"DEVELOPMENT OF ULTRA HIGH STRENGTH CONCRETE USING PUNTKE METHOD OF PARTICLE PACKING"

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

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IN

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With specialization in

STRUCTURAL ENGINEERING

Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the thesis titled **"DEVELOPMENT OF ULTRA HIGH STRENGTH CONCRETE USING PUNKTE METHOD OF PARTICLE PACKING OF TERNARY MIX"** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in "**Structural Engineering**" and submitted to the Department of Civil Engineering, Jaypee University Information Technology, Waknaghat is an authentic record of work carried out by Akanksha Pathania (152664) during a period from July 2016 to May 2017 under the supervision of **Mr. Abhilash Shukla** Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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DECLARATION

I hereby declare that the work submitted in M.Tech thesis entitled **"Development of Ultra High Strength Concrete Using Puntke Method of Particle Packing"** submitted at **Jaypee University of Information Technology , Waknaghat, India** is an authentic record of my work carried out under the guidance of **Prof. Abhilash Shukla Assistant Professor**. I have not submitted this work elsewhere for any other degree or diploma.

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Date : Akanksha Pathania

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ABBREVIATIONS

UHSC- Ultra high strength concrete

RPC- Reactive powder concrete

GGBFS- Ground granulated blast furnace slag

HRWR- High range water reducer

RCPT- Rapid chloride permeability test

w/b- Water to binder ratio

OPC53 – Ordinary Portland cement of 53 Grade

FA-Fly ash

UFS – Ultrafine slag

MK- Metakaolin

RHA- Rice Husk Ash

UHSC-Ultra high strength concrete

SF- Silica Fume

SP- Superplasticizer

SFC – Superfine cement

MS- Manufactured Sand

QZ- Quartz Sand

QP- Quartz powder

GP- Glass Powder

XRF- X ray fluorescence

XRD- X ray diffraction

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Abstract

Ultra high strength concrete is a new kind of concrete whose strength is more than the conventional concrete. Nowadays it has been used in heavy constructions, high rise buildings, long span bridges etc. UHSC is not very different from conventional concrete, although it contains cement, mineral admixtures, superplasticizer, and steel fibers (if any). These mineral admixtures can be pozzolonic or cementitious such as Fly Ash, Rice Husk Ash, Metakaolin, Silica fume, ultrafine slag etc.These mineral admixture's particle size is less than the particle size of cement, therefore they fill the voids in between the cement grains and make concrete more dense. Therefore with cement replacement, cost of cement decreases, also replacement of cement can lowers the carbon production to the environment. Therefore UHSC is a new advancement in concrete industry which can build structures which have high strength, tough and durable. Particle packing, flow properties of this concrete is better than the conventional concrete. The objective of the research is studied here and the procedure for that is also described briefly.UHSC has been able to produce compressive strength ranging from 150MPa-200MPa and above.

Chapter 1. Introduction

1.1. General :

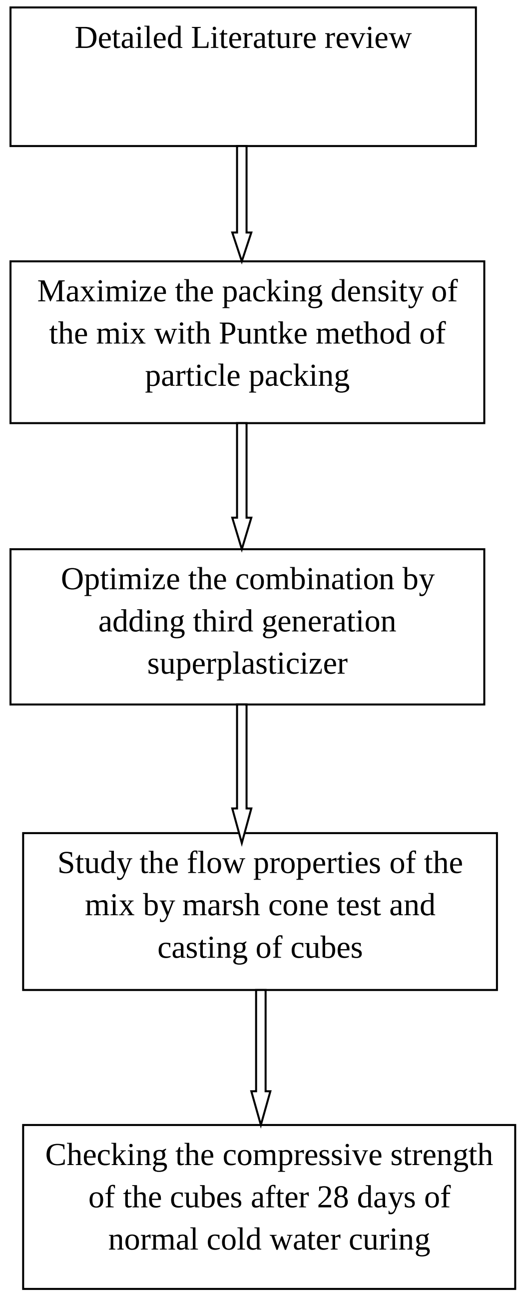
Concrete is a building material consists of cement, fine aggregate, coarse aggregate, which is strong in compression. Ultra High strength also called Reactive Powder Concrete; is a concrete mixture, which possess high durability and high strength as compared to conventional concrete. UHSC is not a special type of concrete, it only contains some mineral and chemical admixtures in addition to fine aggregates and cement to improve its compressive strength, durability, workability etc.Coarse aggregates can be excluded in this type of concrete because in denser concrete coarse aggregates are the weaker link as cracks development take place along coarse aggregates. Also homogeneity increases by eliminating coarse aggregates. Mineral admixtures react with cement hydration product to from additional C-S-H gel which is responsible for high compressive strength. The mineral admixtures could be pozzolonic materials such as fly ash (FA), Silica fume(SF), ground granulated blast furnace slag(GGBFS), ultra fine slag (UFS), Metakaolin (MK). Chemical admixtures is usually a superplasticizer (SP), which lowers the water to binder ratio (w/b) and therefore compressive strength increases. Now for high strength, packing of mineral admixtures should be high. There are many methods of particle packing such as Puntke method, relative density method and wet packing method. In this project Puntke method of particle packing has been used which is also known as minimum water requirement method. Optimum proportions of mineral admixtures are required for maximum particle packing which further enhance the compressive strength of concrete. The concrete having compressive strength above 60Mpa is considered as HSC. However when compressive strength is more than 150MPa it is UHSC. Steel fibers can further improve the compressive strength because they prevent crack formation in concrete. Compressive strength upto 200Mpa and above can be achieved with steel fibers. Curing techniques also enhances the compressive strength of the mix. Accelerated curing, autoclave curing improves the compressive strength of concrete. Usually autoclave curing and accelerated curing gives better results. Major applications of UHSC are in the area of pavements, long span bridges and high rise buildings etc. In this report detailed literature review is done for development of concrete of high compressive strength .After that particle packing is done with Puntke method and then that cubes were casted and their compressive strength has been checked after 28 days of normal cold water curing.

1.2 Objectives of the study

The main objectives of the research were:

1. To determine the ideal combination of Ultra High Strength Concrete by particle packing method.
2. To optimize the ideal combination by adding third generation superplasticizer.
3. To determine the compressive strength of ultra high strength concrete after 28 days of normal cold water curing.

1.3 Flowchart for objective:



Chapter 2. Literature Review

2.1. Particle packing

Long.G. et al.,(2002)[1]studied the effect of ultrafine powder (PFA,PS,SF) on concrete and examined that particle packing can be maximized by relative density method .They examined that fluidity and compressive strength (upto 200MPa) of the mix can be enhanced by mineral admixture, toughness can further increased by the addition of short steel fibers(L/D=60). Super plasticizer used was sulfonated cyanuramide formaldehyde resin base (DFS-2).

Lee.S. et al.,(2003)[2] examined that fluidity of cement paste can be improved by using different fly ash particle distribution. If the 'n' value of Rosin- Rammler distribution function is less than the fluidity of the mix would increase. Unburnt carbon content of fly ash was 1.5% .Hence it was concluded that different ranges of fly ash provide better particle packing and workability of the mix increases.

Nanthagopalan.P. et al.(2008)[3]described that flow properties were dependent on yield value and plastic viscosity. The particle density of C +SF and C+FA was analysed by 'puntke test'.It was concluded that particle density has a remarkable influence on the yield value for C+SF and C+FA, but less on the value of plastic viscosity for C+FA mix.

Peng. Y. et al.,(2009)[4] studied the effect of mineral admixture on particle packing and maximized particle packing by minimum water requirement method . Mineral admixtures i.e. ultrafine fly ash(UFFA), steel slag(SS), silica fume (SF), steel fiber (0.2 mm in diameter , 13 mm long) .

Kwan .A.K.H. and Chen J.J. (2012)[5] studied that superfine cement when added to OPC ,strength , flow property , particle density were increased. Particle packing was done by wet mixing . SFC were of higher fineness and SP used was a polycarboxylate ether – based polymer. SFC was added in the range of 10%-30%. With 20% addition of SFC particle density was increased from 0.659 to0 .679 and void ratio was decreased from 0.517 to 0.473. With 10% SFC maximum compressive strength was 124.8MPa and for 20 % SFC compressive strength was 137.7MPa for 28 days . It was concluded that SFC increases the 7 day compressive strength by 26.5% and 28 days strength by 15.3% . Also after mini slump and marsh cone test it was claimed that flow properties were also improved by adding SFC to cement.

Kwan .A.K.H. (2013)[6]described that addition of fly ash microsphere (40%) can significantly increased the particle packing by 19.7% and void ratio was decreased by 44.5%. It was studied that flow rate and fluidity was increased. The SP used was polycarboxylate ether –based polymer. It was concluded that as w/c ratio was decreased compressive strength of the mix increased.

Wong .V. et al.(2013)[7] studied that for sustainable concrete two things should be taken care of i.e. particle packing and rheology of concrete . It was studied that wall effect and loosening effect cause the problem to particle packing and it can be overcome by lowering the size ratio (fine to coarser aggregate ratio) . And it was justified that pozzolonic material would improve the particle packing .

Kwan A.K.H. (2014)[8] studied wet and dry mixing process for particle density of concrete mix.It was concluded that wet mixing method is appropriate for mixing because wet mixing method was more realistic, effect of SP can be incorporated in it, effect of vibrations can be simulated, beneficial effect of blending is better revealed. It was determined that in blended mix 20% PFA could decrease the void ratio by 13% and 20% CSF could decrease the void ratio by 11% respectively.

Kwan A.K.H et. al. (2014)[9] studied the effect of fine content (size< 75 micro meter) and powder content (<150 micro meter). Being finer these contents filled the pores of mix and increased the particle packing of the mix. Several types of fine were river sand (RS) , crushed rock fine (CRF) and manufactured sand (MS) . But RS was replaced with CRF and MS because of less availability of RS. Particle density obtained by wet mixing process was 0.660 and with dry method it was 0.613. Also when with compaction particle packing density with dry mixing was raised to 0.707 and 0.701 with wet mixing. It was found out that 15% replacement with fine content increased packing by 14% and decreased void ratio by 33%. It was advocated that there should be a certain optimum value of fine content for the best results.

Desai. K. (2016)[10] explained that properties of RPC can be improved by adding SF and kaoline. It was studied that when the content of SF was increased flow increased. Also compressive strength was found to be 138.76 MPa after 28 days . It was advised that kaoline content should be limited to 0.6 . After accerlated curing compressive strength was raised to 168.7MPa . Hence it was concluded that with accerlated curing strength can be raised by 25% .

