# Development of Ultra High Strength Concrete Using Silica Fume and its Mechanical & Durability Properties - Experimental Investigation

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**Original Research**

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# Abstract

This experimental investigation is aimed to develop an ultra-high strength concrete with minimum of 100 MPa as compressive strength.In order to obtain this, twenty different concrete mixes have been tried, using cement, river sand, coarse aggregate, water, silica fume and super plasticizer. During the preparation of trial mixes of concrete, the water / binder ratio of 0.2, silica fume of 10% to the weight of cement, super plasticizer of 10 litres per cubic metre of concrete and coarse aggregate of 1000 kg/m$^3$ were kept as constant. The amount of cement content (as 600-, 650-, 700-, 750- and 800 kg/m$^3$) and the fine aggregate content (as 500-, 600-, 700- and 800 kg/m$^3$) was varied. Totally 300 specimens were cast and tested in this investigation.The100 x 100 x 100 mm size of cubes, 150 x 300 mm size of cylinders, 100 x 100 x 500 mm size of prisms, 100 x 200 mm size of cylinders, 60 x 100 mm size of cylinders were used to test compressive, split tensile, flexural strength, chloride penetration and water penetration tests respectively at the age of 7-, 14- and 28 days. Based on the test results, a suitable mix proportion to produce an ultra-high strength concrete has been identified. Subsequently, from this investigation, the maximum cube compressive strength of 130 MPa, split tensile strength of 6.94 MPa, flexural strength of 21.39 MPa, chloride penetration 36 Coulombs which is lesser than 100 and sorptivity coefficient valueof 0.582 has been achieved.


# 1. Introduction

Due to the paucity of space in cities, there is a huge demand for multistoried buildings. As the number of stories increases, the size of the column members also increases, thereby, requiring additional cost for foundation. To overcome this, nowadays high strength concrete is being adopted in beam and column members. Therefore, in this investigation it is mainly focused to develop the mix for Ultra High Strength Concrete (UHSC) using basic materials.

As per ACI Committee 211 [1], production of high strength concrete is based on suitable selection of constituents. In this report it is stated that addition of High Range Water Reducing Admixture gives better workability therefore no need for modifying the coarse aggregate content and there is a need to modify the cementitious content. For obtaining high strength concrete, optimum mix of cement, fly ash, aggregates should be selected. The type of admixtures, dosage rate, and mix proportions also an important consideration in high strength concrete production.

According to Nageh N et al [2] UHSC is designated by higher dosage of silica fume and cement content with lowest water to cement ratio results in prominent mechanical and durability properties have been obtained. Reactive Powder Concrete with steel fibres gives positive results in mechanical and durability properties.

Adel A et al [3] have been used cement, fine aggregate of maximum size 4.75 mm, steel fibres, water, mineral admixtures such as high reactivity metakaolin, silica fume, and chemical admixture as super plasticizer for making ultra high performance concrete. Coarse aggregate was completely eliminated for casting the specimens.Further, it is concluded that percentage of increment in silica fume and steel fibres lead to improve the compressive strength of cube specimen.

Prabhat Ranjan Prem, et al [4] proposed that Ultra High Performance Concrete made by cement, fine aggregate, silica fume, super plasticizer, quartz powder, steel fibres with lower water to cement ratio and by complete expulsion of coarse aggregate shows better homogeneity. By the mineral and chemical admixtures gives a better gel formation in hydration process.

Mohammad Abdur Rashid, et al [5] investigated that high strength concrete have been produced by lower water to binder ratio, higher ratio of coarse to fine aggregate and optimum dosage of fly ash, silica fume, super plasticizer. Their research also stated that there is an improvement in mechanical property of concrete by obtaining denser packing of solid constituents.

Srinivas Allena et al [6] have tried the development of UHSC using local materials. In their research type I / II cement, silica fume, locally available sand, water reducing admixture and steel fibres were used. The curing of specimens made by moist curing, water bath curing and cured with oven, among which oven dried curing gives more strength than other methods of curing.

