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Performance of Flowable Concrete for Application in Underground Structures -NATM Tunnel and Station Box of Mumbai Metro Project

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Abstract: High-performance flowable concrete offers special combinations of performance, uniformity, and consistency requirements that cannot be possible by traditional normal slump concrete. It is an advanced concrete than traditional concrete with high workability without segregation, bleeding and it is suitable for placing in structures with congested reinforcement of structure, long distance pumping concrete-like inside NATM tunnel, cross passages, and underground station box concrete structures. Flowable concrete can be flow itself but does not have the self-compacting capability. Flowable concrete required vibration to ease flow to reach each corner of formwork and compaction for achieving a smooth surface finish after de-shuttering. Mix proportion of flowable concrete must ensure a good balance between deformability and stability. The behavior of concrete can be affected by the characteristics of selected ingredients in concrete and the mix proportions. It becomes necessary to evolve a procedure for mix design of flowable concrete. The paper presents an experimental procedure for the mix design of flowable concrete for grade M40 and implementation of the same mix at the cast in situ Base slab, Roof slab Rcc walls for underground metro stations, NATM tunnel & cross passages in Mumbai Metro Project, package -UGC-07. The test results for acceptance characteristics of M40 grade flowable concrete such as flow table test, compressive strength at the ages of 7, 28, and 56 days determined, and results are included here. Successful production of temperature control flowable concrete from batching plant, transportation, placement procedures, and proper planning of handling and execution of flowable concrete at the site are presented in this article.

Keywords Flowable Concrete, Mix Design, Fresh concrete Properties, Hardened Concrete Properties, Application at site

I.INTRODUCTION

Rheological properties and behaver of flowable concrete or self-compacting concrete are advanced than traditional normal slump concrete. The hardened concrete is dense, homogeneous, and has the equivalent properties as traditional normal slump concrete. Flowable concrete is suitable for a fast rate of concrete placement, with faster construction times and ease of flow around congested reinforcement without vibration or little bit surface tamping to get better surface finish. "It ensures good homogeneity, pumping ability, best surface, finish and consistent concrete strength and durability to the concrete structure. The workability of concrete describes the flowability, mobility, and stability of fresh concrete.

Specific measurement limits of Slump, Slump flow, Flow table cannot be fixed and its totally depends on placing condition of site, however concrete should be homogenies, cohesive, no settlement and no bleeding in mix"[1]. The mechanical properties of concrete like compressive strength, flexural strength, split tensile etc. are mainly affected by composition of concrete ingredients. In Mumbai region river sand is not available and therefore construction industries are totally depending on manufactured sand. In M-sand it is difficult to maintain required fractions of sieve sizes for getting appropriate zone of sand i.e., zone II as per IS383:2016 [2]. According to site requirements only flowable concrete was suitable due to long distance of pipe installation, pumping and congested reinforcement in the structure.

Hence flowable concrete was developed by conducting several numbers of concrete mix trials and concluded that trials were only achieving standards requirements for flowability by slump flow, flow table tests and sieve segregation resistance tests as per specification mentioned in European standard [3]. Chemical admixtures i.e., superplasticizers required for optimized the cementitious content and minimize the W/C ratio for production of high performance flowable concrete [4]. Appropriate selection of supplementary cementitious materials such like GGBS, Ultrafine GGBS-Alccofine, Crystalline growth admixture etc. are also required for improving durability, decreasing permeability, aiding in pumpability and finish ability, mitigating alkali reactivity and improving the overall hardened properties of concrete. The improved construction practice and performance, combined with the health and safety benefits of structure, high performance flowable concrete is the better solution for cast in situ civil engineering construction.

II. CONCRETE INGREDIENTS

A. Cement

Ordinary Portland cement (Grade 53) of M/s Ultratech is used. Physical & Chemical properties are as given in Table 1 & 2.

B. GGBS

Ground granulated blast furnace slag (GGBS) of M/s JSW obtained from Pen, Raigad, Maharashtra, India. The physical and chemical properties of GGBS are given in the Table 1 and Table 2, respectively.

C. Ultrafine GGBS -Alccofine

Ultrafine GGBS commercially available as Alccofine-1203 is a low calcium silicate-based mineral additive which is generally used as a replacement of silica fume in high-performance concrete [5]. Alccofine 1203 is a slag based SCM having ultra-fineness with optimized particle size distribution [6].

Table 1. Physical Properties of Cement, GGBS and UGGBS-Alcofine 1203

Physical Properties	Cement (OPC-53)	GGBS	UGGBS-Alccofine 1203
W-M-Y	14-04-2021	14-04-2021	14-04-2021
Specific Gravity	3.13	2.9	2.92
Fineness(m2/kg)	288.2	482.5	-
Particle size, micron D_{10} D_{50} D_{90} D_{95}	-	-	 1.6 4.5 9.2 10.8
Normal consistency (%)	29.0%	-	-
Soundness (Autoclave) (%)	0.020	0.020	-
Setting time (min.) Initial Final	130 215	-	-
Strength (N/mm2) 3days 7days 28days	36.5 46 69		
Slag Activity Index, % *a)* At & 7 days *b)* At & 28 days	-	72.8 85.4	92.5 108.4

Table 2. Chemical Properties of Cement. GGBS and UFGGBS-Alccofine 1203

Chemical Properties	Cement	GGBS	UGGBS-Alccofine 1203
Loss on ignition, % by mass	2.98	0.10	0.32
Glass content, % by mass	-	87.24	86.92
Magnesium Oxide (MgO)	1.76	0.17	7.56
Total Sulphur (SO3), % by mass	2.9	0.25	0.22
Insoluble residue, % by mass	0.93	-	-
Alkali Content, % by mass	0.22	0.2	0.22
Total Chloride content, % by mass	0.017	0.011	0.015

OPC 53 grade Cement, GGBS and UGGBS-Alccofine are conformed to Indian Standard Specifications IS: 269-2015, IS 16714-2018and IS 16715-2018 [7], [8] [9]

D. *Chemical admixtures and crystaline growth waterproofing admixture*

Poly carboxylic ether-based superplasticizer admixture brand name Sika ViscoCrete 5138 & Sika ViscoCrete 5229NS M/s Sika are used to bring out the required water reduction and maintain the dispersing effect during time required for transportation and placement at site. Crystalline growth waterproofing admixture brand name SIKA 101 H of M/s Sika. The use of crystalline admixtures (CA) has a potential of improving the durability and reducing permeability of concrete structures especially those exposed to environments like extradosed structure of underground structures [10]

