DESIGN OF 300 YEARS DURABLE CONCRETE FOR NUCLEAR CONFINEMENT ZONE AND CASTING OF TUNNEL FORM WITH SELF COMPACTING CONCRETE

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Abstract - *In this modern era, civil engineers and architectures build many innovative monumental structures. As these structures are constructed by using conventional concrete, the durability of the structure could not be more. Even though the structural works are stunning at the time, their durability will be very low when compared to the efforts put on those structures. Hence a technical revolution has to be made to overcome the durability problem. Self-Compacting Concrete is a flowable concrete which can compact under its own weight throughout the formwork and need not any vibrator. SCC is used in the reinforcement congested area where the manual compaction can not be adopted. Adopting these properties of a concrete, we moved further to produce a high durable concrete which can last for nearly 300 years. In SCC, displacement of aggregates and water due to external compaction is avoided. Hence chances of air-entrapment and honey-combing will be reduced. By reducing water cement ratio and using ultra-fine materials, we are producing a concrete which can last for 300 years and the durability can be of that concrete can be checked as a prediction by using Life-365 software.*

Key Words: 300 years durable concrete, Self Compacting Concrete, Silica fume, Alccofine, Life-365

1.INTRODUCTION

The SCC is that which gets compacted due to its self weight and is deaerated (no entrapped air) almost completely while flowing in the form work. In congested reinforced structural members, it fills completely all the voids and gap and maintains nearly horizontal concrete level after it is placed. With regard to its composition, SCC consists of the same components as conventionally vibrated normal concrete, i.e., cement, aggregates, water, additives or admixtures. However, the high dosage of super-plasticizer used for reduction of the liquid limit and for better workability, the high powder content as 'lubricant' for the coarse aggregates to increase the viscosity of the concrete have to be taken into account. High Range Water Reducer (HRWR) enhances the workability with a very low water/binder ratio. High deformability and high segregation resistance is obtained by increasing the paste volume. These two properties concrete in turn lead to high durability and self compaction. Carbonation is the "Concrete Cancer" which may increase the compressive strength of the concrete initially but they will affect the durability of the concrete as time goes on. To increase the durability of the concrete, reinforcement should be kept protected from corrosion. In most of the structures, as the reinforcement fails, total structure is getting failed. Fine cracks and pores in the concrete should be reduced to increase the impermeability of concrete which will lead to the high protection for the reinforcement from the corroding environment. Carbonation should be minimized to a very low level to achieve a high durable concrete. By decreasing the chances for the carbonation and permeability in the concrete, durability will be increased to a farthest point.

2. MATERIALS USED AND ITS PROPERTIES:

Typical materials used for SCC are

1. Cement,
2. Silica fume,
3. Alccofine 1203,
4. Coarse aggregate,
5. Fine aggregate,
6. Water,
7. PCE based HRWR Admixture.

2.1 Cement

Ordinary Portland Cement 43 grade conforming to IS: 8112:2013 was used. The different laboratory tests were conducted on cement to determine the physical and mechanical properties of the cement used are shown in Table 1.

Table -1: Properties of cement

Physical Property	Result
Fineness (retained on 90-micron sieve)	5%
Normal Consistency	30%
Initial setting time (minutes)	30 min.
Final setting time (minutes)	482 min.
Specific gravity	3.15

2.2 Silica Fume

Silica fume also referred to as micro silica or condensed silica fume, is another material that is used as an artificial pozzolonic admixture. Condensed silica fume is essentially silicon dioxide (more than 90%) in non crystalline form. It is extremely fine with particle size less than 1 micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles. Silica fume has specific surface area of about 30,000m^2/kg, as against 230 to 300 m^2/kg that of cement.

Silica Fume imparts very good improvement to rheological, mechanical and chemical properties of the concrete. It improves the durability of the concrete by reinforcing the microstructure through filler effect and reduces segregation and bleeding. Because of its extreme fineness and very amorphous silicon dioxide content, silica fume is a very reactive pozzolanic material. The pozzolanic reaction between the silica fume and the residual Calcium hydroxide in the cement paste will reduce the chance of carbonation in the concrete. Addition of silica fume also reduces the permeability of concrete (due to its fineness) to chloride ions which leads to the protection of the steel reinforcement from corrosion, especially in chloride rich environments such as coastal regions. With the addition of silica fume, the slump loss with time is directly proportional to increase in the silica fume content due to the introduction of large surface area in the concrete mix by its addition. Although the slump decreases, the mix remains highly cohesive i.e no segregation. The physical properties of silica fume are given in Table 2.