2.2.Durability and Mechanical Properties:

Matte.V. and Moranvilli.M. (1999)[11] studied the influence of silica fume on the leaching properties of very low water/binder pastes. 25% SF was added to the cement at the w/c ratio of 0.20.SP used was polyacrylate. After demoulding, heat treatment was given at a temperature range from 20^0c – 400^0c .Leaching test was carried out by immersing the sample in the deionized water containing –OH- ,Ca^{2+} ,Na^+ ,K^+ etc. Also XRD analysis was carried out and was found that in the altered zone anhydrous part was missing. However cement paste with SF has less leaching effect. Durablity was increased by replacement with SF (i.e. permeability was decreased).

Shaheen .E. et. al (2006)[12] studied that when carbon fibers were added to RPC , then compressive strength of the mix increased . High range water reducing admixture wad added so that w/c ratio can be lowered and strength can be improved. Curing done was autoclave curing, which further raised the strength. Density was also increased with increase in prestressing load.Durablity of RPC was assessed by freezing and thawing cycles. Durability factor was found to be more than 100% after 300 cycles following the ASTM 666 standard.

Cwirzen . A. et. al .(2008)[13] studied the mechanical properties, durability of blended mix. Puntke method was used of particle packing. Experiment was carried out on three types of cement (low heat Portland cement, surface resistant cement and rapid Portland cement), two types of SF (97% of Sio2, 87% of Sio2) . Fine aggregate used were quartz powder and quartz dust. Granite and diabase were the coarse aggregate and Polycarboxylate based SP was used. Microstructure of RPC was analysed by ESEM(environmental scanning electronic microscope).The experiment was carried out on two groups (one which was having sand, quartz filler and steel fibers and second was having coarser aggregates granite and diabase). Now highest compressive strength of 202MPa for heat treated UHS mortar was achieved and for concrete it was 187MPa.For non heat treated mix strength was 130MPa-140Mpa.Steel fibers improved the flexural strength of mortar and there was no effect on concrete (due to the de- bonding of the binder matrix from the aggregate surface in tension).Highest shrinkage value was found to be 1000 micro meter/m for heat treated mortar without quartz filler. Coarse aggregate lowered the creep and shrinkage value effectively. It was concluded that after 56 cycles of freeze and thaw both UHS mortar and concrete were damaged and internal damage can be improved by steel fibers. The concept of hybrid concrete was introduced (combination of UHS mortar and OPC), which improved flexural strength by two times as compare to OPC.

Yazici. H(2009)[14] studied the mechanical properties of RPC under different curing regimes .Mix contained OPC, quartz powder(0-0.4mm) , quartz sand (0.5mm -1.0 mm and 1mm -3mm),FA, GGBFS ,Polycarboxylate – based SP, brass coated steel fiber(6mm long and diameter of 0.15mm). After demoulding some samples were cured with autoclaving curing (under 2MPa for 8hours and temperature was 210^0c). Remaining samples were cured by standard curing at 100^0c for 3 days. Initially when FA+GGBFS; replacement was 40% compressive strength of 2 days was lowered due to slow rate of reaction in early age. But later on strength was increased. After autoclave curing compressive strength was increased between 21%- 35% as compare to standard curing. And steam curing increased compressive strength between 14% - 26%. Also flexural strength test was carried on a prismatic specimen. It was found that steam curing reduced the 28 days flexural strength after as compare to standard curing. Steam and autoclave curing decreased the toughness about 10% -34% and 4%- 18% than standard curing due to the weaker bond between fiber and matrix. Also it was studied that modulus of elasticity was decreased after 30 % replacement.

Yazici.H(2010)[15] studied the mechanical properties of RPC containing high volume of GGBFS. Mix contained OPC, aggregate – Sintered bauxite (0.1mm and 1mm-3mm) , granite (1mm - 3mm) , quartz (0 - 0.4mm and 0.5 mm – 1mm), Polycarboxylate based SP, brass coated steel fiber (6mm length and diameter of 0.15 mm). GGBFS replacement varied 20%, 40% and 60 %.

Three types of curing was done (steam curing, autoclave curing and standard curing). Maximum compressive strength after autoclave curing was 298 MPa. And it was claimed that even at standard curing 200 MPa can be achieved after 28 days. Without steel fibers 185 MPa can be achieved by 40% replacement with GGBFS. When pressure was applied to the mix (30MPa0 on 100×100 cylindrical mix , compressive strength upto 400 MPa was achieved. Also it was found that flexural strength was increased with standard curing.

Aydin .S. et. al (2010)[16] studied the effect of texture , shape , angularity of coarse aggregate on the compressive strength of the RPC. Mix contained OPC, fine aggregate (<100micro meter), coarser aggregate (4mm), steel fiber and HRWR. It was studied that when rough surface aggregate used in RPC compressive strength was increased upto 200 MPa. Compared to the normal curing autoclave curing further increased the compressive strength of the mix. Also the fracture energy was reduced. Pressure application before and during setting also improved compressive strength.

Wille .K. (2010)[17] explained a simple way to produce high strength concrete (>150MPa) without any special curing and temperature application. They showed that for high strength, particle packing should be maximum. Cement should have less C_3A (lower than 8%) for high compressive strength. An optimum sand/ cement should be 1.4. SF should have very low carbon content (< 0.5%). Particle size of SF (1.2 micro meters) larger than commonly used (0.5mm) resulted in less w/c ratio . w/c ratio was 0.16- 0.27. Polycarboxylate ether was used as SP, 25 % replacement of cement by GP was done. Then compressive strength upto 190 MPa was achieved without fiber addition. When short steel fibers were added, compressive strength exceeded 200 MPa.

Rahmatabadi.M.A. (2015)[18] studied the mechanical properties of RPC under the presetting pressure and different curing regimes. Cement with low content of C3A and high content of C3S, C2S was blended with SF, quartz sand (0.6mm to 0.3mm), quartz powder (0.1mm) and a Polycarboxylate based SP Glenium- 5SP . When presetting pressure (60MPa) was applied with heat curing at 90^0c and 250^0c, compressive strength of 500 MPa was achieved. Also 200MPa could be achieved in hot water curing at 90c and in low pressure chamber. Also when a presetting pressure of 2.5 MPa was applied and curing for 7 days at 250^0c was done, compressive strength achieved was 253.2MPa and flexural strength upto 63.67MPa was obtained. Autoclave curing could further raise the strength.

Patel. Y. (2015)[19] studied that when alccofine and FA was blended in the cement, compressive strength was increased. Size of aggregate used was 10mm-20mm. ALCCOFINE 1203 and SP – GLENIUMSKY 784 second generation polycarboxylic ether polymer were used in the mix. Optimum dosage was 8% alccofine and 20% FA were advised for better results. Compressive strength, chloride resistant test, rapid chloride penetration test and accerlated corrosion test were carried out. Compressive strength after 28 days and 56 days were 54.89MPa and 72.9MPa were achieved respectively. The average loss of strength and loss of weight was less due to the addition of alccofine and FA. On addition of alccofine and FA value of RCPT was decreased due to proper particle size distribution. Also loss of steel in was less i.e. less corrosion due to alccofine.

2.3.Workability and Different Curing Regimes:

Kwan .A.K.H. & Fung W.W.S.,(2013)[20] studied the effect of SP on flowability and cohesiveness of cement sand mortar. They found that when w/s ratio and SP dosage was increased, flow rate / workability of the paste was increased. But when w/s ratio was increased strength would decreased. Therefore for better results w/s ratio for maximum strength was taken and then SP dosage was adjusted accordingly. SP dosage was ranging from 0% to 3% in term of liquid mass of SP by mass of cementitious materials. Cohesiveness measurements were taken by microversion of the sieve segregation test for SSC. It was concluded that for cohesiveness w/s ratio should be high .The overall flowability- cohesiveness performance of the mortar sample was evaluated by plotting the concurrently achieved flow spread , flow rate and sieve segregation index in two graphs .

Mehta . D et. al,(2015)[21] studied the effect of dosage of SP and w/c ratio on workability and compressive strength of RPC .Mix contained cement ,quartz sand , SF and SP – Auramix-400. It was found that SP had no direct relation with compressive strength. Although w/c ratio and compressive strength are inversely related to each other. Also when SP dosage increased, workability of concrete increased. Optimum value of w/c ratio, SF/C ratio, SP dosage , quartz sand/cement ratio were 0.3,0.25,8ml and 1.5 respectively.

Canbaz.M,(2014)[22] studied the effect of high temperature on RPC . Sample contained cement, quartz sand, quartz powder, SF, steel wires, SP, polypropylene fiber and water. Polypropylene fiber was added to prevent spalling. It was observed that the cube compressive strength was decreased at 100^0c ,increased at 200^0c-500^0c. Above 600^0c strength again decreased. It was observed that a compressive strength of 200MPa was achieved after water curing at 90^0c for 3 days and after applying a presetting pressure of 80 MPa to the RPC. When 1% steel fibers are added strength was raised to 165MPa. It was suggested that RPC must be produced with polypropylene fiber to withstand high temperature and curing must be applied at high temperature to obtain high strength.

Helmi.M. et. al,(2016)[23] studied the effect of high pressure and temperature curing on RPC microstructure formation. Curing temperature was 240^0c for 48hours and pressure applied wad 8MPa.It was seen that after the heat treatment, compressive strength was increased by 32% without pressure and when pressure was also applied the compressive strength further increased by 41% at 7 days. However 28 days strength was decreased for both by 5% and 16 % respectively. It was seen that the capillary pores were increased due to heat and pressure application. Also the pozzolonic reactions were fast and micro cracks were developed which can be controlled by adding steel fibers.

Li. H & Liu.G,(2016)[24] studied that tensile and flexural strength of the hybrid fiber reinforced reactive powder was increased when exposed to elevated temperature . High temperature test, bending and tensile test were conducted and it was noticed that tensile strength was increased. For temperature below 700^0c, the steel fiber worked effectively and toughness of RPC was improved. But beyond 700^0c, the carbonization of steel fiber occurred and steel fibers in RPC lose effectiveness which increased the brittleness of RPC.

Chapter 3. Materials and Research Methodology:

As per the literature review it was found that for making of Ultra High Strength concrete ultrafine materials have been used. Therefore for making UHSC, following materials were used:

- Ordinary Portland Cement 53 grade(OPC53)
- Ultrafine slag(UFS)
- Metakaolin(MK)
- Fly Ash(FA)
- Rise Husk Ash (RHA)
- Quartz Sand(QS)
- Manufactured sand(MS)
- Quartz Powder(QP)
- Superplasticizer(SP)

OPC 53 Grade: It was procured from Ambuja Cement Darlaghat,Himachal Pradesh conforming to IS: 12269- 2013[25].

Figure. 1 OPC53

UFS: UFS is a new generation, ultrafine, low calcium silicate product, manufactured in India. It has distinct characteristics to enhance 'performance of concrete' in fresh and hardened stages. UFS used in this research was procured from Counto Microfine Products Limited Goa confirming to IS- 12089-1987[26].

Figure. 2 Ultrafine slag

Metakaolin: Metakaolin is a highly reactive amorphous pozzolonic classified as ultra-fine with an average diameter around 1-2 microns and is produced by heating kaolin under a temperature between 650^0c. It was procured from Kaomin Industries LLP, Vadodra Gujrat confirming to IS-1489 part-2(1991).

Figure. 3 Metakaolin

Fly Ash : Fly Ash is a fine mineral admixture obtained from thermal power plant as residue after burning the coal at about 1800^0 c. FA of class F was procured from PSPCL Ghanauli Punjab confirming to IS:1489 (Part 2)-1991.