Table 3. Physical Properties of Chemical admixtures

Characteristics	*Product Name- Sika ViscoCrete 5138*	*Product Name-Sika ViscoCrete 5229NS*
Specific gravity	1.125	1.115
pH	6.43	6.69
Dry material content	42.49	38.45
Chloride (as Cl), % by Mass	< 0.01	< 0.01

Table 4. Physical Properties of Crystalline Waterproofing admixture (C.W.A)

Characteristics	*C.W.A-Product Name Sika 101 H*
Appearance	Gray Powder
Density (kg/lit)	1.3
Dosage (%) by mass of cement	0.8-1
Permeability to water vapor at 3 bar pressures	Impermeable
Initial set time at 30 deg temperature	40 minutes

Concrete admixtures are conformed to Indian Standard Specifications I S: 9103:1999 [11] and Crystalline Waterproofing admixture confirmed to manufacturer technical product data sheet.

E. Aggregates

In Mumbai region, Maharashtra, India, river sand is not available and therefore construction industries are totally depending on manufactured sand.

Coarse aggregate and Manufactured sand are obtained from nearest source i.e., Kunde vahal, Panvel,,Raigargh, Maharashtra . Fine aggregate- M/sand and coarse aggregate are conformed to Indian Standard Specifications IS: 383-2016 [2].

Table 5 shows the physical properties of the coarse and fine aggregates.

Table 5. Physical Properties of Coarse and Fine Aggregates

Physical tests	*Coarse aggregate*	*Fine aggregate M-sand*
Specific gravity	2.78	2.72
Water Absorption (%)	1.89	2.91
Bulk density (kg/m3)	1470	1730

III.CONCRETE MIX COMPOSITIONS

The concrete mix is designed as per absolute volume method according to the Indian standard -Concrete mix proportioning Guidelines [12] to meet environmental exposure condition of Mumbai city, Maharashtra i.e., considered sever condition. The properties of the concrete ingredients differ from one state to another state of the same country, and it is totally depending on actual environmental exposer condition of site and quality of available concrete ingredients for making suitable concrete mix [13].

Concrete mix compositions are presented in Table 6 & Table No-7.

Table 6. Concrete Mix Proportions for Tunnel NATM Lining concrete M40 Grade.

Sr. No.	*Mix*	*Cement (Kg/m3)*	*GGBS (Kg/m3)*	*UGGBS (Kg/m3)*	*Powder (Kg/m3)*	*W/P Ratio*	*C.A (Kg/m3)*	*F.A M-Sand (Kg/m3)*	*C.A /FA ratio (%)*	*Water (Kg/m3)*	*Superplasticizer-Sika ViscoCrete 5138 (Kg/m3)*
1	TR1	330	150	20	500	0.3	999	883	53/47	150	9.0
2	TR2	350	150	20	520	0.317	930	851	52/48	165	7.02
3	TR3	360	160	20	540	0.309	1029	773	57/43	167	8.1
4	TR4	360	160	20	540	0.296	927	848	52/48	160	8.64
5	TR5	330	200	20	550	0.32	778	981	44/56	176	7.7

Five concrete mix design trials were taken of M40 Grade and finalized TR 5 for NATM Lining flowable concrete for implementing in NATM tunnel and Cross passages of underground Mumbai Metro Project in Package- UGC-07, Line -3. Coarse aggregate content, fine aggregate content and cementitious content were optimized, until a slump flow of 500-700 mm is achieved by slump flow test. For each trial, tests are carried out in order that the trial mix satisfies slump flow test, Flow table test and Sieve stability tests.

Table 7. Concrete Mix Proportions for the structures -Base slab, RCC walls and Roof slab Flowable Concrete M40 Grade

Sr. No.	*Mix*	*Cement (Kg/m3)*	*GGBS (Kg/m3)*	*UGGBS (Kg/m3)*	*Powder (Kg/m3)*	*W/P Ratio*	*C.A (Kg/m3)*	*F.A M-Sand (Kg/m3)*	*C.A /FA ratio (%)*	*Water (Kg/m3)*	*Superplasticizer-Sika ViscoCrete 5229 NS (Kg/m3)*	*C.W.A (Kg/m3)*
1	TR6	315	145	20	480	0.313	1049	816	56/44	150	7.2	4.8
2	TR7	260	200	20	480	0.304	1064	814	56/44	146	6.72	4.8
3	TR8	260	200	20	480	0.313	1035	810	56/44	150	6.24	4.8
4	TR9	245	200	15	460	0.35	988	889	53/47	161	5.98	4.6

Four concrete mix design trials were taken for the structures -Base slab, RCC walls and Roof slab Flowable Concrete M40 Grade for metro Station in UGC-07 of Mumbai Metro Project, Line -3. Satisfactory results obtained in trial mix no-TR 9. Coarse aggregate content, fine aggregate content and cementitious content were optimized, until a slump flow of 500-700 mm is achieved by slump flow test. For each trial, tests are carried out in order that the trial mix satisfies slump flow test, Flow table test and Sieve stability tests.

A. Test Methods

Flowable Concrete is able to flow under its own weight without segregation, bleeding with some vibration and these behavior of concrete can be ensured by tests like Flow table test ,Slump flow, Slump test , and Sieve stability tests of concrete to determine the flow ability, passing ability and segregation resistance of SCC mixtures according to BS: EN 12350 Part 2, 5,8, 9, 10, 11, and 12 [14]

Fig.1 Flow Table Test

Fig.2 Slump Flow Test

Fig.3 Slump Test

Fig.4 Funnel test

Fig 5. L-Box test

Fig 6. U- Box Test

Fig 7. Sieve Segregation resistance Test

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Table 8. NATM Lining flowable concrete M40 Grade - Flowing ability, passing ability and segregation resistance are checked after 3 hrs. and results are as below.