G.Venkatesan et al [7] recommended that the Ultra High Strength Concrete which was obtained by lesser water cement ratio and higher binder content.The materials Portland cement, fine aggregate, coarse aggregate (of size 12 mm and 6 mm with saturated and dry condition), silica fume, super plasticizer and water have been used. The results shows that the concrete specimens made by 6 mm aggregate with saturated condition contributes better compressive, split tensile and modulus of elasticity value.

Chong Wang et al [8] suggested that the improvement in strength, reduction in porosity and low water binder ratio have been achieved by addition of silica fume and quartz. Selected dosage of super plasticizer provided better flow ability to concrete without eliminating the coarse aggregate.

P.C. Aitcin [9] conveyed that UHSC is derived by removing the coarse aggregate and improving the density with specific grain size. Further, the usage of glass and iron powder in concrete contributed to attain the strength of 270 MPa and 800 MPa respectively.

Therefore, this study is proposed with an aim to develop a UHSC having compressive strength more than 100 N/mm$^2$ without fibres, glass and iron powder and to examine the mechanical and durability properties of developed UHSC mix.

# 2. Materials Used

In this research, the river sand is used as fine aggregate (which obeys to Zone – II as per IS: 383–1970 [10]), 12 mm coarse aggregate and grade 43 OPC cement, silicafume, super plasticizer were used as constituent materials to prepare trial mixes of concrete. The properties of cement and aggregates are given in Table 1 and for silicafume and super plasticizer are as follows.

## Silica Fume:

The Elkem 920D grade micro silica is improves the concrete performance and mortar formulation. Physically it optimises packing of particle in cement mortar/concrete and chemically act as an extremely responsive pozzolanic. The specific gravity of 2.25 and bulk density between 500–700 kg /$m^3$ of microsilica was used to make Ultra high strength concrete. Concrete proportions and mixing has been made according to IS 9103: 1999 and IS 10262:2009 [11] and [12] respectively.

## Super plasticizer:

Master Glenium Sky 8233 is a type of super plasticizer, based on modified polycarboxylic ether, to achieve high workability concrete with greatly reduced water content. The properties of the super plasticizer used in this investigation are specified in Table 2.

## 3. Experimental Investigations

In order to develop an UHSC, twenty different proportions of trial mixes tried are reported in Table 3. During the trial mix preparation, the water-binder ratio of 0.2, silica fume of 10% by weight of cement, super plasticizer of 10 litres per cubic metre and coarse aggregate of 1000 kg/$m^3$ were kept as constant parameters. The amount of cement content was varied as 600-, 650-, 700-, 750- and 800 kg/$m^3$ and the amount of fine aggregate was varied as 500-, 600-, 700- and 800 kg/$m^3$.

# 3.1 Preparation of Specimens

In this investigation, to develop and optimise the mix proportion for an UHSC, a total number of 300 specimens were prepared; pan mixer was used to mix the concrete are as shown in Fig. 4. The 100 x 100 x 100 mm size of cubes, 150 x 300 mm size of cylinders and 100 x 100 x 500 mm size of prisms, 100 x 200 mm size of cylinders, 60 x 100 mm size of cylinders were cast to test the compressive, split tensile, flexural strength, chloride penetration and water absorption tests at the age of 7-, 14- and 28 days. Table vibrator was used to compact the concrete. After 24 hours, the samples were detached from the steel moulds and positioned for immersion curing into the curing tank as shown in Fig. 6.

## 4. Testing Of Specimens

After mixing, the fresh concrete tests have been performed then the concrete mix poured into the mould. The cast and cured specimens have been tested after 7-, 14- and 28 days of curing to determine its mechanical and durability properties.

# 5. Result And Discussion

## 5.1 Characteristics of fresh concrete

The slump cone test was performed to check the workability of the concrete. It was observed that with zero slump value as shown in Figure 5. Since the silica fume was a very fine particles it absorbs more amount of water.