Fig. 4 Fly Ash

Rise Husk Ash : Amorphous RHA was used as a supplementary cementing material (SCM). It was available in very fine powder form with a grey color. It was procured from KGR fusions Private Limited, Ludhiana Punjab. Different combinations were tried by replacing cement with these cementitious materials to achieve maximum particle packing.

Figure. 5 Rice Husk Ash

Quartz Sand:White coloured quartz sand used as fine aggregate was procured from Surya Min Chem Delhi.Range of particle size of quartz sand used was 150microns to 300 microns.

Figure. 6 Quartz Sand

Manufactured Sand : It is obtained after crushing of hard granite stone . Size of manufactures sand is less than 4.75mm. It was procured locally. Range of particle size of quartz sand used was 300 microns to 600 microns.

Figure. 7 Manufactured sand

Quartz Powder : It is an important mineral; used as a fine aggregate and it was procured from Surya Min Chem, Delhi.

Figure. 8 Quartz powder

Superplasticizer(SP) : It is a chemical admixture and is added to the paste to lowers w/b ratio. Polycarboxylate based SP of third generation has been used in this research.

Figure. 9 Polycarboxylate based SP

3.1. Physical Properties of Cement:

Different tests were carried out to find the physical properties of cement:

- **Consistency of Cement**: This test was done to find out the amount of water required for complete hydration of cement. Vicat's apparatus was used in it.
- **Initial Setting Time of Cement:** This test is done to find the time required for the initial set of the cement. Minimum time for initial set is 30 minutes. This test was also done with Vicat's apparatus.
- **Final Setting Time of Cement:** This test was done to find the amount of time for final set of the cement. Limit of final setting time is 8-10 hours. Vicat's apparatus was used in it .
- **Soundness of Cement**: This test was done to find whether the cement is sound (absence of free lime) or not. This test was done with Le Chaterlier's apparatus. For sound cement limit of expansion is 0-10mm.
- **Fineness of Cement**: Fineness of cement was done to find whether cement was fine to use or not. It was done with 90 microns sieve.
- **Specific Gravity and water absorption:** Specific gravity of cement and all cementitious materials were found out with Le- Chaterlier's bottle. Water absorption of quartz sand and manufactured sand was found out to be 0.004 and 0.01 respectively.

Table 1 Test results:

Cement	Consistency	Initial Setting Time	Final Setting Time	Soundness	Fineness
OPC53	36%	110 minutes	250 minutes	0.5 mm- Sound	0.5 % - Fine

Table 2 Specific gravity of materials:

Materials Used	Specific gravity
OPC53	3.15
UFS	2.86
Metakaolin	2.5
Fly Ash	2.17
RHA	2.53

3.2. Oxide Composition and particle size distribution:

Oxide composition shows the percentages of different compounds in the material. Oxide composition of OPC53, UFS, MK, Fly Ash and RHA were checked by XRF at IIT Bombay. Also particle size of all the materials is an important element for the development of Ultra High Strength Concrete. Proper range of particle size of all the materials should be known for optimum mix proportioning. For this reason particle size distribution was checked for all materials by Laser diffraction analyzer at IIT Bombay. Oxide composition and particle size distribution for all the materials are shown in Table 3 and Figure10 respectively.

Table 3 Oxide Composition

MATERIALS	Al_2O3	CaO	Fe_2O_3	K_2O	Na_2O	SiO_2	MgO
OPC 53	4.74	61.23	3.37	0.961	0.129	19.251	1.87
UFS	12.42	34.78	-	-	-	25.682	11.76
FLYASH	21.34	6.9	3.82	0.93	0.14	56.52	1.657
METAKAOLIN	29.54	0.07	1.06	3.74	1.43	61.72	0.18
RICE HUSK ASH	0.45	0.63	0.64	2.93	0.13	86.76	0.45

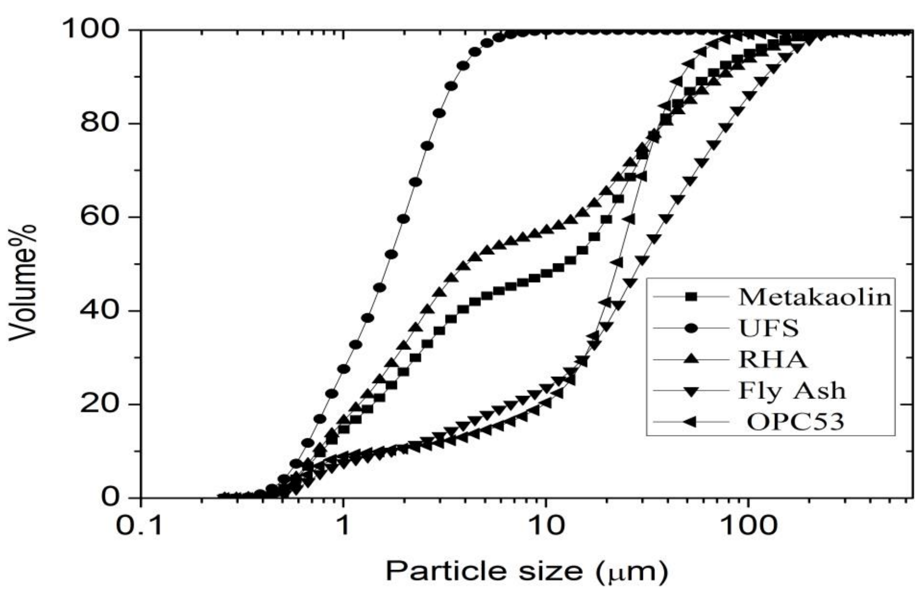


Figure 10 Particle size distribution

3.3. Particle Packing:

As the name suggest particle packing indicates the packing of voids. Generally there are many voids in between the cement grains. Now for filling those voids particle packing is required. Particle packing involves the selection of appropriate sizes and proportions of materials to get suitable combination for optimal packing. The voids in the cement can be filled with fine mineral admixtures such as UFS, MK, FA, RHA etc. Particle packing is expressed in terms of **packing density** which is the volume fraction of the system occupied by solids. There is no standard adapted method for particle packing. It can be done by any method such as wet packing method, relative density method, Puntke method etc. In this research work 'Puntke method' was used for maximum particle packing of ternary mix.

3.3.1 . Puntke Method:

Basic principle – The water fills the voids in between the grains. The water, which is in excess after completely filling the voids, appears at the surface of the mix, indicating the saturation point (Puntke 2002). This method is easy to perform, requires simple apparatus, consumes only small amount of material and the results are reliable.

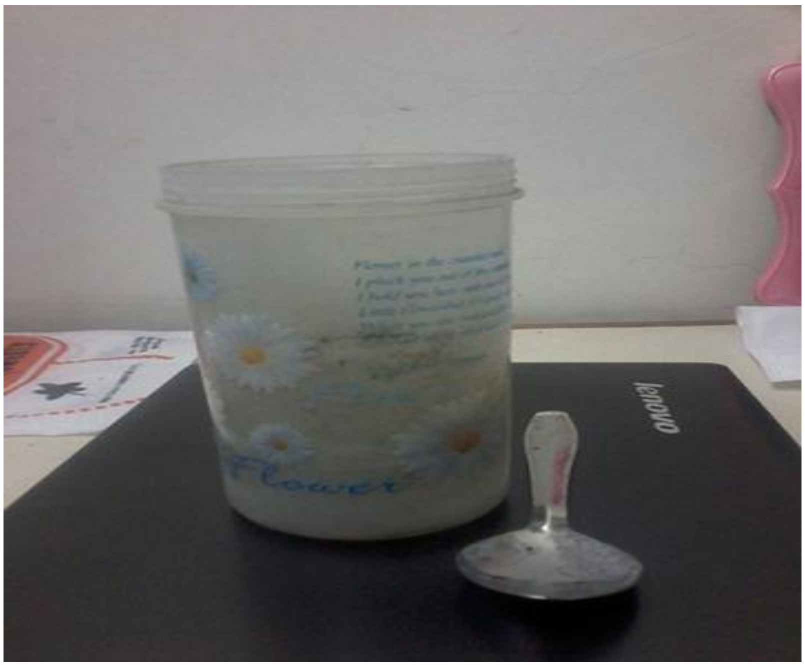


Figure 11 Puntke Method Apparatus

3.3.2. Procedure for Punkte Method:

- Weigh 100gm of the mix (cement + mineral admixture).
- Dry mixing for homogenisation is done initially.
- Water is added gradually to the mixture working with a stirrer until it acquires a closed structure after repeated tapping of the beaker until the saturation point is reached.
- After that water is added drop by drop until mix appears glossy which the indication of saturation point is.
- At this point, the surface smoothes itself after repeated tapping of the beaker and appears glossy.
- Time required for each mix is approximately 10- 15 minutes.

  Packing density (Φ) is calculated using:

$$\phi = 1 - \frac{Vw}{Vw + V_p}$$

Where;

Vw = Volume of water, Vp = Volume of powder

Weights were converted into volumes by dividing them with respective specific gravity of all materials:

$$Vp = \frac{Mc}{Sc} + \frac{M1}{S1} + \frac{M2}{S2}$$

Mc, M1, M2 are the weights of cement and other two mineral admixture

Sc, S1, S2 are the specific gravity of cement and other two mineral admixture

Figure 12 Humid cement particles

Figure 13 Saturated cement particles

3.4. Mix Proportions:

Mix proportion is an important part for getting the optimum material which will provide desired strength. For this reason we have selected 'ternary mix'. A large number of combinations were tried to achieve maximum particle density which will result in maximum particle packing. Weight of cement and other cementitious materials were calculated according to their percentages compared to total weight (100gm). Replacement of cement was done from 5% - 40

% in steps of 5% with mineral admixtures. The percentage of mineral admixture was decided on the basis of their reactivity order. Among all the mineral admixtures Metakaolin and Ultrafine slag is highly reactive. However Fly Ash is least reactive among all. Rice Husk Ash is also reactive. The materials which have low reactivity were kept less as compared to other one. The high rate of reactivity would result in high rate of reaction. Therefore percentages of materials were decided accordingly. For 'ternary mix', the combinations tried were:

- OPC53 + RHA +FA
- OPC53 + MK + UFS
- OPC53 + UFS + FA
- OPC53 + MK + FA
- OPC53 + UFS + RHA
- OPC53 + MK + RHA

Table 4 Combination trials:

Combinations No.	Combination's Name and ratio
	CEMENT : RHA :FA
CRF1	0.95 : 0.025 : 0.025
CRF22	0.95 : 0.03 : 0.02
CRF3	0.9 : 0.05 : 0.05
CRF4	0.9 : 0.06 : 0.04
CRF5	0.9 : 0.065 : 0.035
CRF6	0.9 : 0.07 : 0.03
CRF7	0.9 : 0.075 : 0.025
CRF8	0.85 : 0.075 : 0.075
CRF9	0.85 : 0.09 : 0.06
CRF10	0.85 : 0.0975 : 0.0525
CRF11	0.85 : 0.105 : 0.045
CRF12	0.85 : 0.1125 : 0.0375
CRF13	0.8 : 0.01 : 0.01
CRF14	0.8 : 0.12 : 0.08
CRF15	0.8 : 0.13 : 0.07
CRF16	0.8 : 0.14 : 0.06
CRF17	0.8 : 0.15 : 0.05
CRF18	0.75 : 0.125 :0.125
CRF19	0.75 : 0.15 : 0.10
CRF20	0.75 : 0.1625 : 0.875
CRF21	0.75 : 0.175 : 0.075
CRF22	0.75 : 0.15 : 0.05
CRF23	0.70 : 0.15 :0.15
CRF24	0.70 : 0.18 : 0.12
CRF25	0.70 : 0.195 : 0.105
CRF26	0.70 : 0.21 : 0.09
CRF27	0.70 : 0.1875 : 0.0625
CRF28	0.65 : 0.175 : 0.175
CRF29	0.65 : 0.21 : 0.14
CRF30	0.65 : 0.2275 : 0.1225
CRF31	0.65 : 0.245 : 0.105
CRF32	0.65 : 0.2625 : 0.0875
CRF33	0.60 : 0.2 : 0.2
CRF34	0.60 : 0.24 : 0.16
CRF35	0.60 : 0.26 : 0.14
CRF36	0.60 : 0.28 : 0.12
CRF37	0.60 : 0.3 : 0.1
	CEMENT + MK + UFS
CMU1	0.95 : 0.025 : 0.025
CMU2	0.95 : 0.03 : 0.02