Sr.No	*Mix*	*Slump flow (mm)*	*Flow Table (mm)*	*Slump (mm)*	*V-funnel Tf (sec)*	*V-funnel T5min (sec)*	*L-box Blocking ratio(H2/H1)*	*U-box Difference (mm)*	*Segregation Resistance*	*Remarks*
1	TR1	430	520	190	98	103	0.25	280	-	Not achieved
2	TR2	450	535	195	91	98	0.3	230	-	Not achieved
3	TR3	470	565	200	65	69	0.5	140	-	Not achieved
4	TR4	510	600	210	29	42	0.5	122	11.2	Results are found satisfactory for flowability only
5	TR5	540	620	215	28	36	0.7	43	7.9	Results are found more satisfactory in flowability requirements and near to passing ability tests

Trial mix no TR 4 has achieved all the requirements of filling ability but could not achieve the requirements of passing ability. In trial No-TR 5 achieved all the requirements of filling ability and could not achieve the requirements of passing ability but values are found closer to the requirements. Trial mix no TR5 has been finalized based on above-mentioned tests results values with considering TR5 can be achieved all the parameters of flowing and passing ability at site if apply some vibration during casting the structure. Details of final NATM Lining flowable concrete M40 Grade mix design trial mix no- TR5 is as below.

TABLE 9: Table showing the finalized mix proportion for the high performance flowable concrete Trial Mix No- TR 5 NATM Lining flowable concrete M40 Grade (12.5 MSA)

Cementitious (Kg)			*Water (Kg)*	*Fine Aggregate M-Sand (kg)*	*Coarse aggregate (12.5 MSA) (Kg)*	*Superplasticizer (Kg)*
`Cement	GGBS	UGGBS	176	981	778	7.7
330	200	20				

Table 10. Test Results of NATM Lining flowable concrete M40 Grade in Laboratory

Observation	*Characteristics*	*Acceptance Limits*	*Initial*	*1hr*	*2hrs*	*3 hrs.*
Slump-flow class SF1	Flowability/Filling Ability	≥ 520mm, ≤ 700mm	630	6 10	580	540
Flow Table	Flowability/Filling Ability	500-700	700	690	660	620
Slump Test	Flowability/Filling Ability	---	230	230	220	215
V Funnel Tv	Viscosity Flowability	≤ 10s	15	18	22	28
L Box (H2/H1)	Passing Ratio	≥ 0,75	0.75	0.72	0.7	0.7
U Box Deference	Height difference	30 mm Max	0	5	7	15
Sieve Segregation	Segregation Resistance	< 23 %	9.5	9.2	8.4	7.9
Ambient Temperature			26.5	27.5	28.2	29.4

Mix proportion of selected mix design TR5 implemented at site for Tunnel NATM concrete and NATM cross passages and total 11426 cum concrete quantity is executed from 25th Feb 2020to 30th june'2021.
The flowing ability and passing ability of concrete mix are checked according to conformity criteria for the properties of Flowable concrete [3] at site and observed results are as below.

Table 11. The Average Test Results of Site executed High performance Flowable concrete mix during concreting for Tunnel NATM Lining Concrete.

Observation	*Characteristics*	*Acceptance Limits*	*Results of Batching Plant*	*Before pouring at site (around 1 to 2 hrs after batching time)*	*Remarks (Comparison with 2 hrs results of TR5)*
Slump-flow class SF1	Flowability/Filling Ability	≥ 520mm, ≤ 700mm	630	560	-20 mm than TR 5
Flow Table	Flowability/Filling Ability	500-700	700	650	-10 mm than TR5
Slump Test	Flowability/Filling Ability	---	-	-	Not Taken
V Funnel Tv	Viscosity Flowability	≤ 10s	-	-	Not Taken
L Box (H2/H1)	Passing Ratio	≥ 0,75	-	-	Not Taken
U Box Deference	Height difference	30 mm Max	-	-	Not Taken
Sieve Segregation	Segregation Resistance	< 23 %	-	-	Not Taken
Ambient Temperature		26.5	27.5	28.2	29.4

All the parameters of tests are not checked at site because shifting of all testing apparatus could not practically possible during concreting at site, but Slump flow and Flow table tests were carried out for 1904 Transit Mixers and their average values are mentioned in above table.

Some tests could not be conducted at site laboratory due to non-availability of enough testing equipment's at in house laboratory. Hence samples of specimens were sent to authorized NABL laboratory for conducting tests are as below.

Table 12. Hardened Concrete Test results for Tunnel NATM Lining Concrete.

Sl. NO.	*Test Description*	*Acceptance Requirement*	*Actual Results obtained*
1	RCPT	1000 Coulombs	782.0 coulombs
2	Permeability	10 mm	6 mm
3	Flexural strength	> 0.7 √fck = 5.42 N/mm2	6.25 n/mm 2
4	Split tensile strength	> 0.5 √fck = 3.87 N/mm2	5.01 n/mm 2
5	Drying Shrinkage	0.05 % (Max)	0.026 %
6	Moisture Moment	0.03 % (Max)	0.018 %
7	Chloride content	0.5 % (Max)	0.34 %
8	Sulphate content	3.7 % (Max)	0.35 %

Table 13. The Cube Compressive Strength for Successful Trial Mix no TR-5 for M40 NATM Lining Flowable Concrete in N/mm2

Sr. No	*Age of Cubes*	*No. Specimen*	*Compressive Strength of Specimen in N/mm2*	*Compressive Strength of Sample in N/mm2*	*Avg. Strength of Samples in N/mm2*
1	7 days	9	39.6	40.81	40.14
2			41.2		
3			41.63		
4			38.5	39.58	
5			41.24		
6			38.99		
7			41.66	40.02	
8			38.99		
9			39.41		
10	28 days	18	58.54	59.52	61.34
11			63.49		
12			56.53		
13			63.21	60.33	
14			59.56		
15			58.22		
16			59.73	62.45	
17			63.24		
18			64.38		
19			62.98	61.63	
20			61.22		
21			60.69		
22			59.77	61.66	
23			58.55		
24			66.66		
25			60.12	62.45	
26			58.9		
27			68.33		
28	56	9	76.22	70.46	68.88
29			75.02		
30			60.14		
31			67.43	68.69	
32			66.23		
33			72.41		
34			68.93	67.49	
35			67.73		
36			65.81		

After achieving all the parameters according to the requirements of site conditions for Flowable concrete for grade M40 then same mix is implemented site for the construction of NATM tunnel lining and cross passages. The compressive strength results of site casted cubes for 7 days,28 days and 56 days are represented in table and graph as below.