Cement reaction with water

As the cement reacts with water, it produces $Ca(OH)_2$ which will lead to the increase in carbonation depth due to the chloride attack and sulphate attack.

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.SiO_2.3H_2O + 3Ca(OH)_2$$

$Ca(OH)_2$ reaction with Silica fume

Silica fume reacts with the Calcium hydroxide to form additional binder material known as Calcium Silicate Hydrate, which is the reason for the bonding of all materials in the concrete. The residual $Ca(OH)_2$ will lead to the carbonation in the concrete as it forms as $Ca(CO)_3$ which may give initial strength but it will affect the durability of the concrete. Silica fume plays a major role in improving the durability of the concrete by changing that dangerous compound $Ca(OH)_2$ to the much wanted bonding material CSH. 16% of silica fume in the cement content can react with all the calcium hydroxide produced during the hydration of the cement. Hence the carbonation in concrete will be resisted.

$$2Ca(OH)_2 + SiO_2 \rightarrow 3CaO.SiO_2.3H_2O$$

Table - 2: Physical Property of Silica Fume

S.No	Description	Result
1	Colour	Light to dark grey
2	Specific Gravity	2.9
3	Surface Area	20,000 – 30,000 m^2/kg

2.3 Alccofine 1203

Alccofine 1203 is a product of metakaolin and it is ultrafine in its size. It improves the workability of the fresh concrete and it improves the bonding property of concrete in the hardened state. Due to its ultrafine size, impermeability of the concrete will be increased and segregation in fresh concrete will be reduced. In our project, we used 10% of Alccofine in the total binder content.

2.4 Coarse Aggregate

For the convenience of concreting in reinforcement congested structures, crushed stone with 12mm maximum size used as coarse aggregate, having specific gravity and bulk density as given in Table 2.

2.5 Fine Aggregate

M- Sand with 4.75 mm maximum size conforming to IS 383:2016 was used as fine aggregate having specific gravity and bulk weight as given in Table 2. The superior shape, proper gradation and rough surface texture of the M-sand enhances the cohesive attraction in the concrete bonding. Thus it increases the bonding strength of the concrete. As the M-sand is coming to the market after washed with water or air, silt content will be reduced.

Table - 3: Physical properties of Fine aggregate and Coarse aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.5	2.66
Bulk Density(kg/m^3)	1560	1686.7

2.6 Water

Water that is suitable for drinking is satisfactory to use in concrete. A very low amount of water is used to achieve the impermeable high durable concrete. Water / binder ratio used in our project is 0.28. The water / binder ratio of 0.2 is enough for a complete hydration of the cement particle in the concrete. As our project meet the need of concreting in a tunnel formwork, we need to design the concrete as a self compacting concrete. To achieve the flow in concrete, we have to design the concrete with 0.28 water / binder ratio.

2.7 Admixture

As we are approaching for a 300 years durable concrete with a self compacting property at a very low water / binder ratio, we have to use a High Range Water Reducer. Hence we are using the Poly Carboxylate Ether based HRWR admixture “Auramix 450”. It is a unique combination of the latest generation superplasticisers, based on a polycarboxylate ether polymer with long lateral chains. This greatly improves cement dispersion by inducing the electrostatic repulsion on the cement with other materials. Thus, a pumpable high flow self compacting concrete can be produced at a very low water / binder ratio.

Table - 4: Characteristics of Auramix - 450

Characteristics	Values Obtained
Appearance	Light yellow colored liquid
Specific Gravity	1.11
pH value	Min.6
Chloride Content	Nil (IS: 456)
Solubility	Water Soluble.

