 80 Pa*s are very viscous and flowed slowly.

Therefore, efforts were made in our research laboratories to develop a VMA that affects essentially the plastic viscosity and marginally the yield point; which can be adjusted by the water content, the air content and the superplasticiser dosage

The best performing VMA "A" was tested with 4 types of cements, crushed and natural aggregates, fly ash and limestone filler and 3 types of PCE superplasticisers to evaluate its compatibility. The effect of an additional 10 litres/m3 of water was also evaluated in order to check the "robustness" of the mix. The performance of the laboratory tests was deemed satisfactory and we decided to proceed with the field tests. Table 1 depicts a few trial results.

VMA Type and Dosage	VMA "A"	VMA "B" 3%	VMA "C"
Slump Flow @ 5'	680	690	660
Slump Flow @ 90'mm	625	600	560
T_{50} @ 5'sec.	4	7	8
T_{50} @ 90' Sec.	8	12	11
V-Funnel @ 90' [sec]	19	35	56
L-Box @ 5' (2 bars) h_1/h_2	0.87	0.92	0.83
L-Box @ 90' (2 bars) h_1/h_2	0.81	0.83	--

FIELD TESTS

Before the product may be placed on the market, we are carrying out field tests with some selected industrial partners across the globe. Results of tests made at two ready mixed concrete plants are reported in Table 2.

Table 2: Field tests

Plant	A	B
Cement Type	CEM I 42.5 R	CEM II 42.5 A-LL
Cement Content Kg/m^3	350	250 + 100 fly ash
Sand 0 – 4 mm %	62	60
Coarse aggregate 5-15 mm %	38	40
PCE superplasticiser %	1	1
Water/Binder	0.49	0.54
Slump Flow at the Plant mm	690	680
T_{50} at the Plant seconds	3	2
V Funnel at the Plant seconds	5	6
Slump Flow at the site mm	630	610
T_{50} at the site seconds	5	4
V Funnel at the site seconds	9	12
Transport time minute	40	60

MIX DESIGN APPROACH

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Laboratory trials should be used to verify properties of the initial mix composition with respect to the specified characteristics and classes. If necessary, adjustments to the mix composition should then be made. Once all requirements are fulfilled, the mix should be tested at full scale in the concrete plant and if necessary at site to verify both the fresh and hardened properties.

The mix design is generally based on the approach outlined below:

- Evaluate the water demand and optimize the flow and stability of the paste
- Determine the proportion of sand and the dose of admixture to give the required robustness
- Test the sensitivity for small variations in quantities (the robustness)
- Add an appropriate amount of coarse aggregate which should constitute
- Approximately 40% of the total aggregate in the mix design.
- Produce the fresh SDC in the laboratory mixer, perform the required tests
- Test the properties of the SDC in the hardened state
- Produce trial mixes in the plant mixer.

WORKABILITY TEST FOR THE SDC

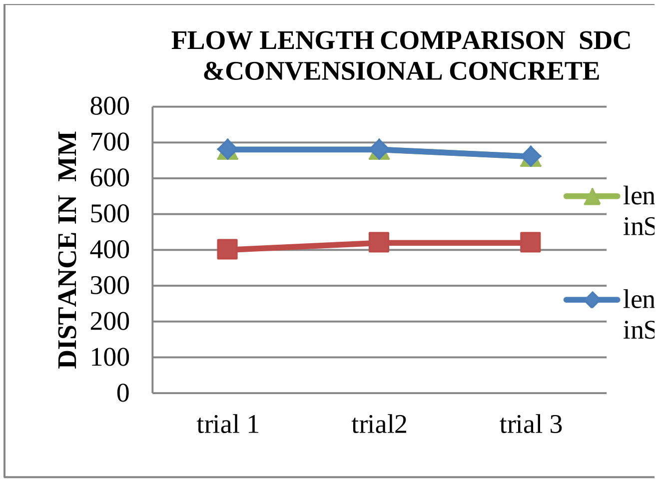
Fresh concrete was subjected to standard and non-standard tests to evaluate the slump flow, bleeding capacity and segregation potential. In order to investigate self compacting characteristics in fresh state of mix proportions for varying SP and VMA slump flow test, V-Funnel flow test, U-Box test and L-Box test were performed according to the procedure proposed by EFNARC. In fact, these methods have found universal acceptance and their values are because of their simplicity and their ability to detect the variations in the uniformity of a mix.