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Table 14. The Compressive Strength of site casted cubes for M40 grade High Performance Flowable Concrete (in N/mm2)

Sr.No	Age of Cube	No. Sample	Avg. Strength of Samples (N/mm2)	% Of Strength Gaining	Standard Deviation (N/mm2)	Coefficient of Variation (%)
1	7 days	8	40.14	100.35	1.82	3.03
2	28 Days	35	60.22	150.55		
3	56 days	8	65.09	162.73		

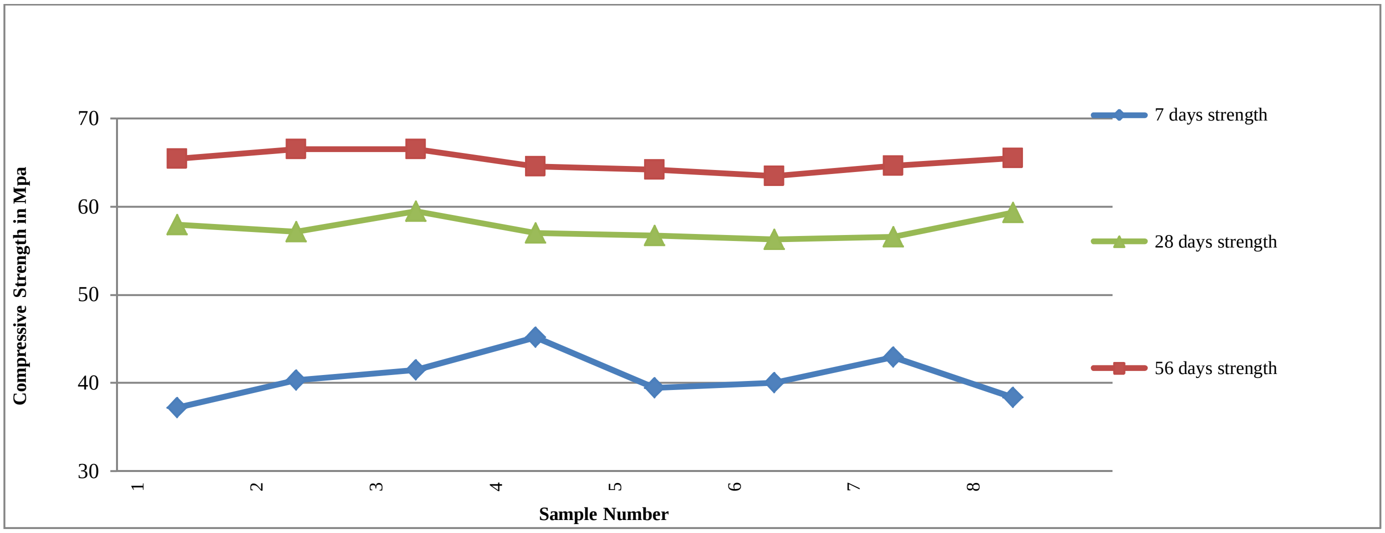

Fig 8. Graphical representation for Compressive Strength of site casted cubes for 7 days, 28 days and 56 days

Concrete cubes were casted for testing of compressive strength of working structures and results are found satisfactory. Samples taken for cube compression strength of working structures, average compressive strength, standard deviation, and coefficient of variation are represented in graph as below.

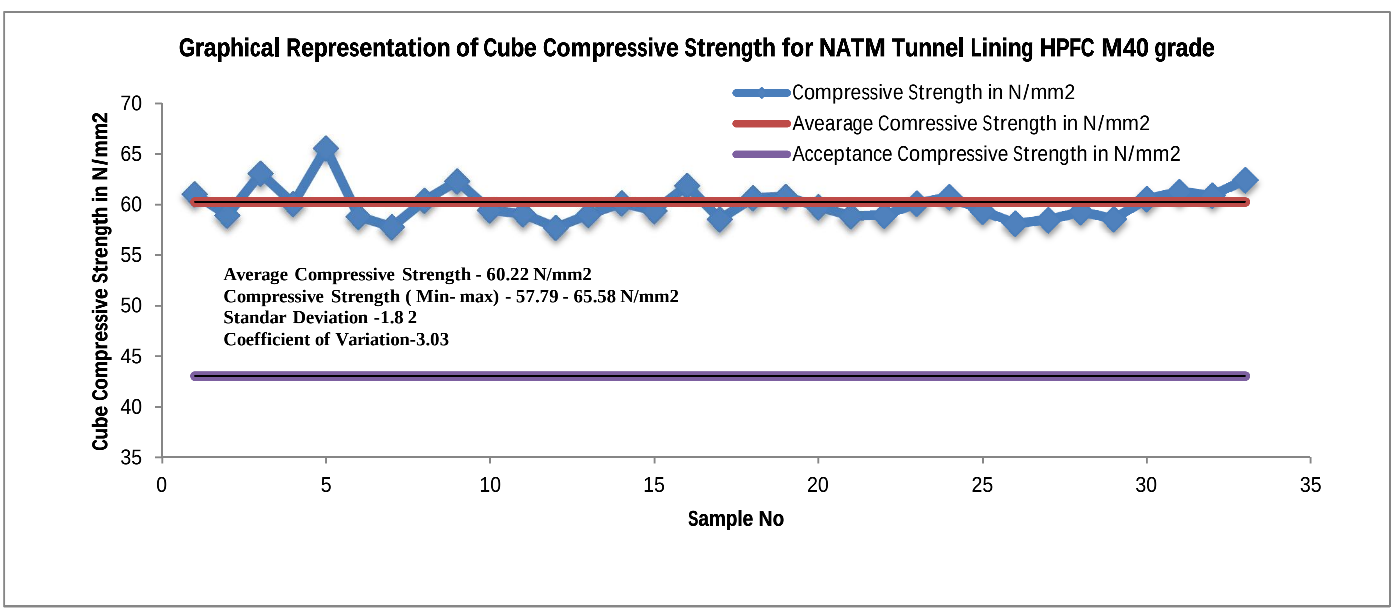

Fig 9. Graphical Representation of site casted Cube Compressive Strength for Tunnel NATM lining flowable concrete M40 Grade.

