High Performance Concrete with the Use of Silica Fumes and Other Materials

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Abstract— Concrete, a composite material, composed of aggregate, generally refers to Portland cement concrete. The downside of plain concrete is that it expands and contracts with change in temperature, shrinks on drying, leads to creeping action, and requires larger sections for carrying load. A new group of concrete that exhibit mainly improved strength & durability properties has recently developed. The Ultra High Performance Concrete (UHPC), also called as Reactive Powder Concrete. It is a high strength, ductile material formulated by combining Portland cement, silica fume, fine sand, Quartz, super plasticizer, steel fibres & water. The aim of this research is to provide a thorough characterization of the UHPC material properties. Various tests like compressive test, split tensile test & durability test have been elaborated in the project for different composition & also comparison between plain concrete and UHPC of different mixes has been discussed with conclusion.

Key words: UHPC, RPC, HRWRA

I. Introduction to UHPC

The concrete should exhibit greater durability characteristics for high strength. It means that the concrete should be high strength and high performance. One of the materials developed in recent years is Ultra High Performance Concrete (UHPC) also known as reactive powder concrete (RPC). Material having a compressive strength greater than 21,750 psi (150 MPa). And the idea of RPC was developed by Richard and Cheyrezy (1994) and was first produced in the early 1990s.

This type of materials is formed with the cement, fine quartz sand, silica fume, steel fibers and HRWRA. (High range water reducing admixture). This material differs from conventional concrete not only of strength, but also of durability. UHPC is more durable because of the low water-to-cementations materials ratio results in very low porosity.

The possibility of achieving high strength, durability, and improved ductility with the use of

A. *Materials Used in UHPC:*

A detail of materials which is used to make UHPC in included in this chapter. Material is the important part of the concrete. Life of concrete depends on quality of materials. Therefore it is important to study about the material. Following are the materials which are used in making UHPC.

- Portland Cement
- Fine sand
- Silica fume
- Ground Quartz
- Super plasticizer
- Steel Fibres
- Water
- Marble Dust

II. Literature Review

Strength and Durability of Ultra High Performance Concrete
Author: Benjamin A. Graybeal & Joseph L. Hartmann

The objective of this research is to fully characterize the material properties of UHPC so that it can be utilized effectively and efficiently in the transportation industry and in particular, for bridge construction.

For use of tensile strength of UHPC, it should be quantified first. There are two direct tensile behaviour test methods. Those are discussed below and named as the mortar briquette tension test and the direct cylinder tension test.

This concrete contains a large amount of cement and cementations materials, a large amount of super plasticizer, and a very small amount of water. The water and accelerator to cementations material (i.e., cement and silica fume) ratio is 0.15.

The specimens tested in the research program were cast in approximately 1.0 cubic foot batches using a 2 cubic foot pan mixer. The mixing of the concrete generally took approximately 18 minutes from the first addition of water to de-airing the mix after the fiber addition.

The curing of UHPC can have a significant impact on its final properties and different strengths for different curing are researched here.

A. *Conclusions:*

- When steam cured as recommended by the manufacturer, the user can expect to achieve a compressive strength of 28 ksi and a tensile cracking strength of at least 1 ksi.
- As compare to normal concretes, a steam cured UHPC section should be effectively resistant to freeze-thaw, scaling, and chloride ion penetration damage.
- The results presented in this study also clearly show that the curing of UHPC can have a large impact on its properties. The properties of air cured UHPC, although still impressive relative to conventional concretes, are significantly different than steam cured UHPC.

III. Mix Design

General Mix proportion is given that us the general procedure for any grade of concrete. Concrete is the main material in the construction field. It is made up of different type of materials. Generally concrete are classified in two groups. Those are,

- By designing the concrete mix - Designing Mix Concrete.
- By adopt the concrete mix- Nominal Mix Concrete.

Mix design concrete is used in construction field, to produce the grade of concrete having the required maximum workability and characteristic strength of a nominal mix it will reduce the cement content which is used in concrete which helps in reducing the water cement ratio and help in increasing the strength also.

- The final Mix Proportion of M40 grade of concrete is:

Materials	Cement	Fine Aggregate	Course Aggregate	Water
Kg/m^3	450	623.63	1085.95	180

Table 1: Mix proportions of M40 grade concrete

A. *Mix Proportions for UHPC:*

Ductile proposed a typical composition of Ultra High Performance Concrete consisting of raw materials like cement, sand, silica fume, ground quartz, super plasticizer, steel fibres & wat.