3. Mix design

Step 1: Target Mean Strength

Target strength for M50 = fck + 1.65 S
= 50 + (1.65 x 5)
= 58.25 Mpa

Step 2: Water/Binder ratio

Adopt w/b = 0.28

Step 3: Water content

Binder content = 560 kg/m^3

Water content = 560 x 0.28
= 156.8 kg/m^3

Step 4: Content of cementitious materials

Cement content = 536 – (Silica Fume Content + Alccofine content)

Silica Fume $= \frac{15}{100} \times 560$

= 84 kg/m^3

Alccofine $= \frac{10}{100} \times 560$
= 56 kg/m^3

Cement content = 560 – (84 + 56)
= 420 kg/m3

Step 5: Volume of paste

Volume of cement $= \frac{420}{3.15 \times 1000} = 0.1333\ m^3$

Volume of Silica fume $= \frac{84}{2.2 \times 1000} = 0.0382\ m^3$

Volume of Alccofine $= \frac{56}{2.9 \times 1000} = 0.0193\ m^3$

Volume of water = 0.1568 m^3

Volume of Admixture
(@ 0.9% by the mass of binder) $= \frac{5.04}{1.11 \times 1000} = 0.0045\ m^3$

Note: Maximum dosage is considered in the design mix for volume calculation.

Volume of paste = 0.1333 + 0.0382 + 0.0193 + 0.1568 + 0.0045
= 0.3521 m^3

Step 6: Volume of aggregates in concrete

Volume of Aggregates = 1 – (0.1333 + 0.0382 + 0.0193 + 0.1568 + 0.0045)
= 1 – 0.3521
= 0.6479 m^3

Volume of Aggregates = 50.5% C.A + 49.5% F.A

Step 7: Mass of coarse and fine aggregates

Mass of Coarse Aggregate = 0.6479 x 2.69 x 0.505 x 1000
= 880.134 kg/m^3

Mass of Fine Aggregate = 0.6479 x 2.61 x 0.495 x 1000
= 837.054 kg/m^3

Table - 5: Mix proportions of concrete (kg/m^3)

Grade of Concrete	W/C	Binder Content			Coarse Aggregate (12.5 mm) (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	Auramix-450 Admixture (kg/m^3)
		Cement (kg/m^3)	Silica fume (kg/m^3)	Alccofine 1203 (kg/m^3)				
M50	0.28	420	84	56	880.134	837.054	156.8	5.04

4. Properties of Fresh concrete

The workability of SCC will be characterised by the following properties:

1. Filling ability
2. Passing ability
3. Segregation resistance

4.1 Free Flow Test:

Free flow test is conducted to measure the filling ability of fresh concrete. Self Compacting Concrete should have the free flow value around 600mm – 800mm without segregation and bleeding. Hence it can flow on the tunnel formwork to a larger extent. Flow values observed at various time interval are given in Table 6.

Table - 6: Flow values of fresh concrete

S.No	Time of Testing (min)	T_{50} (sec)	Dia of the concrete spread (mm)
1.	Initial	3.5	690
2.	30	2.5	730
3.	60	2.5	720
4.	90	3.0	700
5.	120	3.5	680
6.	150	4.5	650
7.	180	4.5	620

Fig.1 Flow after 30 minutes of addition of water (730 mm)

Fig.2 Flow after 90 minutes of addition of water (700 mm)

4.2 L – Box Test:

L – box test is performed to measure the passing ability of concrete. When a concrete has to be poured into a congested reinforcement area, its passing ability through the reinforcement should be more. For a self compacting concrete, its value should lie between 0.8 – 1.0. The values observed in L – box test is given in Table 7.

Table - 7: L – box test values

S.No	Time of Testing (min)	H_1 (cm)	H_2 (cm)	H_2 / H_1
1.	Initial	9.45	8.65	0.915
2.	30	9.10	8.90	0.978
3.	60	9.25	8.80	0.951
4.	90	9.40	8.65	0.920
5.	120	9.65	8.50	0.881
6.	150	9.95	8.40	0.844
7.	180	10.15	8.25	0.813

4.3 V-Funnel test:

V – funnel test is carried out to determine the segregation resistance of the concrete. If the concrete was drained fully around 10 seconds, it has a high segregation resistance. For a self compacting concrete, it is preferred to be have a resistance to segregation. The values obtained for V-funnel test is given in Table 8.