Table 15. RCC works Flowable Concrete M40 Grade - Flowing ability, passing ability and segregation resistance are checked after 3 hrs. . and results are as below.

Sr.No	*Mix*	*Slump flow (mm)*	*Flow Table (mm)*	*Slump (mm)*	*V-funnel Tf (sec)*	*V-funnel T5min (sec)*	*L-box Blocking ratio(H2/H1)*	*U-box Difference (mm)*	*Segregation Resistance*	*Remarks*
1	TR6	380	410	155	-	-	-	-	-	Not achieved
2	TR7	450	535	195	-	-	-	-	-	Not achieved
3	TR8	450	535	195	91	98	0.3	230	6.8	Not achieved
4	TR9	520	610	205	59	71	0.5	122	7.5	Results are found more satisfactory in flowability requirements and near to passing ability tests

In trial No-TR 9 achieved all the requirements of filling ability and could not achieve the requirements of passing ability but values are found nearer to the requirements. Trial mix no TR 9 has been finalized based on above-mentioned tests results values with considering TR9 can be achieved all the parameters of flowing and passing ability at site if apply some vibration during casting the structure.

Details of final RCC works Flowable Concrete M40 Grade mix design trial mix no- TR 9 is as below.

TABLE 16. Table showing the finalized mix proportion for Flowable Concrete, Trial Mix No- TR 9 RCC works Flowable Concrete M40 Grade (20 MSA)

Cementitious (Kg)			*Water (Kg)*	*Fine Aggregate M-Sand (kg)*	*Coarse aggregate (20 MSA) (Kg)*	*Superplasticizer (Kg)*	*C.W.A (Kg)*
`Cement	GGBS	UGGBS	161	889	988	5.98	4.6
245	200	15					

Table 17. Test Results of RCC works Flowable Concrete M40 Grade in Laboratory

Observation	*Characteristics*	*Acceptance Limits*	*Initial*	*1hr*	*2hrs*	*3 hrs.*
Slump-flow class SF1	Flowability/Filling Ability	≥ 520mm, ≤ 700mm	600	580	530	520
Flow Table	Flowability/Filling Ability	500-700	690	670	640	610
Slump Test	Flowability/Filling Ability	---	220	220	215	205
V Funnel Tv	Viscosity Flowability	≤ 10s	25	28	32	59
L Box (H2/H1)	Passing Ratio	≥ 0,75	0.65	0.6	0.55	0.5
U Box Deference	Height difference	30 mm Max	0	5	7	15
Sieve Segregation	Segregation Resistance	< 23 %	9.5	9.2	8.4	7.9
Ambient Temperature			26.5	27.5	28.2	29.4

Mix proportion of selected mix design TR9 implemented at site for RCC structures i.e., Base slab, Roof slab and RCC walls and total 32508 cum concrete quantity is executed from 18th March 2020to 30th june'2021.

The flowing ability of concrete mix are checked according to conformity criteria for the properties of Flowable concrete [3] at site and observed results are as below.

Table 18. The Average Test Results of Site executed high performance flowable concrete mix during concreting for RCC structures.

Observation	*Characteristics*	*Acceptance Limits*	*Results at Batching Plant*	*Before pouring at site (around 1 to 2 hrs after batching time)*	*Remarks (Comparison with 2 hrs results of TR 9)*
Slump-flow class SF1	Flowability/Filling Ability	≥ 520mm, ≤ 700mm	550	-	Not Taken at site
Flow Table	Flowability/Filling Ability	500-700	630	580	-50 mm than TR9
Slump Test	Flowability/Filling Ability	---	230	200	-15 mm than TR9
V Funnel Tv	Viscosity Flowability	≤ 10s	-	-	Not Taken
L Box (H2/H1)	Passing Ratio	≥ 0,75	-	-	Not Taken
U Box Deference	Height difference	30 mm Max	-	-	Not Taken
Sieve Segregation	Segregation Resistance	< 23 %	-	-	Not Taken
Ambient Temperature		26.5	27.5	28.2	29.4

All the parameters of tests are not checked at site because shifting of all testing apparatus could not practically possible during concreting at site, but Slump flow and Flow table tests were carried out for 5118 Transit Mixers and their average values are mentioned in above table.

Some tests could not be conducted at site laboratory due to non-availability of enough testing equipment's at in house laboratory. Hence samples of specimens were sent to authorized NABL laboratory for conducting tests are as below.

Table 19. Hardened Concrete Test results for RCC works Flowable Concrete M40 Grade

Sl. NO.	*Test Description*	*Acceptance Requirement of contract specifications*	*Actual Results obtained*
1	RCPT	1000 Coulombs	652.5 coulombs
2	Permeability	10 mm	4 mm
3	Flexural strength	> 0.7 √fck = 5.42 N/mm2	6.10 n/mm 2
4	Split tensile strength	> 0.5 √fck = 3.87 N/mm2	4.66 n/mm 2
5	Drying Shrinkage	0.05 % (Max)	0.009 %
6	Moisture Moment	0.03 % (Max)	0.011%
7	Chloride content	0.5 % (Max)	0.22 %
8	Sulphate content	3.7 % (Max)	1.87 %

Table 20. The Cube Compressive Strength for Successful Trial Mix no TR-9 for M40 Grade high performance flowable concrete in N/mm2.

Sr.No	*Age of Cubes*	*No. Specimen*	*Compressive Strength of Specimen in N/mm2*	*Compressive Strength of Sample in N/mm2*	*Avg. Strength of Samples in N/mm2*
1	7 days	9	34.6	35.81	35.14
2			36.2		
3			36.63		
4			33.5	34.58	
5			36.24		
6			33.99		
7			36.66	35.02	
8			33.99		
9			34.41		
10	28 days	18	52.54	53.52	55.34
11			57.49		
12			50.53		
13			57.21	54.33	
14			53.56		
15			52.22		
16			53.73	56.45	
17			57.24		
18			58.38		
19			56.98	55.63	
20			55.22		
21			54.69		
22			53.77	55.66	
23			52.55		
24			60.66		
25			54.12	56.45	
26			52.9		
27			62.33		
28	56 days	9	73.22	67.46	65.88
29			72.02		
30			57.14		
31			64.43	65.69	
32			63.23		
33			69.41		
34			65.93	64.49	
35			64.73		
36			62.81		

After achieving all the parameters according to the requirements of site conditions for Flowable concrete for grade M40 then same mix is implemented site for the construction of RCC structures i.e., Base Slab, Roof slab and RCC walls. The compressive strength results of site casted cubes for 7 days,28 days and 56 days are represented in table and graph as below.