## 5.2 Hardened concrete tests

### 5.2.1 Investigation of Mechanical properties

Compressive strength, split tensile strength, and flexural strength have been performed for investigating the mechanical behaviour of selected mix proportions of Ultra High Strength Concrete.

The specimens prepared for this investigation were tested using a 4000 kN capacity of CTM as per IS 516: 1959 code [13]. The test results of concrete cube are reported in Table 4, Figure 1 and test setup is as shown in Figure 7. The cylinders were tested using computerised UTM of 1000kN capacity as per IS 5816: 1999 code [14]. The test results of cylinder are described in Table 5, Figure 2 and test setup are as shown in Figure 8. The prisms were tested using the flexural testing machine of 1000 kN capacity as per IS 9399:1979 code [15].The test results of prism are reported in Table 6 and Figure 3 and test setup are as shown in Figure 9. Based on 20 trial mixes reported in Table 3, the optimum mix to achieve an UHSC has been identified. The recommended design mix to produce UHSC is given in Table 7.

It is observed from Table 7, that the C series mixes of C1, C2, C3 and C4 yields compressive strength value more than 100 $N/mm^2$.

A significant rise in the concrete compressive strength is witnessed by the addition of cement content. The cement content was increased at the rate of 50 $kg/m^3$ for A, B, C, D and E series of cubes respectively. This high strength is attributed due to the packing of fine silica fume and the improved strength of cement paste between aggregates.

The C series of trial mixes provides higher strength since the cement content is optimum. In series A & B cement content is less and, in series D& E cement content is more than optimum value. The influence of the higher dosage of cement beyond 700 kg/ $m^3$ (Series C) may deliver increased amount of heat due to the reaction with water, which may be the indication for the development of internal small cracks even it is controlled by silica fume and super plasticizer content.

A notable rise in split tensile strength of concrete are obtained from series A to series C with the increase in cement content. From the experimental study, the following four mix proportions are recommended to obtain an UHSC with the compressive strength of more than 100 $N/mm^2$.

1. 1: 0.71:1.43:0.1
2. 1: 0.86:1.43:0.1
3. 1:1:1.43:0.1
4. 1:1.14:1.43:0.1

Similar trend of improvement is witnessed for flexural strength of concrete with the growth in cement up to series C. Due to the more intense of cement content, the series C concrete mixes yields 70% higher flexural strength than the series A mixes. By that time the optimum cement content where reached for the given mix. Hence, further addition of cement content in concrete leads to the strength decrease about 40% for Series D and Series E mixes. From Table 4-6, it could be observed that the experimental results on all mechanical strength exhibits a gradual growth from series A to series C, after that decrease for series D and a small increment in series E also were observed.

# 5.2.2 Investigation of Durability Properties:

In order to study the durability of series C mixes rapid chloride penetration and water sorptivity tests were carried out.

# 5.2.2.1 Rapid Chloride Penetration Test (RCPT):

Rapid Chloride Penetration Test (RCPT) was completed as per ASTM C1202-97[16]. A cylinder was cut three equal parts as top, middle and bottom with the diameter of 100 mm and height of 200 mm. Each part of the cut specimen was kept in the acrylic cell. Sodium chloride (3%) and sodium hydroxide (0.3 N) solutions were used as negative and positive terminals respectively subjected to 60 Volts potential for 6 hours as shown in Figure 10. For every 30 minutes, the results were recorded to calculate the current passed up to 6 hours. The penetration of the ions in the concrete specimen is depends on the permeability of concrete. The test results are as presented in Table 8. The more permeable concrete shows the higher Coulombs and the less permeable concrete, shows the lower Coulombs.

Q (in Coulombs) = $900 \times (I_o + 2 \times I_{30} + 2 \times I_{60} + 2 \times I_{120} + \ldots I_{360})$

$= 900 \times (0.005 + 2 \times 0.005 + 2 \times 0.005 + 2 \times 0.005 + 0.005)$

$= 900 \times (0.04)$

= 36 Coulombs

The current flowing through the cells have the value of 36 Coulombs which was less than 100, therefore it is concluded that the chloride permeability rating is negligible, concrete particles have been closely packed.