Material	Amount (lb/yd^3)	Percent by Weight
Portland Cement	1200	28.7
Fine Sand	1720	41.1
Silica Fume	390	9.3
Ground Quartz	355	8.5
Superplasticizer	22	0.5
Steel Fibers	270	6.4
Water	230	5.5
1 lb/yd^3 = 0.593 kg/m^3		

Table 2: Typical Composition of UHPC

Now, the mix proportions for UHPC are considered using different proportions for marble dust and also the typical composition of it.

Mixes			Materials(Kg/m^3)					
	Sand	Cement	Silica	Ground	Super plasticizer	Steel	Water	Marble
			Fume	Quartz		Fibres		Dust
UHPC-1	1020	712	231	210	13	160	136	Nil
UHPC-2	969	712	231	210	13	160	136	51
UHPC-3	918	712	231	210	13	160	136	102

Table 3: Mix proportions of UHPC

Here, UHPC-1= Typical Composition of UHPC by Ductal
UHPC-2= Replacing 5% of Sand with Marble Dust
UHPC-3= Replacing 10% of Sand with Marble Dust

B. *Material Calculations*

Description	Compressive Test		Split Tensile Test		Durability Test	
Specimen Size(mm)	150*150*150			150*300	150*150*150	
Days of Testing	7	28	7	28	7	28
Normal Mix M40	3	3	3	3	3	3
UHPC-1	3	3	3	3	3	3
UHPC-2	3	3	3	3	3	3
UHPC-3	3	3	3	3	3	3
Total Number of Specimens		24		24		24
Volume of each specimen in m^3		0.003375		0.0053		0.003375
Volume of all specimens in m^3		0.081		0.1272		0.081
Total Volume of Concrete in m^3				0.2892		

Table 4: Calculations of number of cubes and cylinders

Mixes				Materials(Kg)				
	Sand	Cement	Silica	Ground	Super plasticizer	Steel	Water	Marble
			Fume	Quartz		Fibres		Dust
UHPC-1	81.11	56.61	18.37	16.68	1.023	12.71	10.8	Nil
UHPC-2	77.065	56.61	18.37	16.68	1.023	12.71	10.8	4.054
UHPC-3	73	56.61	18.37	16.68	1.023	12.71	10.8	8.111
Total=	231.175	169.83	55.11	50.04	3.07	38.13	32.4	12.165
			For Normal M40:					
Mixes		Materials(Kg)						
	Cement	Sand	Course	Water				
			Aggregate					
M40	35.788	49.626	85.737	14.315				

Table 5: Calculations of raw materials

- Mixing Procedure
- Weighting of different materials according to the mix design.
- Mixing of dry materials like sand, cement, silica fume, ground quartz and marble dust for few minutes.
- Add steel fibres to the mix of dry materials and mix it till it is uniformly dispersed.
- Add half the amount of required water as per mix design to the super plasticizer and add it in the mixer.
- Now add the remaining water to the mix.
- After the desired workability is achieved by seeing visually, the mixer is stopped and UHPC is ready.

IV. EXPERIMENTAL SETUP

A. *Compressive Strength Test:*

1) *Objective:*

To determine the concrete strength and its suitability for the job.

2) *Equipment & Apparatus:*

Compression testing machine (3000 KN) Curing tank/Accelerated curing tank
Balance (0-10 Kg)

3) *Procedure:*

1) Representative samples of concrete shall be taken and used for casting cubes 15 cm x 15 cm x 15 cm.
2) later the concrete is pour into the moulds in layers nearly about 5 cm deep.
3) The sample is stored at site for 24+ ½ h under damp matting. Then the samples are stored in clean water at 27+20C up to the time of test.
4) Tested specimen immediately on removal from water and while they are still in wet condition.
5) The surface of the testing specimen should wipe clean and any loose material removed from the surface.

6) Align the axis of the specimen with the steel plate.
7) Apply the load slowly without shock and increased gradually at a rate of approximately 140 kg/sq.cm/min.

4) Calculation:

Compressive strength is calculate using the following formula

Compressive strength (KN/m2) = Wf / Ap

Where;

Wf = Maximum applied load just before load, (KN)

Ap = Plan area of cube mould, (m2).