Table 21. The Compressive Strength of site casted cubes for M40 grade High Performance Flowable Concrete (in N/mm2)

Sr.No	Age of Cube	No. Sample	Avg. Strength of Samples (N/mm2)	% Of Strength Gaining	Standard Deviation (N/mm2)	Coefficient of Variation (%)
1	7 days	9	33.87	84.68%	1.77	3.48
2	28 Days	35	50.81	127.03		
3	56 days	9	61.91	154.78		

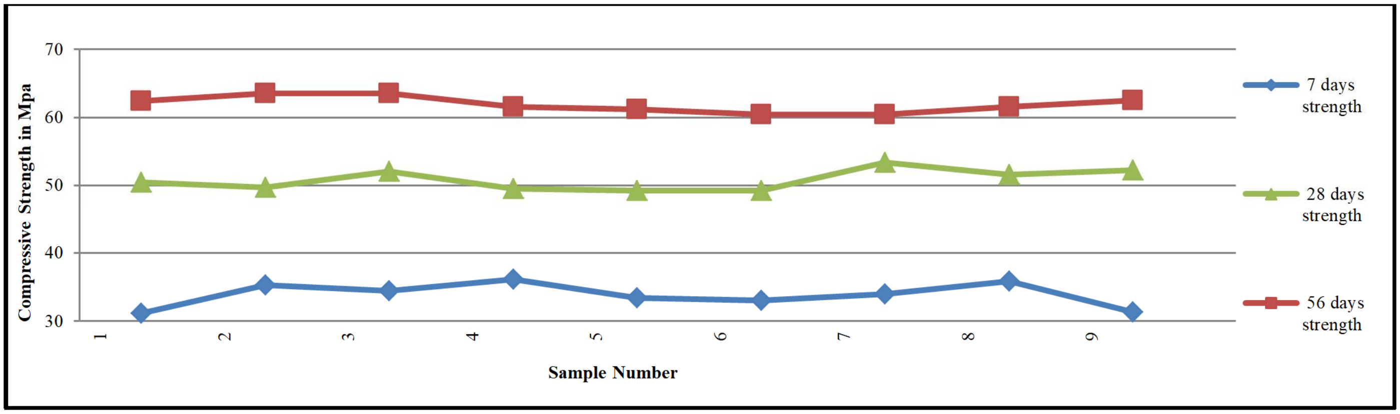

Fig 10. Graphical representation for Compressive Strength of site casted cubes for 7 days, 28 days and 56 days

Concrete cubes were casted for testing of compressive strength of working structures and results are found satisfactory. Samples taken for cube compression strength of working structures, average compressive strength, standard deviation, and coefficient of variation are represented in graph as below.

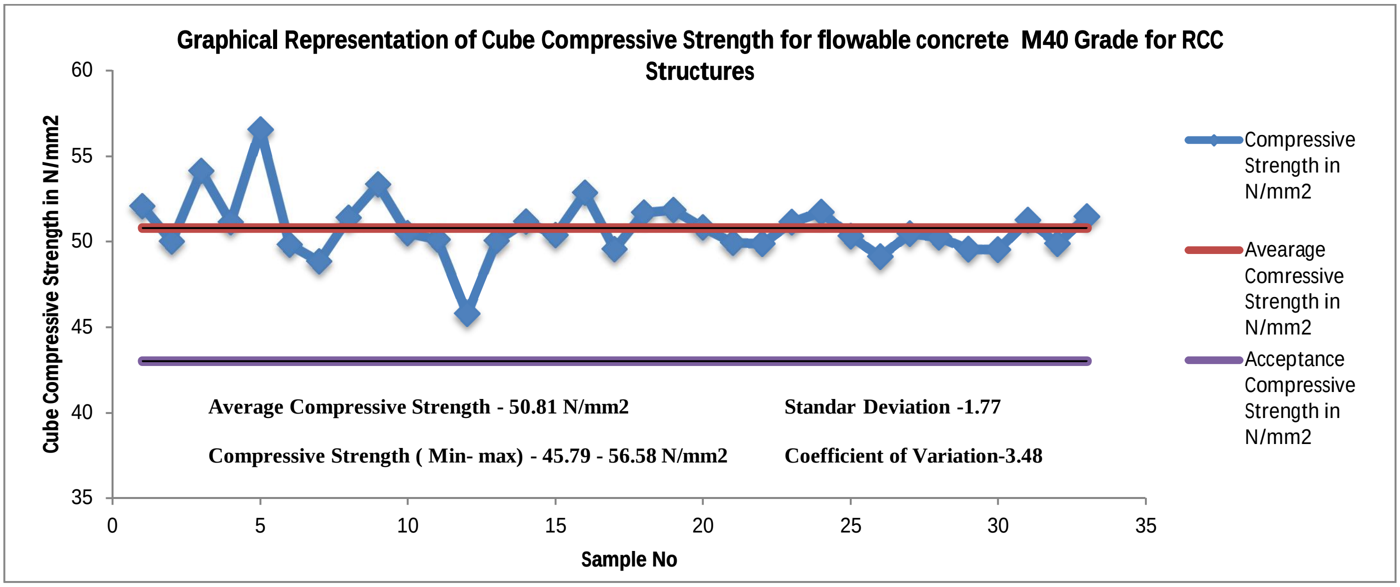

Fig 11. Graphical Representation of site casted Cube Compressive Strength for flowable concrete M40 Grade

IV. EXECUTION OF THE CONCRETE POURING AT SITE

Following points were ensured at site before and during placement of high performance flowable concrete.

1) Assessment for the placement situations of HPFC either by using boom placer, long distance pipe pumping, direct placing via a chute or a concrete bucket placement.
2) Shutter were designed for the capability and withstanding in the forces of lateral pressure of fresh concrete.