Table - 8: V-Funnel test values

S.No	Time of Testing (min)	T_0 (sec)	T_5 (sec)
1.	Initial	8.53	11.17
2.	30	6.58	8.25
3.	60	6.87	8.92
4.	90	7.41	9.84
5.	120	8.63	11.72
6.	150	9.27	13.19
7.	180	10.38	14.27

5. Properties of Hardened concrete:

5.1 Compressive strength Test:

Compressive strength test is carried out to test the capacity of the concrete to withstand the load without any damage causing to it. Three cubes were tested for each curing period of 3 days, 7 days and 28 days respectively.

Table 9: Test results for the compressive strength of the concrete

S.No	Days	Compressive strength (N/mm2)	Average compressive strength (N/mm2)
1.	3 days	22.67	24.74
		28	
		23.56	
2.	7 days	44.44	44.59
		42.67	
		46.67	
3.	28 days	66.67	62.58
		57.7	
		63.37	

Fig.3,4. Compressive strength of concrete

Sorptivity Test:

To measure the amount of water absorbed by capillary action through the specimen. Increase in the amount of water absorption of concrete indicates the low resistivity of concrete to the water absorption. It will affect the durability of the concrete adversely. The test values were given in the Table 10.

Table 10: Test results for sorptivity

Intervals	Volume of water absorbed (cm³)			Sorptivity (cm/sec½)
	Sample 1	Sample 2	Sample 3	
15 min	0.002	0.003	0.003	1.126x10-6
30 min	0.003	0.005	0.004	1.12x10-6
60 min	0.0035	0.008	0.004	1.09x10-6
120 min	0.0035	0.008	0.0045	8x10-7
240 min	0.0037	0.0082	0.0045	5.8x10-7
480 min	0.004	0.0085	0.0045	4.251x10-7
960 min	0.004	0.0085	0.005	3.094x10-7
1440 min	0.004	0.009	0.005	2.24x10-7

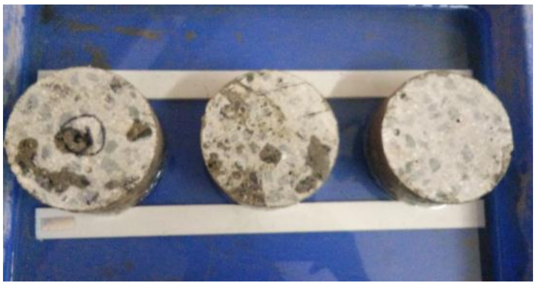


Fig.5 Sorptivity Test

Rapid Chloride Penetration Test (RCPT):

RCPT is conducted to determine the penetration amount of chloride ions through the concrete. In this laboratory test, concrete specimen were subjected to a heavy load of chloride ions and the chloride penetration were observed and the values for chloride penetration is given in the Table 11.

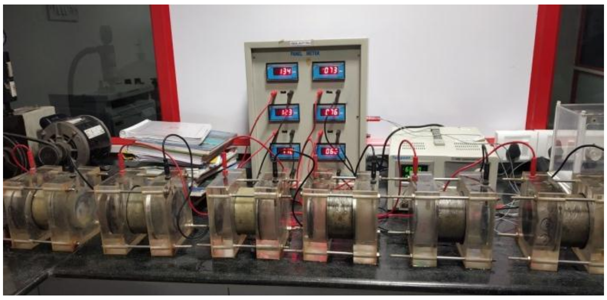


Fig.6 Rapid Chloride Test

Table 11: Test results for Rapid Chloride Permeability Test

TIME	SAMPLE 1	TEMP	SAMPLE 2	TEMP	SAMPLE 5	TEMP
0	66	24°C	67	24°C	60	24°C
30	68	25°C	76	25°C	65	25°C
60	70	25°C	79	25°C	66	25°C
90	71	26°C	80	26°C	67	26°C
120	72	26°C	81	26°C	68	26°C
150	73	27°C	82	27°C	69	27°C
180	75	27°C	82	27°C	69	27°C
210	76	28°C	82	28°C	69	28°C
240	76	29°C	83	29°C	70	29°C
270	76	29°C	84	29°C	70	29°C
300	76	29°C	84	29°C	70	29°C
330	76	30°C	84	30°C	70	30°C
360	76	30°C	84	30°C	70	30°C
Average	1447.2		1750.5		1472.4	
Average = 1556.7 coulombs						

Corrected value for chloride penetration = 1404.87 coulomb

According to ASTM C 1202, this value (1000 – 2000) lies in a low chloride penetration rate.