CMU3	0.90 : 0.05 : 0.05
CMU4	0.90 : 0.06 : 0.04
CMU5	0.90 : 0.065 : 0.035
CMU6	0.90 : 0.07 : 0.03
CMU7	0.90 : 0.075 : 0.025
CMU8	0.90 : 0.025 : 0.075
CMU9	0.90 : 0.03 : 0.07
CMU10	0.90 : 0.035 : 0.065
CMU11	0.90 : 0.04 : 0.06
CMU12	0.90 : 0.02 : 0.08
CMU13	0.85 : 0.075 : 0.075
CMU14	0.85 : 0.09 : 0.06
CMU15	0.85 : 0.0975 : 0.0525
CMU16	0.85 : 0.105 : 0.045
CMU17	0.85 : 0.1125 :0.0375
CMU18	0.85 :0.0375 : 0.1125
CMU19	0.85 : 0.045 : 0.105
CMU20	0.85 : 0.0525 : 0.0975
CMU21	0.85 : 0.06 : 0.09
CMU22	0.85 : 0.03 :0.12
CMU23	0.80 : 0.1 :0.1
CMU24	0.80 : 0.12 : 0.08
CMU25	0.80 : 0.13 :0.07
CMU26	0.80 : 0.14 : 0.06
CMU27	0.80 : 0.15 : 0.05
CMU28	0.80 : 0.05 : 0.15
CMU29	0.80 : 0.06 : 0.14
CMU30	0.80 : 0.07 : 0.13
CMU31	0.80 : 0.08 : 0.12
CMU32	0.80 : 0.04 : 0.16
CMU33	0.75 : 0.125 : 0.125
CMU34	0.75 : 0.1625 : 0.0875
CMU35	0.75 : 0.10 : 0.15
CMU36	0.75 : 0.10 :0.15
CMU37	0.75 : 0.1875 : 0.0625
CMU38	0.75 : 0.0625 : 0.1875
CMU39	0.75 : 0.075 : 0.175
CMU40	0.75 : 0.0875 : 0.1625
CMU41	0.75 : 0.1 :0.15
CMU42	0.75 : 0.05 : 0.20
CMU43	0.70 : 0.15 : 0.15
CMU44	0.70 : 0.18 : 0.12
CMU45	0.70 : 0.195 : 0.105
CMU46	0.70 : 0.21 : 0.09
CMU47	0.70 : 0.225 : 0.075
CMU48	0.70 : 0.075 : 0.225

CMU49	0.70 : 0.09 : 0.21
CMU50	0.70 : 0.105 : 0.195
CMU51	0.70 : 0.12 : 0.18
CMU52	0.70 : 0.06 : 0.24
CMU53	0.65 : 0.175 : 0.175
CMU54	0.65 : 0.21 : 0.14
CMU55	0.65 : 0.2275 : 0.1225
CMU56	0.65 : 0.105 : 0.245
CMU57	0.65 : 0.2625 : 0.0875
CMU58	0.65 : 0.0875 : 0.2625
CMU59	0.65 :0.105 : 0.245
CMU60	0.65 : 0.1225 : 0.225
CMU61	0.65 : 0.14 : 0.21
CMU62	0.65 : 0.07 : 0.28
CMU63	0.60 : 0.2 : 0.2
CMU64	0.60 : 0.24 : 0.16
CMU65	0.60 : 0.26 : 0.14
CMU66	0.60 : 0.28 : 0.12
CMU67	0.60 : 0.30 : 0.10
CMU68	0.60 : 0.10 : 0.30
CMU69	0.60 : 0.12 : 0.28
CMU70	0.60 : 0.14 : 0.26
CMU71	0.60 : 0.16 : 0.24
CMU72	0.60 : 0.08 : 0.32
	CEMENT + UFS +FA
CUF1	0.95 : 0.025 : 0.025
CUF2	0.95 : 0.03 : 0.02
CUF3	0.90 : 0.05 : 0.05
CUF4	0.90 : 0.06 : 0.04
CUF5	0.90 : 0.0625 : 0.035
CUF6	0.90 : 0.07 : 0.03
CUF7	0.90 : 0.075 : 0.025
CUF8	0.90 : 0.08 : 0.02
CUF9	0.85 : 0.075 : 0.075
CUF10	0.85 : 0.09 : 0.06
CUF11	0.85 : 0.0975 : 0.0525
CUF12	0.85 : 0.0.105 : 0.045
CUF13	0.85 : 0.1125 : 0.0375
CUF14	0.80 : 0.10 : 0.10
CUF15	0.80 : 0.12 : 0.08
CUF16	0.80 : 0.13 : 0.07

CUF17	0.80 : 0.14 : 0.06
CUF18	0.80 : 0.15 : 0.05
CUF19	0.75 : 0.125 : 0.125
CUF20	0.75 : 0.15 : 0.10
CUF21	0.75 : 0.1625 : 0.0875
CUF22	0.75 : 0.175 : 0.075
CUF23	0.75 : 0.20 : 0.05
CUF24	0.70 : 0.15 : 0.15
CUF25	0.70 : 0.18 : 0.12
CUF26	0.70 : 0.195 : 0.105
CUF27	0.70 : 0.21 : 0.09
CUF28	0.70 : 0.225 : 0.075
CUF29	0.65 : 0.175 : 0.175
CUF30	0.65 : 0.21 : 0.14
CUF31	0.65 : 0.2275 : 0.1225
CUF32	0.60 : 0.2 : 0.2
CUF33	0.60 : 0.24 : 0.16
CUF34	0.60 : 0.26 : 0.14
	CEMENT + MK. +FA
CMF1	0.95 : 0.025 : 0.025
CMF2	0.95 : 0.03 : 0.02
CMF3	0.90 : 0.05 : 0.05
CMF4	0.90 : 0.06 : 0.04
CMF5	0.90 : 0.0625 : 0.035
CMF6	0.90 : 0.07 : 0.03
CMF7	0.90 : 0.08 : 0.02
CMF8	0.85 : 0.075 : 0.075
CMF9	0.85 : 0.09 : 0.06
CMF10	0.85 : 0.0975 : 0.0525
CMF11	0.85 : 0.0.105 : 0.045
CMF12	0.85 : 0.1125 : 0.0375
CMF13	0.80 : 0.10 : 0.10
CMF14	0.80 : 0.12 : 0.08
CMF15	0.80 : 0.13 : 0.07
CMF16	0.80 : 0.14 : 0.06
CMF17	0.80 : 0.15 : 0.05
CMF18	0.75 : 0.125 : 0.125
CMF19	0.75 : 0.15 : 0.10

CMF20	0.75 : 0.1625 : 0.0875
CMF21	0.75 : 0.175 : 0.075
CMF22	0.75 : 0.20 : 0.05
CMF23	0.70 : 0.15 : 0.15
CMF24	0.70 : 0.18 : 0.12
CMF25	0.70 : 0.195 : 0.105
CMF26	0.70 : 0.21 : 0.09
CMF27	0.70 : 0.225 : 0.075
	Cement +UFS+RHA
CRU1	0.95 : 0.025 : 0.025
CRU2	0.95 : 0.03 : 0.02
CRU3	0.90 : 0.05 : 0.05
CRU4	0.90 : 0.06 : 0.04
CRU5	0.90 : 0.0625 : 0.035
CRU6	0.90 : 0.07 : 0.03
CRU7	0.90 : 0.08 : 0.02
CRU8	0.85 : 0.075 : 0.075
CRU9	0.85 : 0.09 : 0.06
CRU10	0.85 : 0.0975 : 0.0525
CRU11	0.85 : 0.0.105 : 0.045
CRU12	0.85 : 0.1125 : 0.0375
CRU13	0.80 : 0.10 : 0.10
CRU14	0.80 : 0.12 : 0.08
CRU15	0.80 : 0.13 : 0.07
CRU16	0.80 : 0.14 : 0.06
CRU17	0.80 : 0.15 : 0.05
CRU18	0.75 : 0.125 : 0.125
CRU19	0.75 : 0.15 : 0.10
CRU20	0.75 : 0.1625 : 0.0875
CRU21	0.75 : 0.175 : 0.075
CRU22	0.75 : 0.20 : 0.05
CRU23	0.70 : 0.15 : 0.15
CRU24	0.70 : 0.18 : 0.12
CRU25	0.70 : 0.195 : 0.105
CRU26	0.70 : 0.21 : 0.09
CRU27	0.70 : 0.225 : 0.075
CRU28	0.65 : 0.2275 : 0.1225
CRU29	0.65 : 0.105 : 0.245
CRU30	0.65 : 0.2625 : 0.0875

CRU31	0.65 : 0.0875 : 0.2625
CRU32	0.65 :0.105 : 0.245
CRU33	0.60 : 0.2 : 0.2
CRU34	0.60 : 0.24 : 0.16
CRU35	0.60 : 0.26 : 0.14
CRU36	0.60 : 0.28 : 0.12
CRU37	0.60 : 0.30 : 0.10
	Cement +MK + RHA
CMR1	0.95 : 0.025 : 0.025
CMR2	0.95 : 0.03 : 0.02
CMR3	0.90 : 0.05 : 0.05
CMR4	0.90 : 0.06 : 0.04
CMR5	0.90 : 0.0625 : 0.035
CMR6	0.90 : 0.07 : 0.03
CMR7	0.90 : 0.08 : 0.02
CMR8	0.85 : 0.075 : 0.075
CMR9	0.85 : 0.09 : 0.06
CMR10	0.85 : 0.0975 : 0.0525
CMR11	0.85 : 0.0.105 : 0.045
CMR12	0.85 : 0.1125 : 0.0375
CMR13	0.80 : 0.10 : 0.10
CMR14	0.80 : 0.12 : 0.08
CMR15	0.80 : 0.13 : 0.07
CMR16	0.80 : 0.14 : 0.06
CMR17	0.80 : 0.15 : 0.05
CMR18	0.75 : 0.125 : 0.125
CMR19	0.75 : 0.15 : 0.10
CMR20	0.75 : 0.1625 : 0.0875
CMR21	0.75 : 0.175 : 0.075
CMR22	0.75 : 0.20 : 0.05
CMR23	0.70 : 0.15 : 0.15
CMR24	0.70 : 0.18 : 0.12
CMR25	0.70 : 0.195 : 0.105
CMR26	0.70 : 0.21 : 0.09
CMR27	0.70 : 0.225 : 0.075

3.5 . Particle Packing Density Calculations:

234 combinations were tried for all six set of combinations and packing densities were calculated. All tried combinations are listed here in Table 4, Table 5, Table 6, Table 7, Table 8 and Table 9 respectively.