3) Concrete pour plans were prepared for every concrete pour for maintaining sequence of concrete production from batching plant, placing at site, movements of pump and pipe's location during concreting to maintain the concrete pour rate and avoid formation of cold joints.
4) Quality control tests and checks at batching plant before despatching the concrete and same tests were performed at site also before pouring at the structure.
5) Avoid direct free fall of HPFC more than 1.5 m height.
6) During concrete pouring visual checks were carried out on potential segregation inside the formwork and found no segregation.
7) Concrete pour rate was maintained to avoid entrainment and to limit the pressure on the formwork.
8) Shutter vibrators, needle vibrators were used according to placing condition to ease of flow and reach each corner of formwork and compaction for achieving smooth surface finish after de-shuttering.

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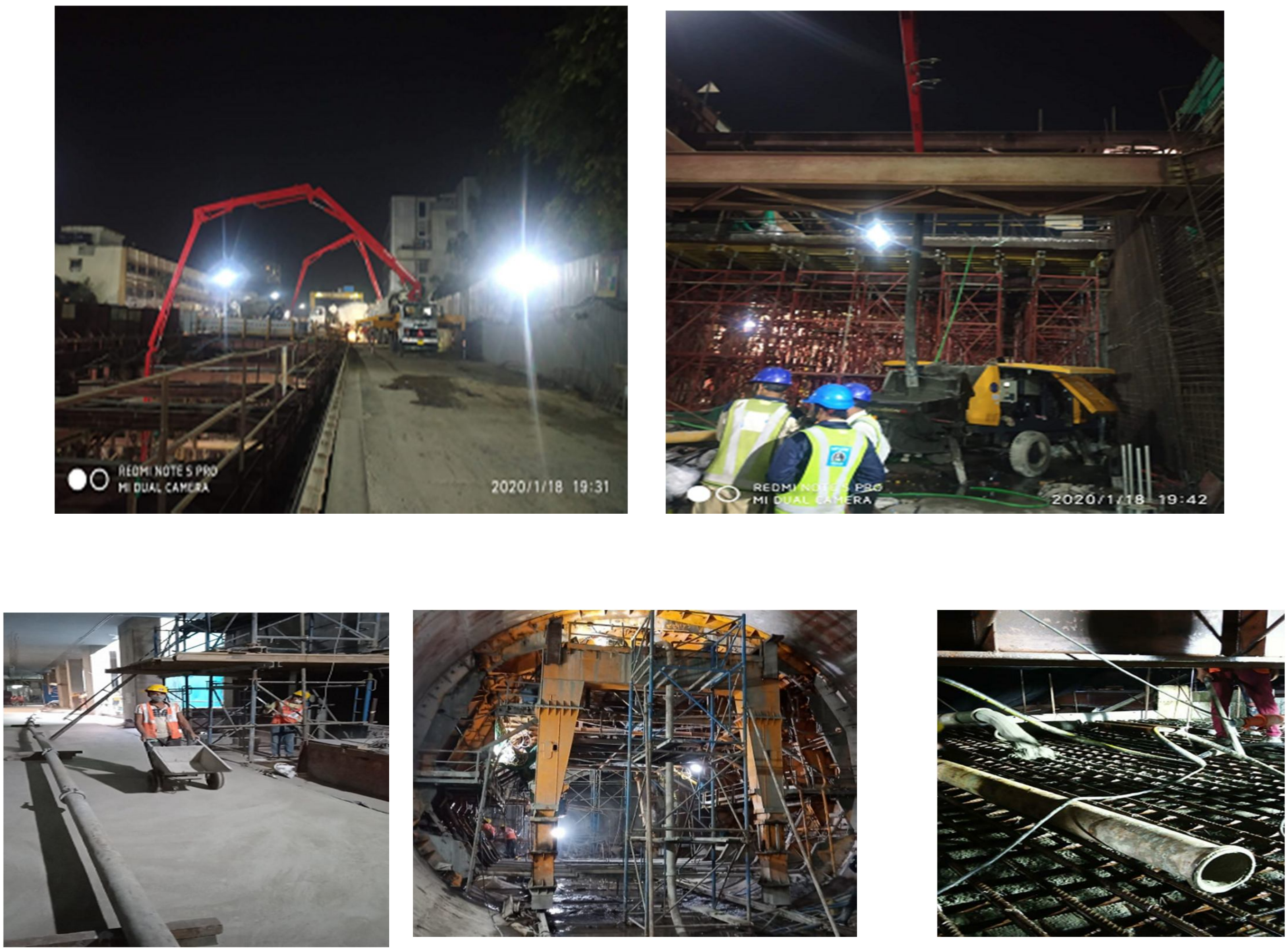

Fig 12 Actual site photographs during concrete placing at site showing two stages of concrete pouring and nos of bends to reach at placement point.

A. Quality Control Checks &Concrete surface finish after De-shuttering of the Structure

Appropriate technical team and testing equipment's were deployed at Batching plant, TM checking point and placement point. Flowable concrete has been placed successfully in formwork without any break downs and obstacles due to proper planning and systematic arrangement. After De-shuttering NATM tunnel lining, Cross passage lining RCC walls concrete surfaces found smooth.