SLUMP FLOW TEST

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstruction. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. In case of severe segregation most coarse aggregate will remain in the centre of the pool of concrete and mortar and cement paste at the concrete periphery. In case of minor segregation a border of mortar without coarse aggregate can occur at the edge of the pool of concrete. If none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period.

SLUMP FLOW TEST

Trial Mix	Slump Flow		Requirement after 2 hrs	T_{50cm} Slump flow		Requirements
	Initial	2 hrs		Initial	2 hrs	
Units	mm	mm	mm	sec	sec	Sec
TR1	680	480	650-800	6.74	7.12	2-5
TR2	680	510	650-800	5.67	6.81	2-5
TR3	660	550	650-800	4.95	7.54	2-5

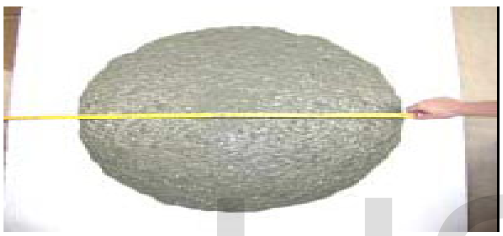


section is expressed as a proportion of that remaining in the vertical section (H2/H1in the diagram). It indicates the slope of the concrete when at rest.

This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted.

The blocking ratio = $\frac{H2}{H1}$

The whole test has to be performed within 5 minutes.



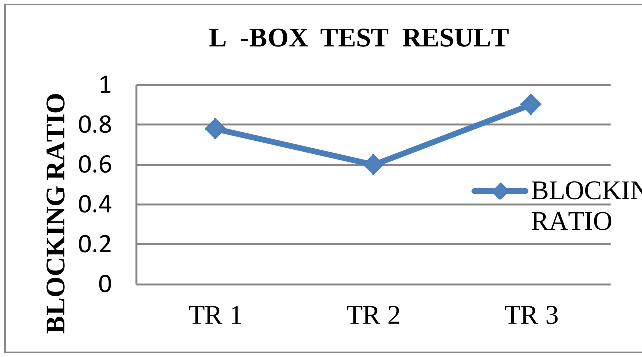
SLUMP FLOW

L - BOX TEST METHOD

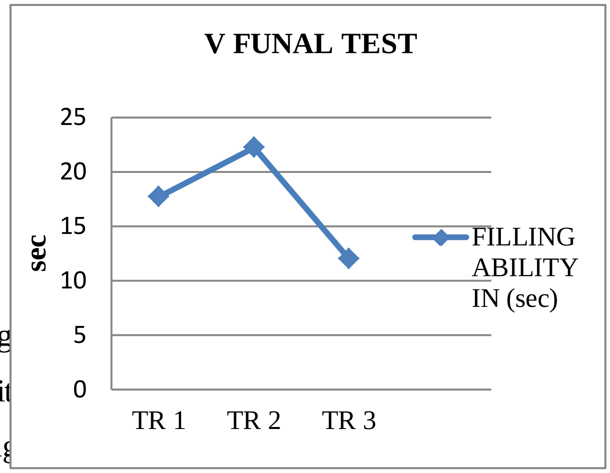
The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. The apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section is filled with concrete, and then the gate is lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete at the end of the horizontal

Table L-Box test results for Trial mixes

Trial Mix	L - Box Test						Requirements
	Initial			2 Hours			
	H_1	H_2	H_2/H_1	H_1	H_2	H_2/H_1	H_2/H_1
Units	mm	mm	-	mm	mm	-	-
TR1	9	7	0.78	10	6	0.6	0.8 – 1.1
TR2	10	6	0.60	11	5	0.5	0.8 – 1.1
TR3	**9**	**8**	**0.90**	**11**	**5**	**0.5**	**0.8 – 1.1**



TR2	17.69	19.69	8-12	39.44	42.1	11-15
TR3	22.2	24.2	8-12	48.6	51.4	11-15
	12	**15**	**8-12**	**17**	**20**	**11-15**



V FUNNEL TEST

V-funnel test is used to determine the filling (flow ability) of the concrete with a maximum agg size of 20mm. The funnel is filled with about 12 lit concrete and the time taken for it to flow throug apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

U-BOX TEST METHOD

The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments. An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacing of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 liters of concrete then the gate lifted and concrete flows upwards into the other section. The height of the concrete in both sections is measured.