# 5.2.2.2 Sorptivity Test

The sorptivity test is used to determine the water penetration in concrete. Three cylinder of 60 x 100mm (diameter x height) were considered and weighed initially. The specimens were placed in to the water by ensuring that the water level for the height of 5 mm from the bottom as shown in Figure 11. For every 30 minutes the specimens was removed from the water and weighed after wiped out the surface. The sorptivity coefficient values were calculated by the following formula and the results are given in Table 9.

$$\frac{W}{(A \times \sqrt{t})} = k\left(\frac{g}{sq.mm}\right) \times 0.0001$$

$$494 / (\pi \times 60^2/4 \times 100 \times 30) = k \times 0.0001$$

$$k = 0.582$$

Since the obtained value is less than 6, it is accepted for lab concrete, which shows the selected mix proportion for  UHSC has lesser sorptivity coefficient value. Therefore, the penetration of water through the concrete is very low, and it was concluded that the concrete does not allow the water penetration.

# 6. Conclusions

In this investigation an attempt has been made, to develop an Ultra High Strength Concrete having compressive strength more than 100 N/mm$^2$. Based on the study, on twenty trial mixes, the following conclusions were made

1. In this study, the Ultra High Strength Concrete mix was obtained using silica fume without adding of fibres, glass and iron powder.
2. The suitable mixes are recommended in Table 7 to obtain Ultra High Strength Concrete with minimum concrete strength of 100 N/mm$^2$.
3. The improved compressive strength, split tensile strength, flexural strength, rate of chloride penetration and rate of water absorption is achieved for series C mix with cost effective.
4. A significant rise in the strength is witnessed by the adding cement content at the rate of 50 kg/m$^3$ for series A, B, and C of cubes respectively. This increment in strength is attributed due to the dense pack of fine silica fume and the strength improvement in cement paste between aggregates.
5. The increase of cement content up to 700 kg/ m$^3$ (C series) resulted in significant improvement of the mechanical strength and durability of UHSC. However, beyond the 700 kg/ m$^3$ addition of cement leads to the decrease in these properties.
6. The influence of the higher dosage of cement beyond 700 kg/ m$^3$ may deliver increased amount of heat due to the reaction with water, which may be the indicationfor the development of internal small cracks even it is controlled by silica fume and super plasticizer content.

## Declarations

# Funding:

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# Conflicts of interest/Competing interests:

Nil

# Ethics approval:

Not applicable

# Consent to participate:

Not applicable

# Consent for publication:

Yes

# Availability of data and material:

Easily Available

# Code availability:

Codes Available for casting and testing

# Authors' contributions :

Not applicable

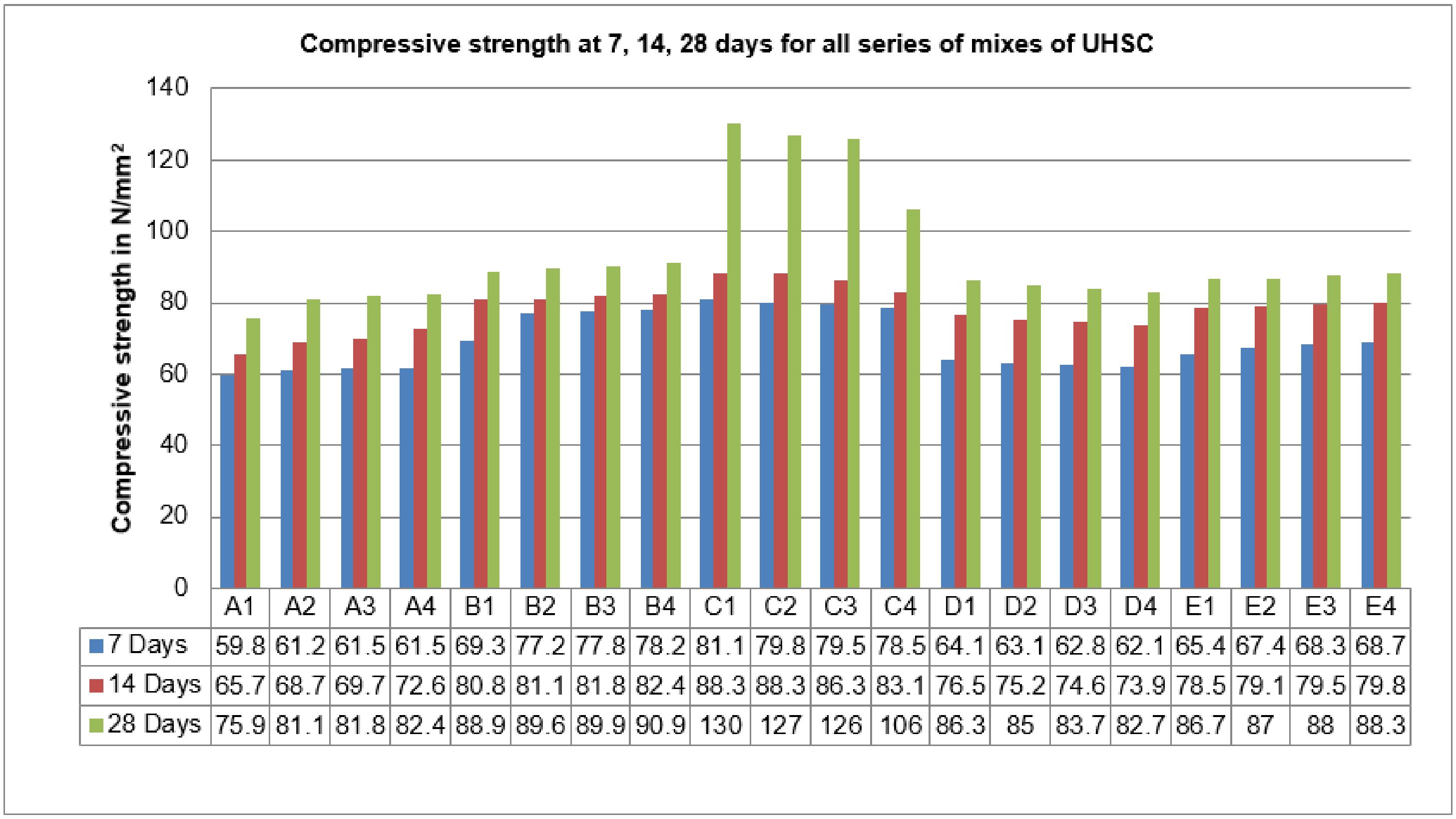
## References

1. ACI Committee 211 (1993) Guide for selecting Proportions for High Strength Concrete with Portland cement and Fly Ash. American Concrete Institute, Detroit, Michigan, 13 pp (ACI 211.4R-93)
2. Nageh N, Meleka AA, Bashandy, Mohamed A, Araab (2013) Ultra High Strength Concrete using Economical Materials. International Journal of Current Engineering Technology 3(2):393–402
3. Adel A. Al-Azzawi AS Ali and Husam K, Risan (2011) Behavior of ultra-high performance concrete structures. ARPN Journal of Engineering Applied Sciences 6:ISSN 1819–6608
4. Prem PR, Bharathkumar BH, Nagesh R, Iyer (2012) Mechanical Properties of Ultra High Performance Concrete. World Academy of Science, Engineering and Technology, Vol. 6, p.p. 8–23
5. Mohammad Abdur Rashid and Mohammad Abdul Mansur (2009) Considerations in producing high strength concrete. Journal of Civil Engineering (IEB),Pages 53–63
6. SrinivasAllena, Newtson CM (2011) Ultra-High Strength Concrete Mixtures Using Local Materials. Journal of Civil Engineering and Architecture, Vol.5, No. 4 (Serial No.41), pp. 322–330, ISSN 1934–7359, USA