B. Split Tensile Strength Test:

The tensile strength of concrete is one of the basic and important properties. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces.

1) Objective:

To determine the split tensile strength of concrete.

2) Reference Standards:

IS 5816:1999

3) Equipment & Apparatus:

Compression Testing Machine

Two Packing Strips of Plywood 30 cm long and 12 mm wide.

4) Procedure:

1) Concrete cylinder moulds are of 15 cm diameter & 30cm long.
2) Each mould is provided with a metal base plate mould and base plate should be coated with a thin film of mould oil before use, in order to prevent adhesion of concrete.
3) Made the test specimen quick as practicable after the concrete is filled into the mould in layers approximately 5 cm deep.
4) The test specimen should be stored in a place at a temperature of 27° +/- 2°C for 24 +/- 0.5 hrs. From the time addition of water to the dry ingredients.
5) Take the wet specimen from water after 7 days of curing
6) Wipe out water from the surface of specimen
7) Represent diametrical lines of the specimen's two ends. to ensure that they are on the same axial place.
8) Note the weight and dimension of the specimen.
9) For the essential range, set the compression testing machine
10) Keep is plywood strip on the lower plate and place the specimen.
11) Specimen should be in align therefore the lines marked on the ends are vertical and cantered over the bottom plate.
12) Place the other plywood strip above the specimen.
13) Bring down the upper plate to touch the plywood strip.
14) Apply the load gradually without shock at a rate of approximately 14-21kg/cm2/minute (Which corresponds to a total load of 9900kg/minute to 14850kg/minute).
15) Note down the breaking load (P).

5) Calculation:

As per IS: 456, split tensile strength of concrete= 0.7Fck

The splitting tensile strength is calculated using the formula

Tsp = 2P/ DL

Where;

P = applied load, D = diameter of the specimen & L = length of the specimen

C. Durability Test:

Durability test is done to check the durability of concrete that whether the concrete can resist the weathering effects or chemicals effects on it due to hazardous chemicals like Sulphur, chlorine etc.

1) Objective:

To check the whether the concrete is durable or not.

2) Equipment & Apparatus:

Compression testing machine (3000 KN)

Curing tank/Accelerated curing tank

Balance (0-10 Kg)

3) Procedure:

1) Samples of concrete taken and used for casting cubes 15 cm x 15 cm x 15 cm.
2) Next the concrete filled into the moulds in layers approximately 5 cm deep.
3) The specimen shall be stored at site for 24+ ½ h under damp matting or sack. After that, the samples shall be stored in clean water at 27+20C for 28 days.
4) The removed cubes are then weighed and marked as W1.
5) Then the cubes are the kept in the solution of sodium sulphate of 5% by weight of water for 28 days and 56 days respectively.
6) The cubes are removed from the solution, their surfaces are wiped off by cloth and then they are weighed and marked as W2. % weight loss= (W1-W2/W1)*100
7) Now these cubes are taken for compression testing in CTM and they are compared to the 28 days compressive strength.

V. Results

A. Compression Test:

1) Compressive Strength at 7 days

Sample	Number of cubes	Load(KN)	Compressive Strength(MPa)	Avg. Compressive Strength(MPa)
M40	1	753.8	33.5	36.29
	2	857.9	38.12	
	3	843.75	37.23	
UHPC-1	1	2479.72	110.21	106.41
	2	2383.87	105.97	
	3	2319.08	103.07	
UHPC-2	1	2297.7	102.12	101.46
	2	2266.2	100.72	
	3	2284.65	101.54	
UHPC-3	1	2191.27	97.38	96.91
	2	2210.85	98.26	
	3	2139.75	95.10	

Table 6: Compressive Strength at 7 days

2) Compressive Strength at 28 days

Sample	Number of cubes	Load(KN)	Compressive Strength(MPa)	Avg. Compressive Strength(MPa)
M40	1	1025.1	45.56	45.61
	2	1046.4	46.5	

	3	1007.77	44.79	
UHPC-1	1	2639.7	117.32	117.05
	2	2667.6	118.56	
	3	2593.8	115.28	
UHPC-2	1	2567.03	114.09	112.78
	2	2487.6	110.56	
	3	2558.47	113.71	
UHPC-3	1	2446.65	108.74	107.76
	2	2472.5	109.89	
	3	2354.85	104.66	