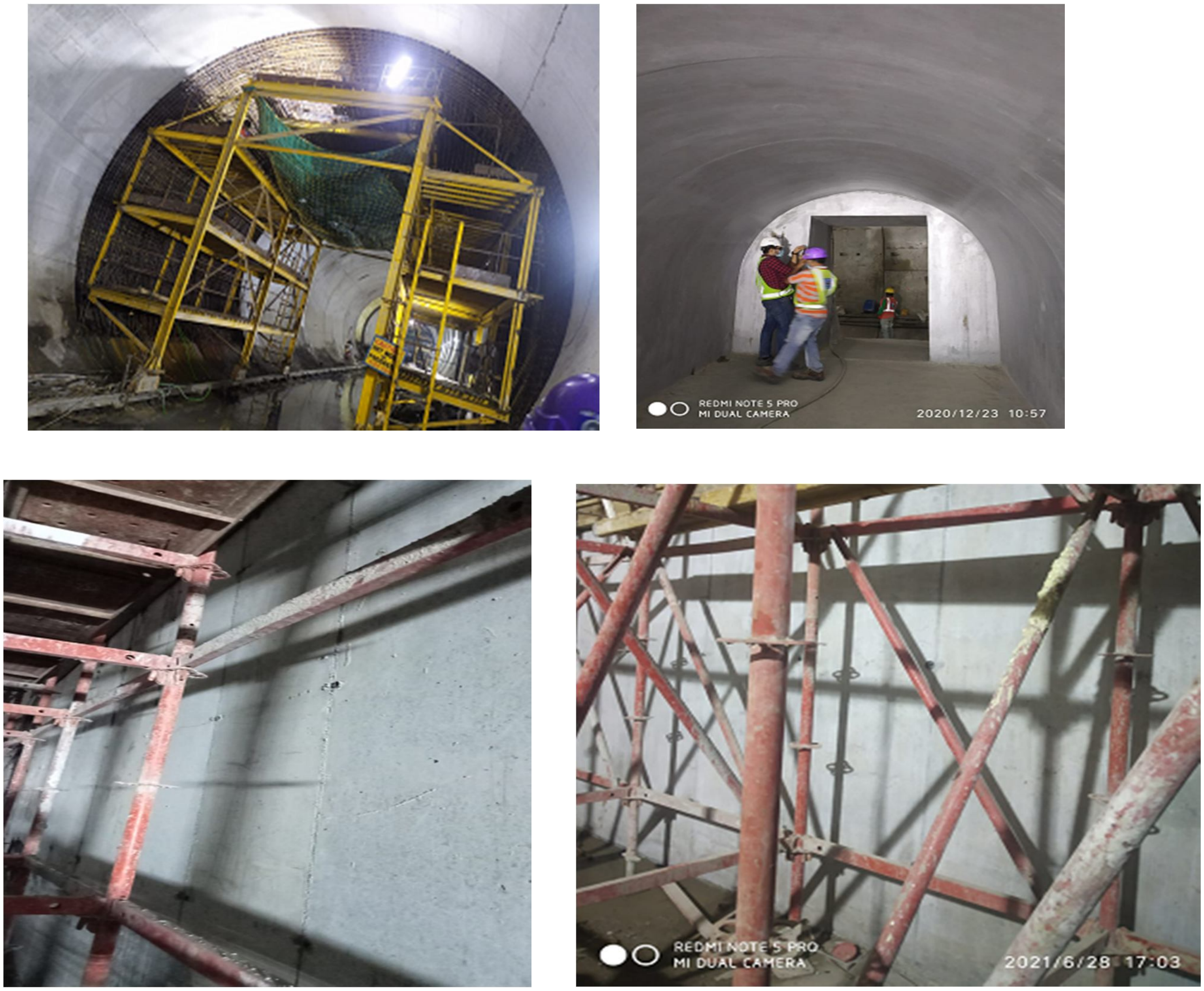

Fig 13. Smooth surfaces of the cast in situ high performance flowable concrete

V.CONCLUSION

1) High performance flowable concrete can be developed with partially fulfills the requirements of self-compacting concrete and implemented at site also according to site situations.
2) High performance flowable concrete can be easily placed in long distance pumping and congested reinforcement structure with some vibration during the placement.
3) Crystalline waterproofing admixture plays effective role for reducing permeability and increase durability of the structures.
4) Water permeability tests and RCPT values found less in low cementitious concrete i.e., TR 9 due to adding of crystalline waterproofing admixture as compared to high cementitious concrete trial mix no TR 5.
5) More impermeable and durable concrete can be developed in optimized cementitious content using crystalline waterproofing admixture in concrete.

VI.ACKNOWLEDGMENT

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Compliance with ethical standards
Conflict of interest - On behalf of all authors, the corresponding author states that there is no conflict of interest.

REFERENCES

[1] Chiara F. Ferraris, "Measurement of the Rheological Properties of High Performance Concrete: Sate of the Art Report," Journal of Research of the National Institute of Standards and Technology, vol. 104(5), no. 8, pp. pp.461-478, 1999.

[2] IS 383: 201 6 Bureau of Indian Standards (New Delhi) Indian standard coarse and fine aggreagtes for concrete specification, IS 383: 201 6 .

[3] The European Guidelines for Self-Compacting Concrete Specification, Production and Use, May2005, 2005.

[4] A. I. Hassan EL-Chabib, "The performance of high-strength flowable concrete made with binary," Construction and Building Materials 47 (2013) 245–253, vol. 47, no. 47, pp. pp 245-253, 2013.

[5] P. M. A. S. B. S. V. V. A. P. N. Ojha, "Optimization and evaluation of ultra high-performance con-crete," Journal of Asian Concrete Federation, vol. Vol. 6, no. No. 1, pp. pp. 26-36, June 2020, June 2020.

[6] M. V. a. P. D. b. V. K. c. B. Venkatesan a, "Experimental study on concrete using partial replacement of cement by," Materials Today: Proceedings, vol. Volume 37, no. Part 2, pp. Pages 2183-2188, 2021.

[7] IS 269:2015. Ordinary Portland Cement- Specification, 2015.

[8] IS 16714-2018. GGBS for use in cement, mortar and concrete-specifications, 2018.

[9] IS: 16715-2018 "Ultrafine Ground Granulated Blast Furnace Slag", 2018.

[10] C. Xue, "Self-healing efficiency and crack closure of smart cementitious composite with crystalline admixture and structural polyurethane," Construction and Building Materials, vol. Volume 260, p. 119955, November 2020.

[11] IS 9103:1999, Concrete Admixtures: Specification, Bureau of Indian Standard, Delhi, pp. 1–14., 1999.

[12] IS :10262:2009 Concrete mix proportioning - Guidelines, 2009.

[13] W. OH, "Why is SCC Different from Country. Fourth International Symposium on SCC," Chicago, 2005.

[14] MSZ EN 12350, Testing fresh concrete, Part 2,5, 8, Part 9, Part 10, Part 11, Part 12, (2010), 2010.

[15] K. K. D. C. S. T. Patrick Paultre, "tructural performance of self-consolidating concrete used in confined concrete columns," ACI Struct J, 102 (7) (2005), pp. 560-568, vol. 7, no. 102, pp. pp. 560-568, 2005.

[16] A. D. Adesina, "Concrete Sustainability Issues," in 38th Cement and Concrete Science Conference, London, 2018.

[17] B. K. a. W. C. P. Steven H. Kosmatka, "Design and Control of concrete mixtures," Portland Cement Association, United States of America, 2008.