7. Venkatesan G, T.Tamizhazhagan (2016) Ultra High Strength Concrete. International Journal of Innovative Research in Science, Engineering and Technology, Vol.5, Issue 3
8. Chong Wang,Changhui, Yang F, Liu C, Wan X Pu (2012) Preparation of Ultra High Performance Concrete with common technology and materials. Cement Concr Compos 34:538–544, ISSN 0024–9831
9. P.Aitcin (2016) Science and Technology of Concrete Admixtures
10. IS 383 (1970) Specification for coarse and fine aggregates from natural sources for concrete. Bureau of Indian Standard, New Delhi
11. IS 9103: 1999 Specification for admixtures for concrete, (1st revision). Bureau of Indian Standard, New Delhi
12. IS 10262:2009 Recommended Guidelines for concrete mix proportioning. Bureau of Indian Standard, New Delhi
13. IS 516: 1959 Method for strength of concrete. Bureau of Indian Standard, New Delhi
14. IS 5816: 1999 Splitting tensile strength of concrete - Method of test. Bureau of IndianStandard, New Delhi
15. IS 9399:1979 Specification for apparatus for flexural testing of concrete. Bureau of Indian Standard, New Delhi
16. ASTM C1202-97 (1997) Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration. ASTM International, West Conshohocken

# Tables

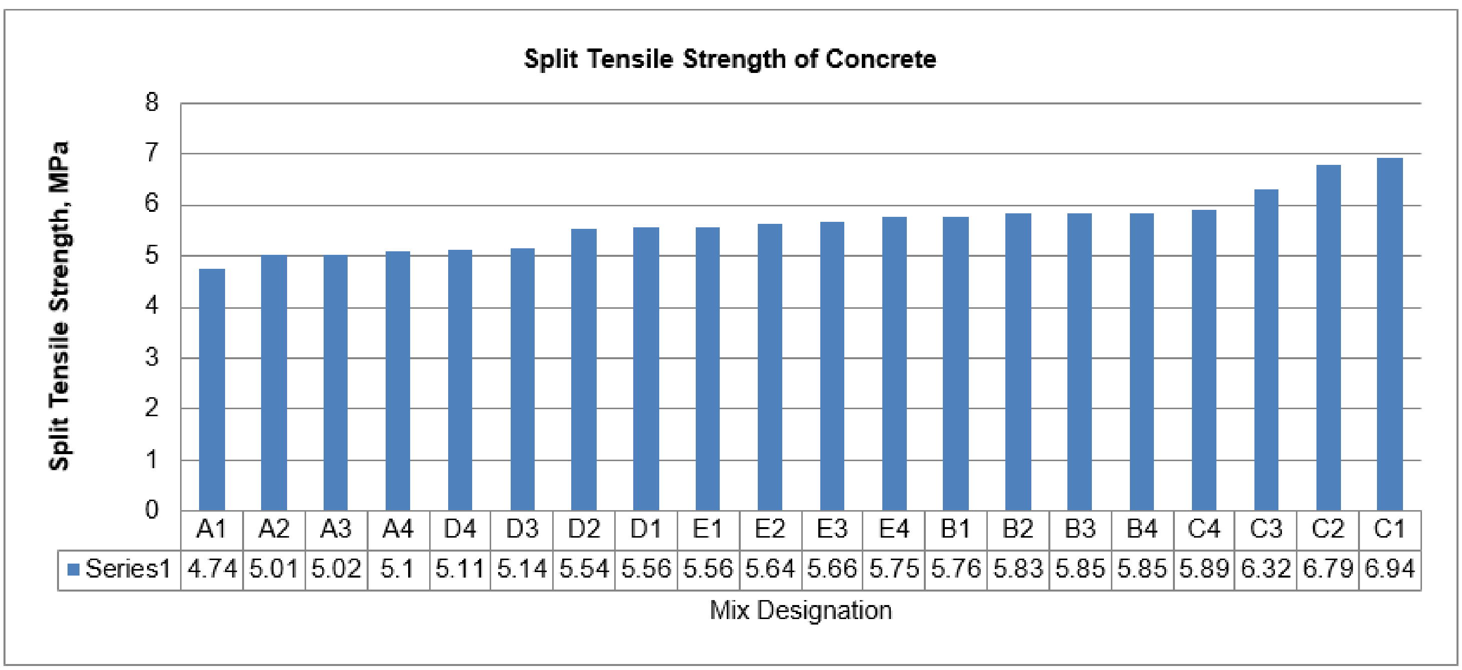
Due to technical limitations, tables are only available as a download in the Supplemental Files section.