Table 7: Compressive strength at 28 days

Sample	Avg. Compressive strength after 7 days(MPa)	Avg. Compressive strength after 28 days(MPa)
M40	36.29	45.61
UHPC-1	106.41	117.05
UHPC-2	101.46	112.78
UHPC-3	96.91	107.76

Table 8: Average compressive strength at 7 & 28 days

B. *Conclusions:*

- The 7 days compressive strength of M40 is 36.29 MPa while the 28 days compressive strength is 45.61MPa.
- The 7 days compressive strength of UHPC-1 is 106.41 MPa while the 28 days compressive strength is 117.05 MPa.
- The 7 days compressive strength of UHPC-2 is 101.46 MPa while the 28 days compressive strength is 112.78MPa.
- The 7 days compressive strength of UHPC-3 is 96.91 MPa while the 28 days compressive strength is 107.76MPa.

C. *Split Tensile Test:*

1) *Split Tensile Strength at 7 days*

Sample	Number of cubes	Load(KN)	Split tensile strength(MPa)	Avg. Split tensile strength(MPa)
M40	1	276.75	3.91	3.67
	2	247.77	3.5	
	3	243.42	3.44	
UHPC-1	1	720.63	10.2	10.21
	2	735.12	10.4	
	3	710.03	10.05	
UHPC-2	1	703.67	9.96	9.92
	2	701.55	9.93	
	3	696.6	9.86	
UHPC-3	1	666.9	9.44	9.44
	2	671.1	9.5	
	3	663.14	9.39	

Table 9: Split Tensile Strength at 7 days

2) *Split Tensile Strength at 28 days*

Sample	Number of cubes	Load(KN)	Split tensile strength(MPa)	Avg. Split tensile strength(MPa)
M40	1	346.18	4.9	4.89
	2	342.6	4.85	
	3	347.59	4.92	
UHPC-1	1	1103.5	15.62	15.47
	2	1083.77	15.34	
	3	1091.5	15.54	
UHPC-2	1	1053.3	14.91	14.76
	2	1050.5	14.87	
	3	1028.6	14.56	
UHPC-3	1	1005.34	14.23	14.29
	2	1023.01	14.48	
	3	1001.11	14.17	

Table 10: Split Tensile Strength at 28 days

Sample	Avg. Split tensile strength after 7 days(MPa)	Avg. Split tensile strength after 28 days(MPa)
M40	3.67	4.89
UHPC-1	10.21	15.74
UHPC-2	9.92	14.76
UHPC-3	9.44	14.29

Table.11 Average split tensile strength at 7 & 28 days

3) *Graph of Avg. split tensile strength for 7 & 28 days*

a) Conclusions:

- The 7 days tensile strength of M40 is 3.617 MPa while the 28 days tensile strength is 4.89 MPa.
- The 7 days tensile strength of UHPC-1 is 10.217 MPa while the 28 days tensile strength is 15.47MPa.
- The 7 days tensile strength of UHPC-2 is 9.91 MPa while the 28 days tensile strength is 14.76MPa.
- The 7 days tensile strength of UHPC-3 is 9.44 MPa while the 28 days tensile strength is 14.29 MPa.

D. *Durability Test:*

1) *Compressive Strength on durability of concrete at 28 days in Na2SO4*

Sample	Number of cubes	Load(KN)	Compressive strength(MPa)	Avg. compressive strength(MPa)
M40	1	967.47	42.92	43.32
	2	977.63	43.45	
	3	980.78	43.59	
UHPC-1	1	2568.86	114.17	114.67
	2	2554.65	113.54	
	3	2576.03	114.49	
UHPC-2	1	2482.2	110.32	109.38
	2	2542.2	112.20	
	3	2369.7	105.32	
UHPC-3	1	2260.13	100.45	103.96
	2	2267.1	100.76	
	3	2490.07	110.67	

Table 12: Compressive Strength on durability of concrete at 28 days in Na2SO4

Sample	Avg. compressive strength(MPa) after 28 days in water	Avg. compressive strength(MPa) after 28 days in water & 28 days of Na2S04
M40	45.61	43.32
UHPC-1	117.05	114.67
UHPC-2	112.78	109.38
UHPC-3	107.76	103.96

Table 13: Average compressive strength

2) *Conclusions:*

- The average compressive strength after 28 days in water for M40 is 45.61 MPa. While the average compressive strength after 28 days in water & 28 days in Na2SO4 is 43.32 MPa. The percentage loss in strength after 28 days in Na2SO4 is 5.02%.
- Similarly, for UHPC-1 the percentage loss in strength after 28 days in Na2SO4 is 2.55%.
- For UHPC-2 the percentage loss in strength after 28 days in Na2SO4 is 3.1%.
- For UHPC-3 the percentage loss in strength after 28 days in Na2SO4 is 3.52%.