Table V-Funnel test results for Trial mixes

Trial Mix	**V-Funnel Test**		**Requirements**	$T_{5\ min}$		**Requirements**
Units	**Initial**	**2 hrs**		**Initial**	**2 hrs**	
TR1	sec	sec	Sec	sec	Sec	Sec

REMARKS OF THE TRIAL MIXES

The test values of all the Table., Table., Table. and Table. were compared with the requirements as per EFNARC. It was clear from the above mentioned tables that the trial mix TR1has failed in the filling and the passing ability, since T_{50cm} slump flow was quite high and the results of U-box was out of the range.

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Trial mix TR2 failed in both filling and p ability as segregation of concrete and blockage was s V-Funnel and L-Box respectively.

The trial mix **TR3**satisfied all the requireme EFNARC and found bleeding only for 2 seconds an was **confirmed** and mix design with varying dosa chemical admixture.

Table Performances of "Tailor Made" VMA

VMA Type and Dosage	VMA "A"	VMA "B"	VMA "C"
Slump Flow @ 5' mm	680	690	660
T 50 @ 5' sec	4.95	7.54	8
V-Funnel @ 5' sec	11	18	24
L-Box @ 5' (3 bars) h_1/h_2	0.87	0.92	0.83

Table Mix proportions of SDC

Cementitious (kg)	Fine aggregate (kg)	Coarse Aggregate (kg)
370	793	1025
1	**2.14**	**2.7**

Dosages of chemical admixture were varied in the above mix design as 0.6%, 0.8%, 1.0% and 1.2%,1.3% and named as SDC series Glenium HyperPlasticiser , Rheomatrix were done for each dosage of chemical admixture with a total of 12 batches. The rheological properties were studied for each batch of varying dosage and compared with the recommendations given in EFNARC.

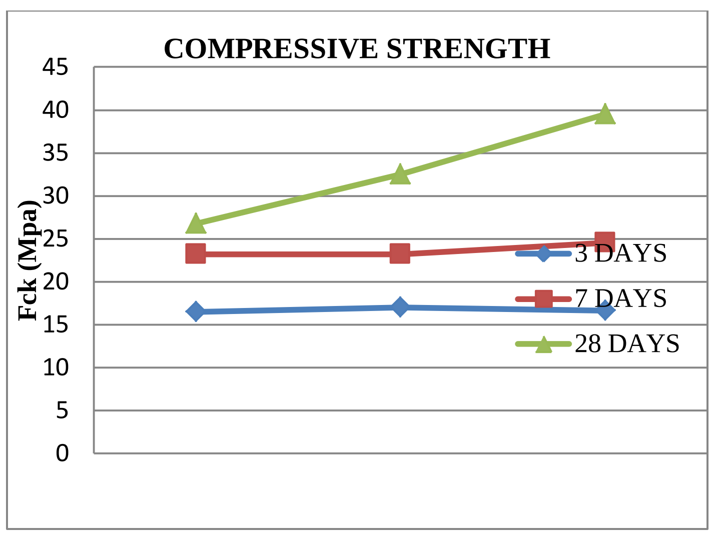
HARDENED CONCRETE TEST

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep.

Tests can be made to ensure the properties of concrete correspond to specifications for the application

Table COMPRESSIVE STRENGTH (MPA)

DAY	Compressive strength N/mm²	Compressive strength N/mm²	Compressive strength N/mm²
3 Days	16.5	17	16.67
7 Days	23.23	23.22	24.52
28Days	26.78	32.53	39.5



CONCLUSIONS

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SMARTDYNAMIC ONCRETE (Low fines SCC) addresses the needs of the ready mixed concrete industry where more than 90% of the concrete produced is of strength class of 30 -35 MPa and less. This technology innovation helps in achieving

- Optimum yield value plastic viscosity
- Superior homogeneity of the mix
- Minimum energy dissipation
- Minimization of paste volume

This type of concrete goes into structures that are not heavily reinforced (ordinary RCC structures; no prestressed concrete, etc). This eliminates the extra costs related to fines (material, silos, handling, logistics, etc.) and reduction of the binder content to the required strength class as well the heat of hydration. This means less cement or use of a lower grade cement or more supplementary cement materials (SCM) which helps in enhancing durability. The innovative viscosity modifying admixture is now available and achieves a break through for increasing the use of self-compacting concrete in the ready mix concrete industry, especially in Asia Pacific .

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