Table 5 Particle Packing Density Calculation for CRF:

Sr. No.	OPC 53 (gm)	RHA(gm)	Fly Ash (gm)	Vw	Vp	Packing density
CRF 1	95	2.5	2.5	26.5	32.30	0.549
CRF 2	95	3	2	26.85	32.27	0.546
CRF 3	90	5	5	25.8	32.85	0.560
CRF 4	90	6	4	26.1	32.79	0.557
CRF 5	90	6.5	3.5	25.15	32.75	0.566
CRF 6	90	7	3	25.63	32.72	0.561
CRF 7	90	7.5	2.5	25.5	32.69	0.562
CRF 8	85	7.5	7.5	27.25	33.40	0.551
CRF 9	85	9	6	26.75	33.31	0.555
CRF 10	85	9.75	5.25	25.375	33.26	0.567
CRF 11	85	10.5	4.5	25.75	33.21	0.563
CRF 12	85	11.25	3.75	25.375	33.16	0.566
CRF 13	80	10	10	25.25	33.96	0.574
CRF 14	80	12	8	25.125	33.83	0.574
CRF 15	80	13	7	25.5	33.76	0.570
CRF 16	80	14	6	26.625	33.70	0.559
CRF 17	80	15	5	26.125	33.63	0.563
CRF 18	75	12.5	12.5	27.875	34.51	0.553
CRF 19	75	15	10	27.55	34.35	0.555
CRF 20	75	16.25	8.75	25.75	34.26	0.571
CRF 21	75	17.5	7.5	27.3	34.18	0.556
CRF 22	75	15	5	26.125	32.04	0.551
CRF 23	70	15	15	27.5	35.06	0.560
CRF 24	70	18	12	27.5	34.87	0.559
CRF 25	70	19.5	10.5	26.75	34.77	0.565
CRF 26	70	21	9	28.5	34.67	0.549
CRF 27	70	18.75	6.25	26.875	32.51	0.547
CRF 28	65	17.5	17.5	28.5	35.62	0.555
CRF 29	65	21	14	28.75	35.39	0.552
CRF 30	65	22.75	12.25	27.75	35.27	0.560
CRF 31	65	24.5	10.5	28.8	35.16	0.550
CRF 32	65	26.25	8.75	28.375	35.04	0.553

CRF 33	60	20	20	30.05	36.17	0.546
CRF 34	60	24	16	29.5	35.91	0.549
CRF 35	60	26	14	27.625	35.78	0.564
CRF 36	60	28	12	28.625	35.64	0.555
CRF 37	60	30	10	27.875	35.51	0.560

Table 6 Particle packing density for Cement + MK +UFS:

Sr. No.	OPC 53 (gm)	MK	UFS	Vw	Vp	Packing density
CMU 1	95	2.5	2.5	26	32.03	0.552
CMU 2	95	3	2	24.13	32.06	0.571
CMU 3	90	5	5	24.73	32.32	0.567
CMU 4	90	6	4	24.35	32.37	0.571
CMU 5	90	6.5	3.5	23.95	32.40	0.575
CMU 6	90	7	3	25.38	32.42	0.561
CMU 7	90	7.5	2.5	24	32.45	0.575
CMU 8	90	2.5	7.5	23.25	32.19	0.581
CMU 9	90	3	7	23.88	32.22	0.574
CMU10	90	3.5	6.5	23.4	32.24	0.579
CMU11	90	4	6	24.03	32.27	0.573
CMU12	90	2	8	23.4	32.17	0.579
CMU13	85	7.5	7.5	25.6	32.61	0.560
CMU14	85	9	6	25.5	32.68	0.562
CMU15	85	9.75	5.25	25.13	32.72	0.566
CMU16	85	10.5	4.5	26.75	32.76	0.550
CMU17	85	11.25	3.75	24.65	32.80	0.571
CMU18	85	3.75	11.25	23.75	32.42	0.577
CMU19	85	4.5	10.5	24.55	32.46	0.569
CMU20	85	5.25	9.75	23.88	32.49	0.576
CMU21	85	6	9	24.5	32.53	0.570
CMU22	85	3	12	23.5	32.38	0.579
CMU23	80	10	10	26	32.89	0.559
CMU24	80	12	8	25.63	32.99	0.563

CMU25	80	13	7	25.38	33.04	0.566
CMU26	80	14	6	27	33.09	0.551
CMU27	80	15	5	25.38	33.15	0.566
CMU28	80	5	15	25.13	32.64	0.565
CMU29	80	6	14	25.5	32.69	0.562
CMU30	80	7	13	24.75	32.74	0.570
CMU31	80	8	12	25.48	32.79	0.563
CMU32	80	4	16	23.88	32.59	0.577
CMU33	75	12.5	12.5	26.23	33.18	0.559
CMU34	75	15	10	26	33.31	0.562
CMU35	75	16.25	8.75	25.75	33.37	0.564
CMU36	75	10	15	26.2	33.05	0.558
CMU37	75	18.75	6.25	25.33	33.49	0.569
CMU38	75	6.25	18.75	24.4	32.87	0.574
CMU39	75	7.5	17.5	25.53	32.93	0.563
CMU40	75	8.75	16.25	24.88	32.99	0.570
CMU41	75	10	15	25.5	33.05	0.565
CMU42	75	5	20	24.5	32.80	0.572
CMU43	70	15	15	26.63	33.47	0.557
CMU44	70	18	12	26.23	33.62	0.562
CMU45	70	19.5	10.5	25.88	33.69	0.566
CMU46	70	21	9	27.75	33.77	0.549
CMU47	70	22.5	7.5	26.38	33.84	0.562
CMU48	70	7.5	22.5	24.88	33.09	0.571
CMU49	70	9	21	25.63	33.16	0.564
CMU50	70	10.5	19.5	24.85	33.24	0.572
CMU51	70	12	18	25.5	33.32	0.566
CMU52	70	6	24	24.75	33.01	0.572

CMU53	65	17.5	17.5	27.13	33.75	0.554
CMU54	65	21	14	26.5	33.93	0.561
CMU55	65	22.75	12.25	26.25	34.02	0.564
CMU56	65	10.5	24.5	26.75	33.40	0.555
CMU57	65	26.25	8.75	26.68	34.19	0.562
CMU58	65	8.75	26.25	25.38	33.31	0.568
CMU59	65	10.5	24.5	26.25	33.40	0.560
CMU60	65	12.25	22.5	25.5	33.40	0.567
CMU61	65	14	21	26.23	33.58	0.561
CMU62	65	7	28	24.75	33.23	0.573
CMU63	60	20	20	27.5	34.04	0.553
CMU64	60	24	16	27	34.24	0.559
CMU65	60	26	14	26.78	34.34	0.562
CMU66	60	28	12	28.38	34.44	0.548
CMU67	60	30	10	27.25	34.54	0.559
CMU68	60	10	30	26.03	33.54	0.563
CMU69	60	12	28	27	33.64	0.555
CMU70	60	14	26	26.08	33.74	0.564
CMU71	60	16	24	26.75	33.84	0.559
CMU72	60	8	32	25.4	33.44	0.568

Table 7 Particle Packing Density for CUF:

Sr. No.	OPC 53 (gm)	UFS	Fly Ash	Vw	Vp	Packing density
CUF 1	95	2.5	2.5	23.5	32.18	0.578
CUF 2	95	3	2	23.75	32.13	0.575
CUF3	90	5	5	23.25	32.62	0.584
CUF4	90	6	4	23.5	32.51	0.580
CUF5	90	6.25	3.5	23.75	32.37	0.577
CUF6	90	7	3	24	32.40	0.574
CUF7	90	7.5	2.5	24.25	32.35	0.572
CUF8	90	8	2	24.5	32.29	0.569
CUF9	85	7.5	7.5	23.5	33.06	0.585
CUF10	85	9	6	24	32.90	0.578
CUF11	85	9.75	5.25	24.5	32.81	0.573
CUF12	85	10.5	4.5	24.75	32.73	0.569
CUF13	85	11.25	3.75	25	32.65	0.566
CUF14	80	10	10	23.75	33.50	0.585
CUF15	80	12	8	24.5	33.28	0.576
CUF16	80	13	7	25	33.17	0.570
CUF17	80	14	6	25.5	33.06	0.565
CUF18	80	15	5	25.75	32.95	0.561
CUF19	75	12.5	12.5	24	33.94	0.586
CUF21	75	15	10	24.5	33.66	0.579
CUF22	75	16.25	8.75	25	33.52	0.573
CUF23	75	17.5	7.5	25.5	33.38	0.567
CUF24	75	20	5	25.8	33.11	0.562
CUF25	70	15	15	25	34.38	0.579
CUF26	70	18	12	25.25	34.05	0.574
CUF27	70	19.5	10.5	25.5	33.88	0.571
CUF28	70	21	9	26.2	33.71	0.563
CUF29	70	22.5	7.5	26.5	33.55	0.559
CUF30	65	17.5	17.5	25.5	34.82	0.577
CUF31	65	21	14	25	34.43	0.579
CUF32	65	22.75	12.25	25.5	34.23	0.573
CUF33	60	20	20	26	35.26	0.576
CUF34	60	24	16	26.25	34.81	0.570
CUF35	60	26	14	26.5	34.59	0.566

Table 8 Particle Packing Density for CMF:

Sr. No.	OPC 53 (gm)	MK	Fly Ash	Vw	Vp	Packing density
CMF1	95	2.5	2.5	24.5	32.31	0.569
CMF2	95	3	2	25	32.28	0.564
CMF3	90	5	5	25.5	32.88	0.563
CMF4	90	6	4	25.75	32.70	0.559
CMF5	90	6.25	3.5	26	32.68	0.557
CMF6	90	7	3	26.5	32.75	0.553
CMF7	90	8	2	26.75	32.69	0.550
CMF8	85	7.5	7.5	26	33.44	0.563
CMF9	85	9	6	26.25	33.35	0.560
CMF10	85	9.75	5.25	26.5	33.30	0.557
CMF11	85	10.5	4.5	26.5	33.26	0.557
CMF12	85	11.25	3.75	26.75	33.21	0.554
CMF13	80	10	10	26.5	34.01	0.562
CMF14	80	12	8	26.75	33.88	0.559
CMF15	80	13	7	27	33.82	0.556
CMF16	80	14	6	27.5	33.76	0.551
CMF17	80	15	5	28	33.70	0.546
CMF18	75	12.5	12.5	27.5	34.57	0.557
CMF19	75	15	10	28	34.42	0.551
CMF20	75	16.25	8.75	28.25	34.34	0.549
CMF21	75	17.5	7.5	28.5	34.27	0.546
CMF22	75	20	5	28.75	34.11	0.543
CMF23	70	15	15	28.5	35.13	0.552
CMF24	70	18	12	28.75	34.95	0.549
CMF25	70	19.5	10.5	29	34.86	0.546
CMF26	70	21	9	29.25	34.77	0.543
CMF27	70	18.75	11.25	29.5	34.91	0.542

Table 9 Particle Packing Density for CRU:

Sr. No.	OPC 53 (gm)	RHA	UFS	Vw	Vp	Packing density
CRU1	95	2.5	2.5	25	32.02	0.562
CRU2	95	3	2	25.25	32.00	0.559
CRU3	90	5	5	24.25	32.30	0.571
CRU4	90	6	4	24.75	32.25	0.566
CRU5	90	6.25	3.5	25	32.14	0.562
CRU6	90	7	3	25.25	32.20	0.561
CRU7	90	8	2	25.5	32.16	0.558
CRU8	85	7.5	7.5	24.5	32.57	0.571
CRU9	85	9	6	25.25	32.50	0.563
CRU10	85	9.75	5.25	25.5	32.47	0.560
CRU11	85	10.5	4.5	25.75	32.43	0.557
CRU12	85	11.25	3.75	26	32.40	0.555
CRU13	80	10	10	25	32.85	0.568
CRU14	80	12	8	25.75	32.75	0.560
CRU15	80	13	7	26	32.71	0.557
CRU16	80	14	6	26.25	32.66	0.554
CRU17	80	15	5	26.5	32.62	0.552
CRU18	75	12.5	12.5	26.5	33.12	0.556
CRU19	75	15	10	26	33.01	0.559
CRU20	75	16.25	8.75	26.75	32.95	0.552
CRU21	75	17.5	7.5	27	32.89	0.549
CRU22	75	20	5	27.25	32.78	0.546
CRU23	70	15	15	26.5	33.40	0.558
CRU24	70	18	12	26.75	33.26	0.554
CRU25	70	18.75	6.25	27	31.25	0.536
CRU26	70	19.5	10.5	27.25	33.19	0.549
CRU27	70	21	9	27.5	33.12	0.546
CRU28	65	17.5	17.5	26.75	33.67	0.557
CRU29	65	21	14	27	33.51	0.554
CRU30	65	22.75	12.25	27.5	33.43	0.549
CRU31	65	24.5	10.5	27.75	33.35	0.546
CRU32	65	26.25	8.75	28	33.27	0.543
CRU33	60	20	20	27.5	33.95	0.552
CRU34	60	24	16	27.8	33.76	0.548

CRU35	60	26	14	28	33.67	0.546
CRU36	60	28	12	28.5	33.58	0.541
CRU37	60	30	10	28.75	33.49	0.538

Table 9: Particle Packing Density for Cement + RHA+MK:

Sr. No.	OPC 53 (gm)	MK	RHA	Vw	Vp	Packing density
CMR1	95	2.5	2.5	24.5	32.15	0.567
CMR2	95	3	2	25	32.14	0.563
CMR3	90	5	5	25.5	32.55	0.561
CMR4	90	6	4	25.8	32.54	0.558
CMR5	90	6.25	3.5	26	32.44	0.555
CMR6	90	7	3	26.25	32.54	0.553
CMR7	90	8	2	26.5	32.53	0.551
CMR8	85	7.5	7.5	27	32.95	0.550
CMR9	85	9	6	27.3	32.94	0.547
CMR10	85	9.75	5.25	27.75	32.94	0.543
CMR11	85	10.5	4.5	28.25	32.93	0.538
CMR12	85	11.25	3.75	28.75	32.93	0.534
CMR13	80	10	10	27.25	33.35	0.550
CMR14	80	12	8	27.75	33.34	0.546
CMR15	80	13	7	28	33.34	0.543
CMR16	80	14	6	28.5	33.33	0.539
CMR17	80	15	5	29	33.33	0.535
CMR18	75	12.5	12.5	27.75	33.75	0.549
CMR19	75	15	10	28	33.74	0.546
CMR20	75	16.25	8.75	28.75	33.73	0.540
CMR21	75	17.5	7.5	29	33.73	0.538
CMR22	75	20	5	29.5	33.71	0.533
CMR23	70	17.5	17.5	29.8	36.14	0.548
CMR24	70	21	14	30	36.12	0.546
CMR25	70	22.75	12.25	30.6	36.11	0.541
CMR26	70	2.5	10.5	31	27.41	0.469
CMR27	70	26.25	8.75	31.5	36.18	0.535

3.6. Packing density variation with Cement percentage:

As shown in previous section various combinations were tried for achieving maximum particle packing with the help of 'Puntke Method'. Here the pattern of the graphs is shown for different combinations at different cement percentages.

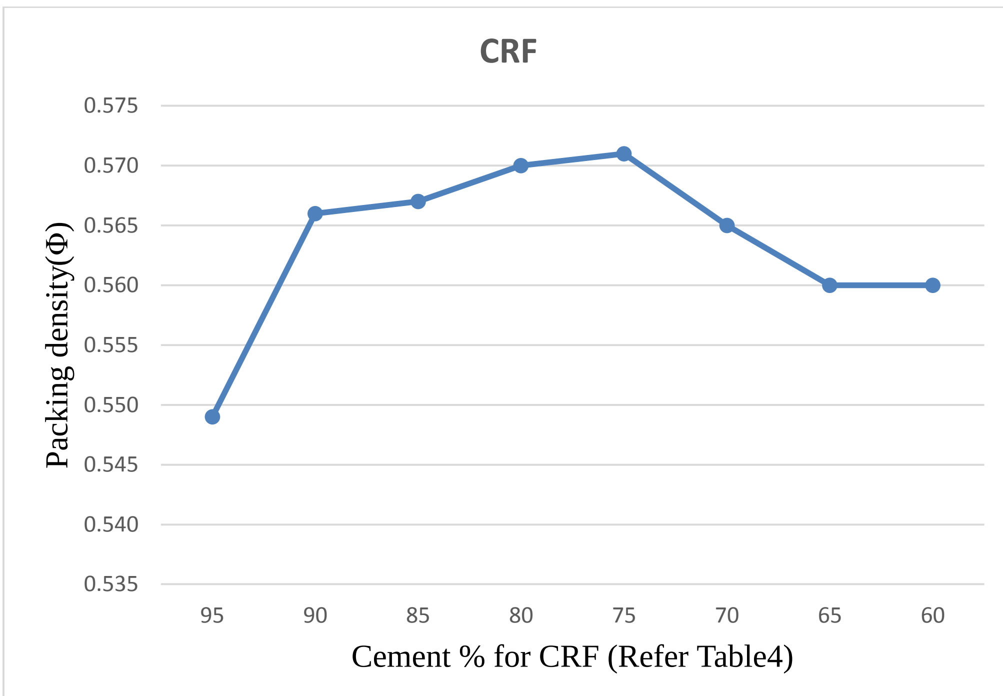


Figure 14 (Plot of packing density v/s cement percentage for CRF)

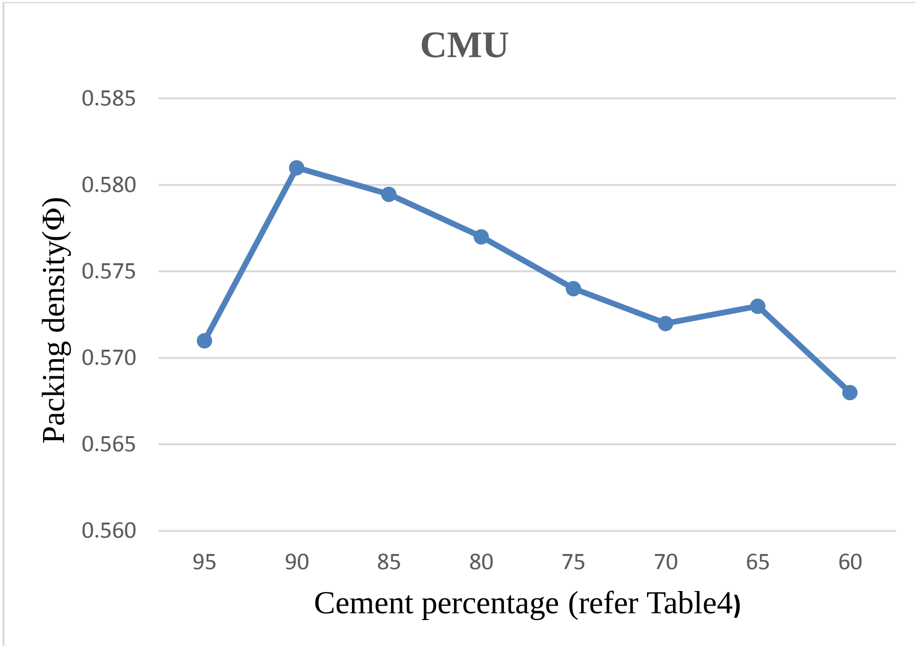


Figure 15 (Plot of packing density v/s cement percentage for CMU trials)

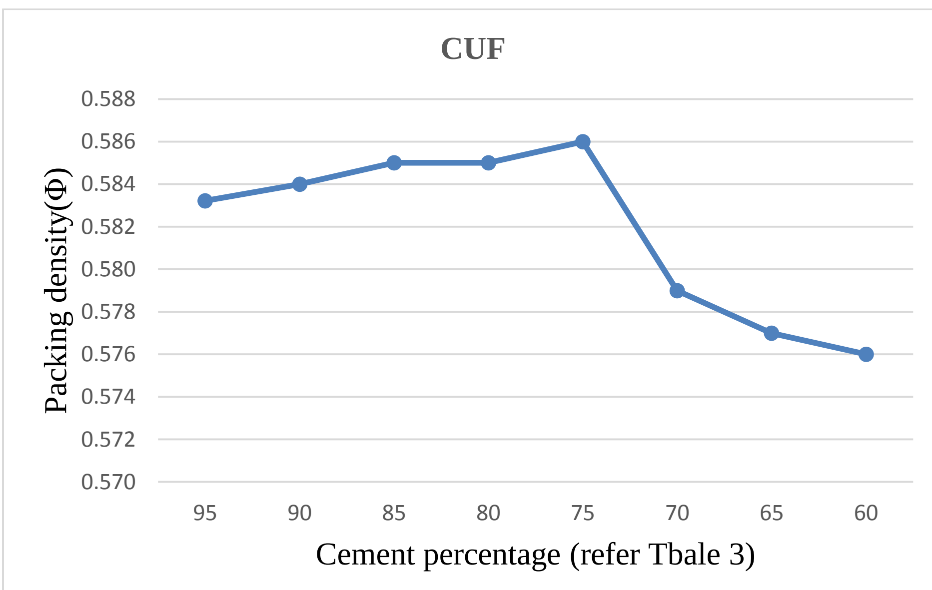


Figure 16 Plot of packing density v/s cement percentage for CUF trials)

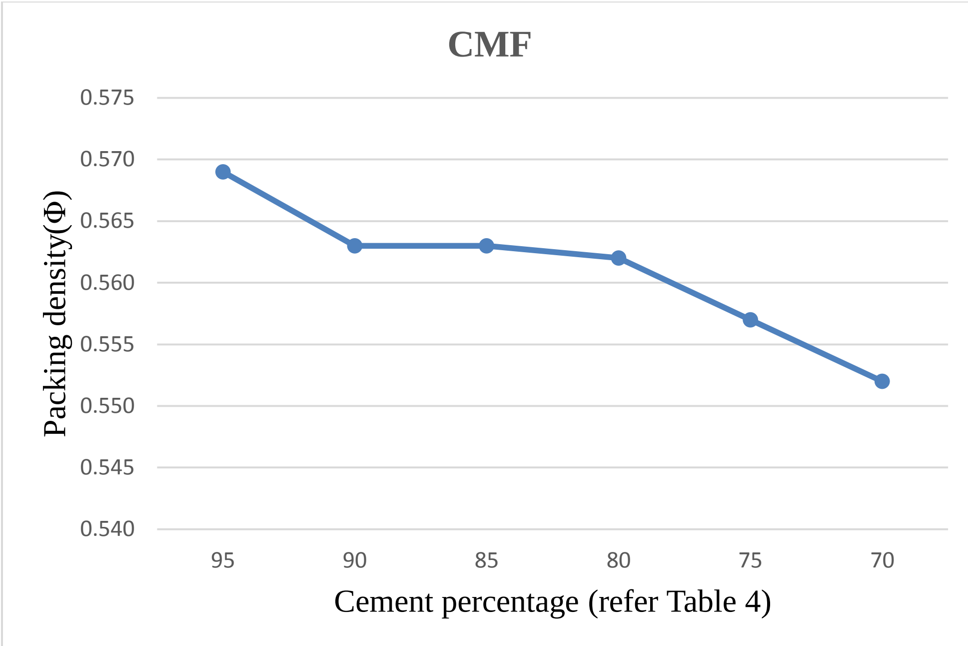


Figure 17 (Plot of Packing density v/s Cement percentage for CMF)