3) *Weight loss after 28 days in Na2SO4*

Sample	Wt. after removing from water	Wt. after removing from sodium sulphate	% wt. loss
M40	8.656	8.62	0.415
UHPC-1	8.067	8.057	0.123
UHPC-2	7.917	7.905	0.157
UHPC-3	7.634	7.620	0.183

Table 14: Weight loss after 28 days in Na2SO4

a) Conclusions:

- The average weight of cube after 28 days in water for M40 is 8.656 Kg. While the weight after 28 days in water & 28 days in Na2SO4 is 8.62 Kg. The percent loss in weight is 0.415%.
- Similarly, for UHPC-1 the percentage loss in weight after 28 days in Na2SO4 is 0.123%, For UHPC-2 the percentage loss in weight after 28 days in Na2SO4 is 0.157%. For UHPC-3 the percentage loss in weight after 28 days in Na2SO4 is 0.183%. UHPC is lighter in weight to that of M40.
- While UHPC-3 is lighter than UHPC-2 and UHPC-2 is lighter than UHPC-1.

E. Cost comparison

1) *For M40*

For 1 cubic meter				
Materials	Weight/cubic meter (kg/m3)	Rate	Per	Amount
Cement	450	280	Bag	2520
Sand	623.63	2	Kg	1248
Coarse aggregate	1085.95	9	Kg	9765
		Total amount=		135333
For 0.29 cubic meter = 3924.5 Rs.				

Table 15: Cost of M40

2) *For UHPC-1*

For 1 cubic meter				
Materials	Weight/cubic meter (kg/m3)	Rate	Per	Amount
Sand	1020	2	Kg	2040
Cement	712	280	Bag	3987
Silica fumes	231	20	Kg	4620
Ground quartz	210	15	Kg	3165
Super plasticizer	13	150	Kg	4605
Steel fibres	160	90	Kg	14040
		Total amount=		32457
For 0.29 cubic meter = 9420 Rs.				

Table 16: Cost of UHPC-1

3) *For UHPC-2*

For 1 cubic meter				
Materials	Weight/cubic meter (kg/m3)	Rate	Per	Amount
Sand	969	2	Kg	1938
Cement	712	280	Bag	3987
Silica fumes	231	20	Kg	4620
Ground quartz	210	15	Kg	3165
Super plasticizer	13	150	Kg	4605
Steel fibres	160	90	Kg	14040
Marble dust	51	1	Kg	51
		Total amount=		32390
For 0.29 cubic meter = 9390 Rs.				

Table 17: Cost of UHPC-2

4) *For UHPC-3*

For 1 cubic meter				
Materials	Weight/cubic meter (kg/m3)	Rate	Per	Amount
Sand	918	2	Kg	1836
Cement	712	280	Bag	3987
Silica fumes	231	20	Kg	4620
Ground quartz	210	15	Kg	3165
Super plasticizer	13	150	Kg	4605
Steel fibres	160	90	Kg	14040
Marble dust	102	1	Kg	102
		Total amount=		32350
For 0.29 cubic meter = 9350 Rs.				

Table 18: Cost of UHPC-3

Sample	Total amount (Rs.)
M40	3925
UHPC-1	9420
UHPC-2	9390
UHPC-3	9350

Table 19: Total Cost comparison

VI. CONCLUSIONS

For 0.29 cubic meters, the cost of M40, UHPC-1, and UHPC-2 & UHPC-3 is Rs.3925, Rs.9420, and Rs.9390 & Rs.9350.
By replacing sand by 5% & 10% of marble dust in UHPC-1, the cost reduces by 0.32% & 0.75% respectively.
The cost of UHPC is approximately 2.4 times that of M40, but cost cycle of the structure made from UHPC is less than the M40 and greater savings are obtained as shown in the figure below.

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