Water permeability Test:

Water permeability test is conducted to determine the how much depth that water penetrated through the concrete. When concrete is permeable, it can cause corrosion in reinforcement in presence of oxygen, moisture, CO_2, SO^{3-} and Cl^- etc. This formation of rust due to corrosion becomes nearly 6 times the volume of steel oxide layer, due to which cracking develops in reinforced concrete and spalling of concrete starts. So, if the concrete is made impermeable, the corrosion and ultimately spalling of concrete can be prevented.

Table 12: Test results for water permeability

Sl.No	Sample	Depth of water penetration (mm)
1.	A	15.0
2.	B	18.0
3.	C	14.0
Average		15.7

Fig.7, 8: Water Permeability Test

Life-365 Analysis:

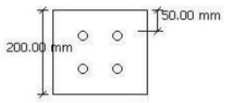
Using the results obtained from various tests, expected service-life was analysed by using Life-365.

The expected service life of our concrete is obtained as more than 306 years.

Life-365 v2.2 - Concrete Mixes and Service Lives

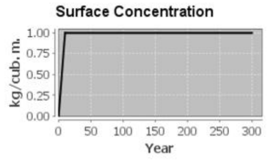
Project: R-300 Description: Analysis of durability using Life-365

Analyst: T.K.Rajaguru Date: 03/30/2019



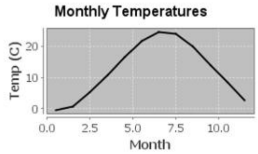
slabs and walls (1-D)

Outer dim: 200mm; clear cover: 50mm



Max surface: 1.000 kg/cub. m.

Years to buildup: 10



Loc: user-defined

Type: user-defined

Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
Base case	yes	n/a	n/a	n/a		Black Steel

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Base case	-> 3.44E-13 m*m/sec	-> 0.26	-> 1.18 kg/cub. m.	300+ yrs	-> 6 yrs	**306+ yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Reference:

[1] IS 8112-2013, "Specification for 43 grade ordinary Portland cement", Bureau of Indian Standards, New Delhi, 1989.
[2] IS: 456- 2000, "Plain and reinforced concrete code for practice", Bureau of Indian Standards New Delhi, India.
[3] IS 10262 – 2009, "Guidelines for concrete mix design proportioning", Bureau of Indian Standards New Delhi, India.
[4] IS: 383-1970, "Specifications for Coarse and Fine aggregates from Natural sources for Concrete", Bureau of Indian Standards, New Delhi, India.
[5] IS 4031 – 1996, "Methods of physical tests for hydraulic cement", Bureau of Indian Standards, New Delhi, India.
[6] IS 2386 – 1963, "Methods of test for aggregates for concrete", Bureau of Indian Standards, New Delhi, India.
[7] EFNARC. "Specification and guidelines for self-compacting concrete. European Federation of Producers and Applicators of Specialist Products for Structures", 2002.
[8] Okamura H., Ozawa K., Mix Design for Self-Compacting Concrete, Concrete Library of Japanese Society of Civil Engineers, June 25, 1995, p. 107-120.
[9] K.Gayathri, Durability and cementing efficiency of Alccofine in concrete.
[10] Dr. Mohd.Hamraj (2014), Experimental study on binary blended high strength steel fiber reinforced concrete using Alccofine as mineral admixture, International Journal of science and technology, Vol.2, pp.56-62.
[11] Gouws SM, Alexander MG, Maritz G (2001) Use of durability index tests for the assessment and control of concrete quality on site. Concr Beton 98:5–16
[12] Alexander MG, Ballim Y, Mackechnie JR (1999) Concrete durability index testing manual. Research Monograph No. 4, Department of Civil Engineering, University of Cape Town, 33 pp
[13] Mackechnie JR, Alexander MG (2000) Rapid chloride test comparisons. Concr Int 22(5):40–46
[14] Mackechnie, J.R., 'Predictions of Reinforced Concrete Durability in the Marine Environment – Research Monograph No. 1', Department of Civil Engineering, University of Cape Town, (2001) 28 pp.
[15] M.S. Pawar, A.C. Saoji, "Effect of Alccofine on Self Compacting Concrete" The International Journal of Engineering and Science (IJES), Volume 2 ||Issue|| 6 ||Pages|| 05-09||2013|| ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805