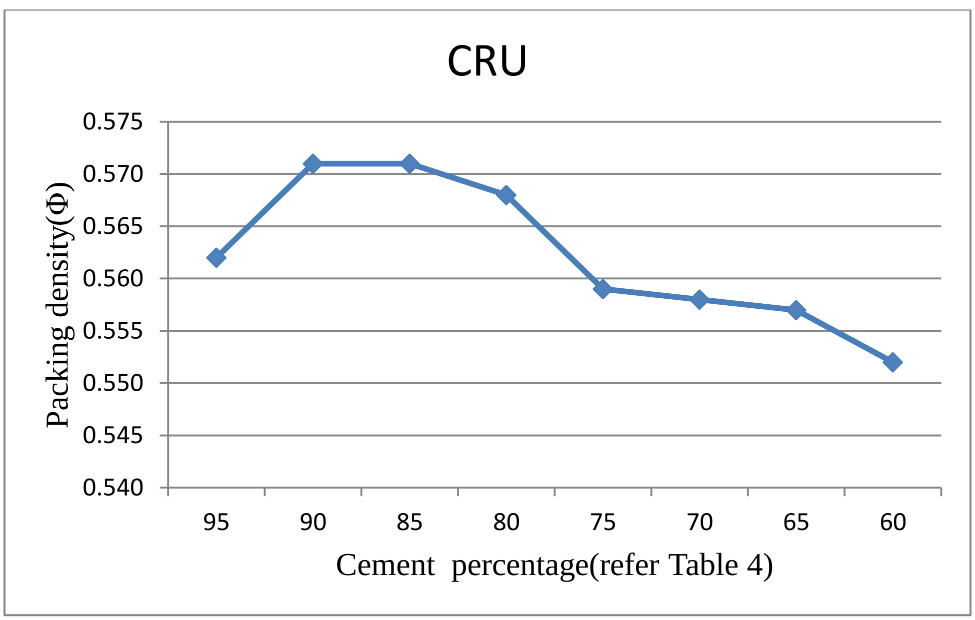


Figure 18 (Plot of Packing density v/s cement percentage for CUR)

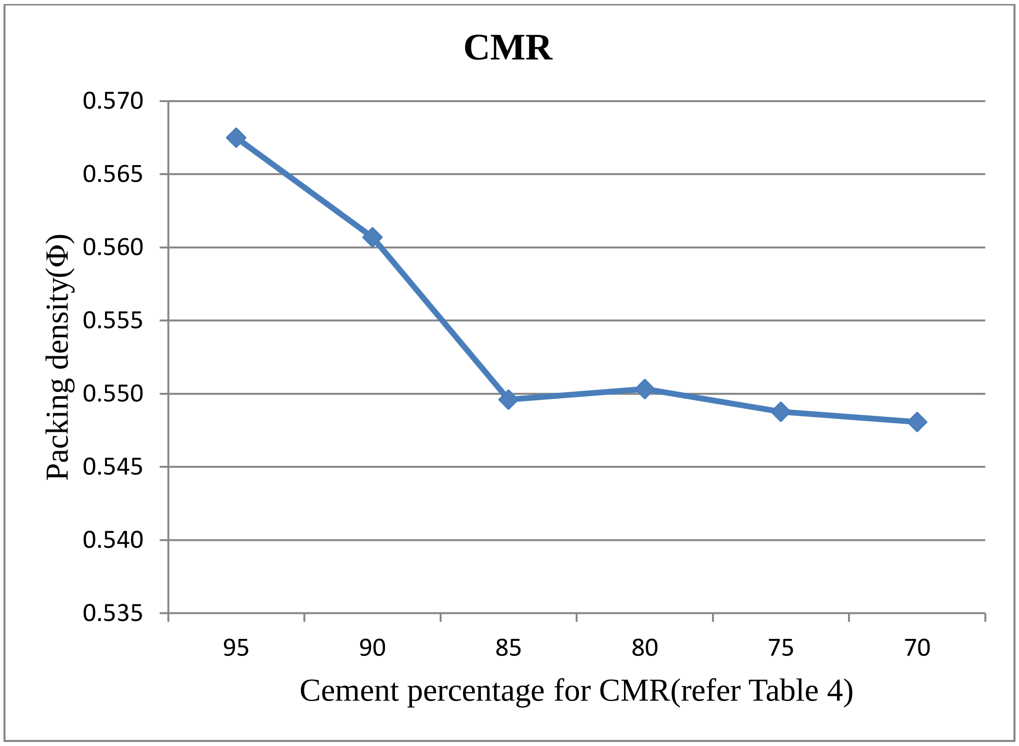


Figure 19 (Plot of packing density v/s cement percentage for CMR)

3.7. Discussion on packing density:

After trying 234 combinations it was observed that packing density varied from 0.538 to 0.586. Maximum particle packing density of 0.586 was obtained in the mix combination of OPC53 + FA+ UFS. It was seen that as the fine content increased, packing density increased upto certain percentage and then it decreased gradually. It was due to the increased surface area and as a result of that water demand increased and therefore packing density decreased. The mix combinations which gave maximum particle packing density in different combinations are:

- Cement (75%) + RHA (16.25%) + FA (8.75%) gives packing density of 0.571 in CRF trials
- Cement (90 %) + MK (2.5 %) + UFS (75%) gives maximum packing density of 0.581 in CMU trials

- Cement (75%) + FA (12.5%) + UFS (12.5 %) gives maximum packing density of 0.586 in CFU trials
- Cement (95%) + FA (2.5%) + MK (2.5 %) gives maximum packing density of 0.569 in CFM trials
- Cement (85 %) + RHA (7.5 %) + UFS (7.5%) gives maximum packing density of 0.571 in CRU trials
- Cement (95%) + MK (2.5%) +RHA (2.5%) give maximum packing density of 0.567 in CRM trials.

Among all the combinations following five were selected for optimization and cube casting so that effect of all mineral admixtures on the compressive strength can be studied.

- CUF20: Cement (75%) + UFS (12.5%) + FA (12.5%)
- CUF15: Cement (80%) + UFS (10%) + FA (10%)
- CRF20: Cement (75%) + RHA (16.25%) + FA (8.75%)
- CRU8: Cement (85%) +UFS (7.5%) + RHA (7.5%)
- CMU8: Cement (90%) + MK (2.5%) + UFS (7.5%)

3.8. Optimization:

The top five trials which gave maximum packing density were optimized by third generation superplasticizer (Polycarboxylate ether) to obtain minimum w/b ratio and optimum super plasticizer dosage. Mixing was done with planetary mixer (Hobart Mixer). Mixing and Marsh Cone test was done with following procedure:

- Materials were weighted and pour in the container of the mixer, and then dry mixing was done on first gear for 2 minutes.
- Then 70 % of water and 70 % of super plasticizer were added gradually for 2 minutes on first and second gear.
- Finally the remaining water and super plasticizer were added on second or third gear whichever was suitable for 2 minutes. Then Marsh cone test was carried out with that paste.

- Poured the paste in marsh cone apparatus.
- This paste was made to flow through the marsh cone and time was noted with the help of stop watch.
- This procedure was repeated for different dosages of super plasticizer from 0.75% to 1.5 % in step of 0.05%.
- The super plasticizer dosage which takes least time for flow was considered as optimum dosage.

Figure 20 Planetary mixer

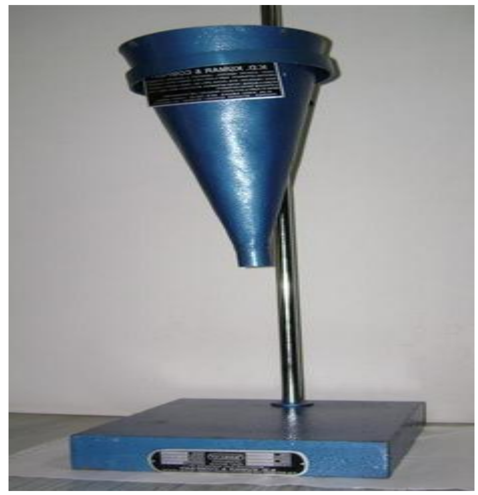


Figure 21 Marsh Cone apparatus

3.8.1. Optimization Of Different Mixes:

Top five combinations which have maximum packing density were optimized with third class super plasticizer and results are listed in Table 10 to Table 18 respectively.

Table 10 Optimization of CUF20: Cement (75%) + UFS (12.5%) + FA (12.5%):

Total Cementitious material (g)	cement (g)	Fly Ash (gm)	UFS(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content (g)	marsh cone test (sec)
1466.6	1100	183.3	183.3	263.9	0.75	0.27	10.99	3.95	256.94	180
1466.6	1100	183.3	183.3	263.9	0.8	0.288	11.73	4.22	256.47	181
1466.6	1100	183.3	183.3	263.9	0.85	0.306	12.46	4.48	256.00	182
1466.6	1100	183.3	183.3	263.9	0.9	0.324	13.19	4.75	255.54	189
1466.6	1100	183.3	183.3	263.9	0.95	0.342	13.93	5.01	255.07	215
1466.6	1100	183.3	183.3	263.9	1	0.36	14.66	5.27	254.60	212

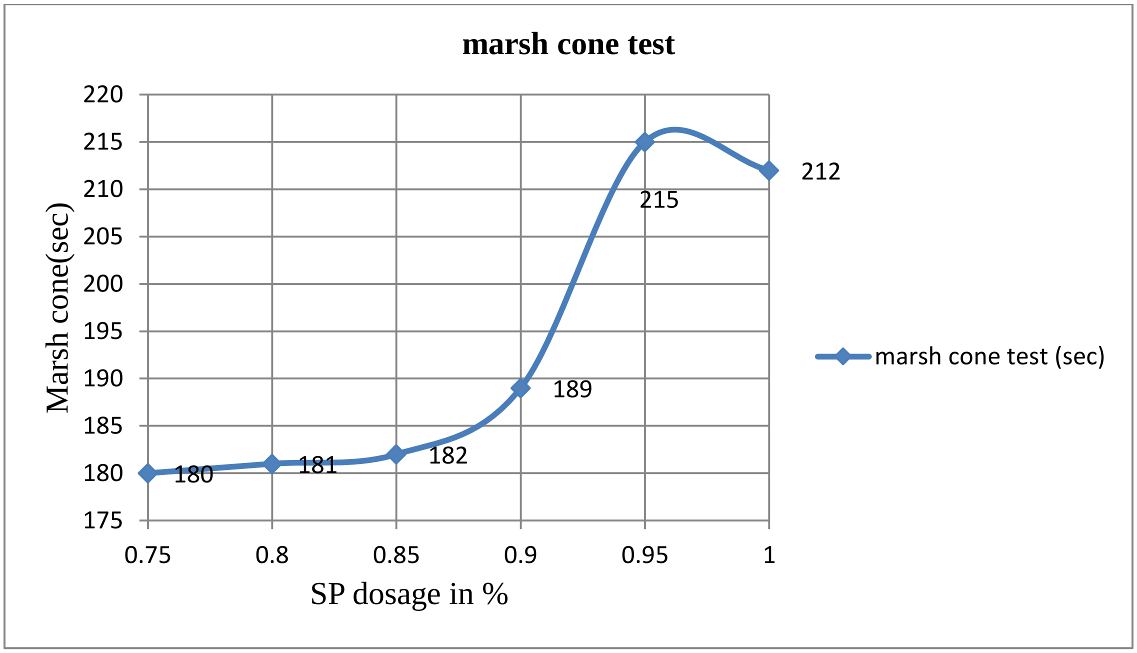


Figure 22 Marsh cone test for CUF20

Table 11 Optimization of CUF15 : Cement(80%) + UFS(10%) + FA(10%):