# Figures




## Figure 1

Compressive strength test




## Figure 2

Split tensile strength test

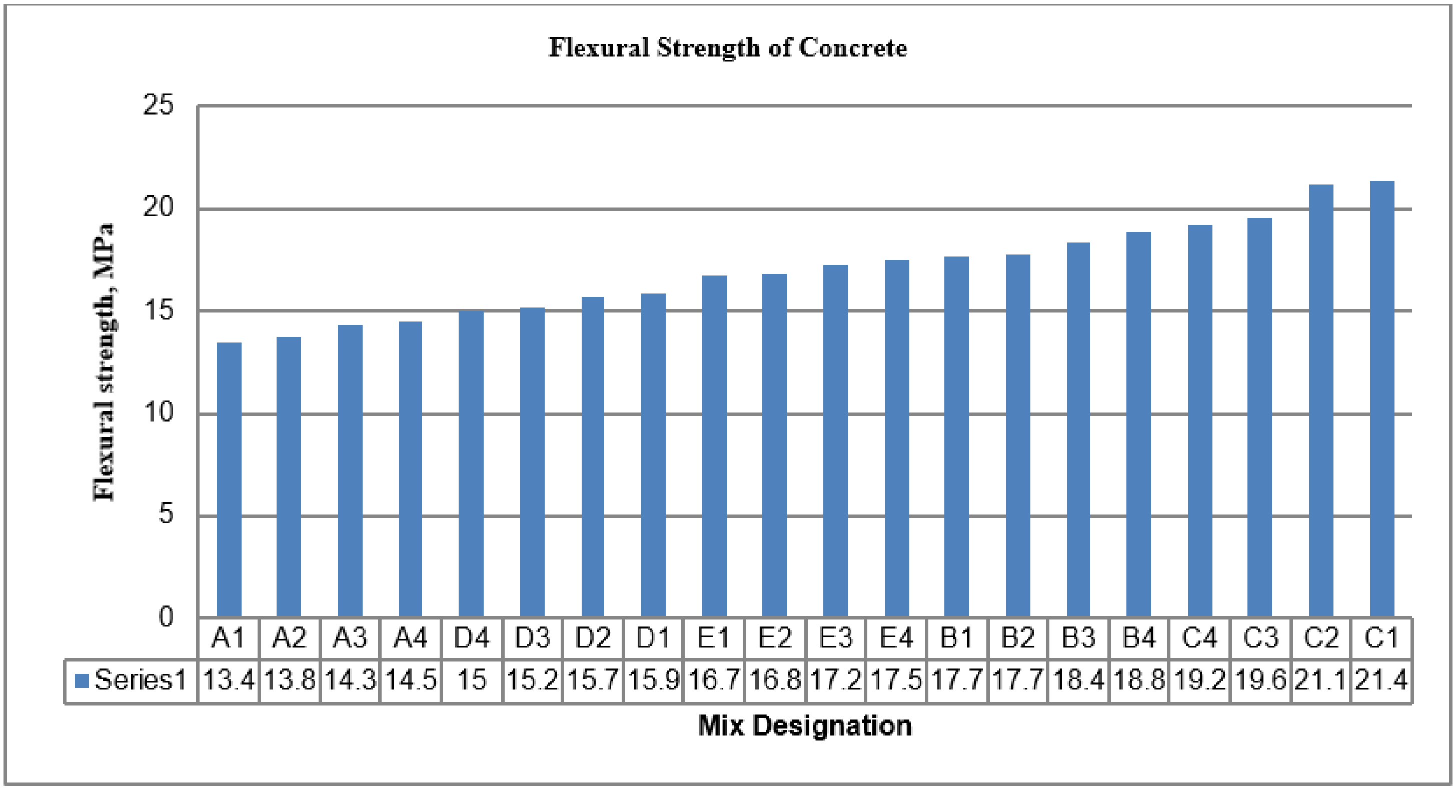



**Figure 3**

Flexural strength test

**Figure 4**

Preparation of specimens

**Figure 5**

Slump cone test

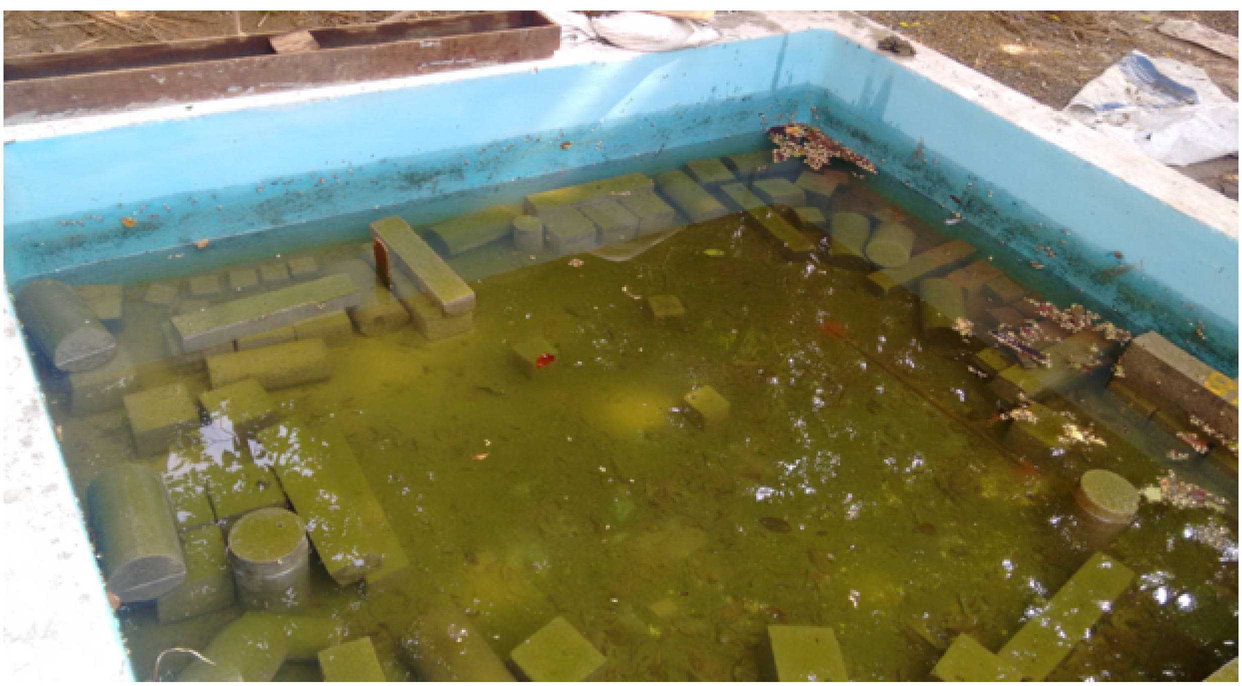


**Figure 6**

Curing of Specimens


**Figure 7**

Compression Test setup

**Figure 8**

Split Tensile strength test setup

**Figure 9**

Flexural strength test setup


**Figure 10**

Chloride penetration test setup for Ultra High Strength Concrete

**Figure 11**

Sorptivity test setup for Ultra High Strength Concrete

# Supplementary Files

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- TablesRevisedUHSC.docx