Total Cementitious material (g)	cement (g)	Fly Ash (gm)	UFS(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content (g)	marsh cone test (sec)
1375	1100	137.5	137.5	261.2	0.75	0.27	10.31	3.71	254.65	185
1375	1100	137.5	137.5	261.2	0.8	0.288	11	3.96	254.21	180
1375	1100	137.5	137.5	261.2	0.85	0.306	11.68	4.20	253.77	187
1375	1100	137.5	137.5	261.2	0.9	0.324	12.37	4.45	253.33	194
1375	1100	137.5	137.5	261.2	0.95	0.342	13.06	4.70	252.89	215
1375	1100	137.5	137.5	261.2	1	0.36	13.75	4.95	252.45	212

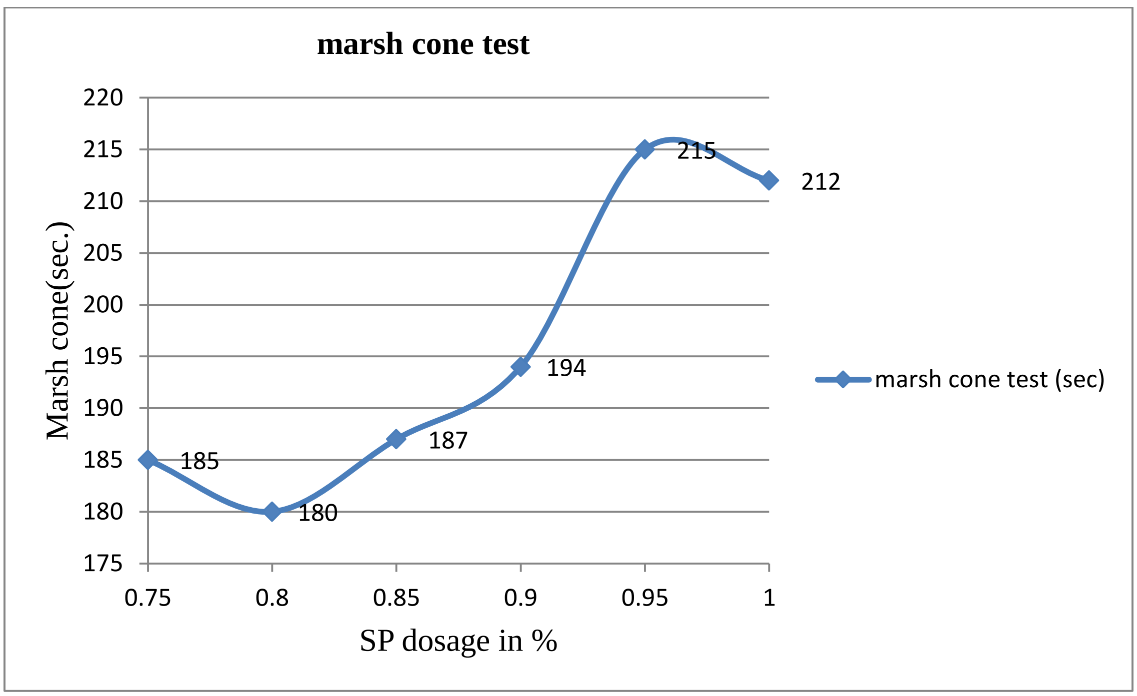


Figure 23 Marsh cone test for CUF15

Table 12 Optimization of CRF20 : Cement(75%) + Rice Husk Ash(16.25%) +FA(8.75%):

Total Cementitious material (g)	cement (g)	RHA(gm)	Fly Ash(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content(g)	marsh cone test (sec)
1459.33	1100	238.33	121	277.27	0.75	0.27	10.94	3.94	270.26	200
1459.33	1100	238.33	121	277.27	0.8	0.288	11.67	4.20	269.80	202
1459.33	1100	238.33	121	277.27	0.85	0.306	12.40	4.46	269.33	198
1459.33	1100	238.33	121	277.27	0.9	0.324	13.13	4.72	268.86	197
1459.33	1100	238.33	121	277.27	0.95	0.342	13.86	4.99	268.40	196
1459.33	1100	238.33	121	277.27	1	0.36	14.59	5.25	269.27	215
1459.33	1100	238.33	121	277.27	1.25	0.45	18.24	6.56	269.27	195

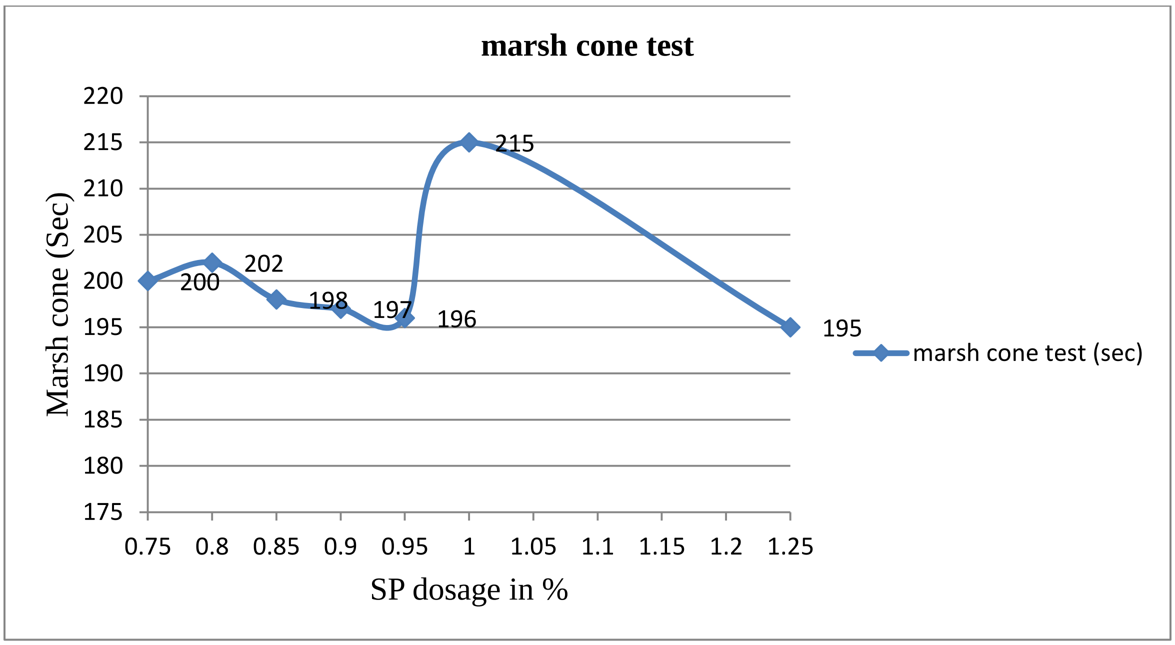


Figure 24 Marsh cone test for CRF20

Table 13 Optimization of CRU8 : Cement(85%) + RHA (7.5%) + UFS(7.5%):

Total Cementitious material (g)	cement (g)	RHA(gm)	UFS(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content(g)	marsh cone test (sec)
1294.118	1100	97.05	97.05	245.88	0.75	0.27	9.70	3.49	239.67	187
1294.118	1100	97.05	97.05	245.88	0.8	0.288	10.35	3.72	239.25	198
1294.118	1100	97.05	97.05	245.88	0.85	0.306	11	3.96	238.84	212
1294.118	1100	97.058	97.05	245.88	0.9	0.324	11.64	4.19	238.42	191
1294.118	1100	97.05	97.05	245.88	0.95	0.342	12.29	4.42	238.01	194
1294.118	1100	97.058	97.05	245.88	1	0.36	12.94	4.65	269.27	185

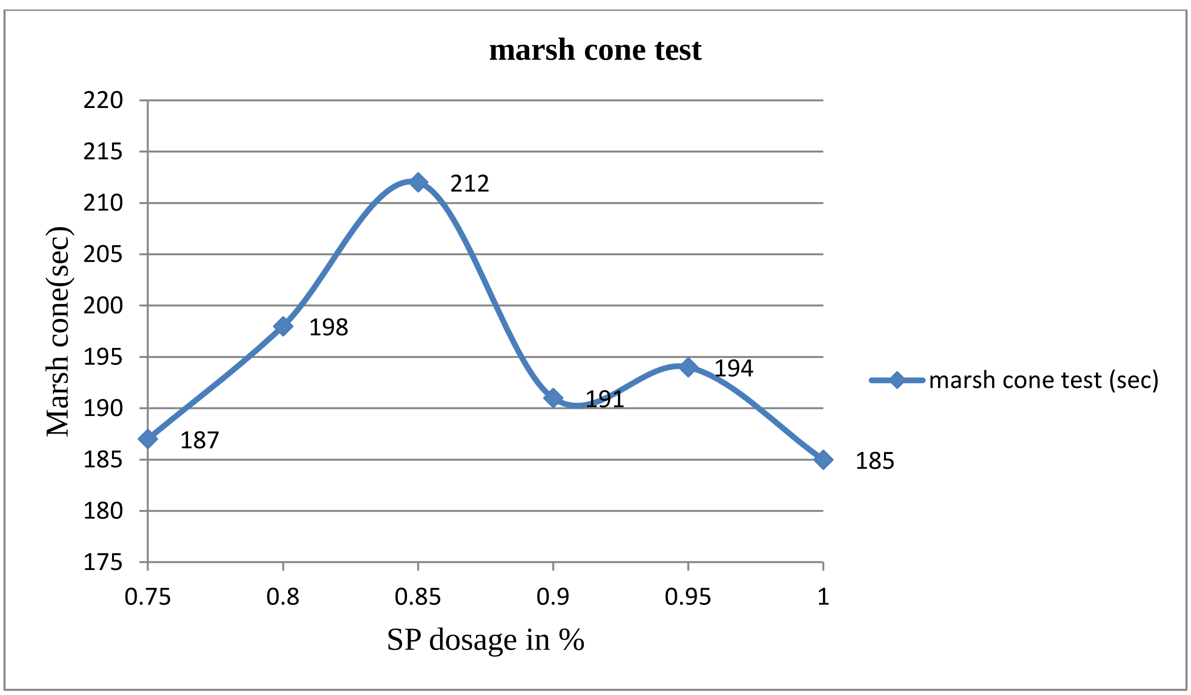


Figure 25 Marsh cone test for CRU8

Table 14 Optimization of CMU8 : Cement(90%) + MK(2.5% + UFS(7.5%):

Total Cementitious material (g)	cement (g)	Meta.(gm)	UFS(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content(g)	marsh cone test (sec)
1222.22	1100	30.6	91.7	232.22	0.75	0.27	9.2	3.29	226.4	184
1222.22	1100	30.6	91.7	232.22	0.8	0.288	9.8	3.51	226.0	190
1222.22	1100	30.6	91.7	232.22	0.85	0.306	10.4	3.73	225.6	196
1222.22	1100	30.6	91.7	232.22	0.9	0.324	11.0	3.95	225.2	192
1222.22	1100	30.6	91.7	232.22	0.95	0.342	11.6	4.17	224.8	183
1222.22	1100	30.6	91.7	232.22	1	0.36	12.2	4.39	224.4	212

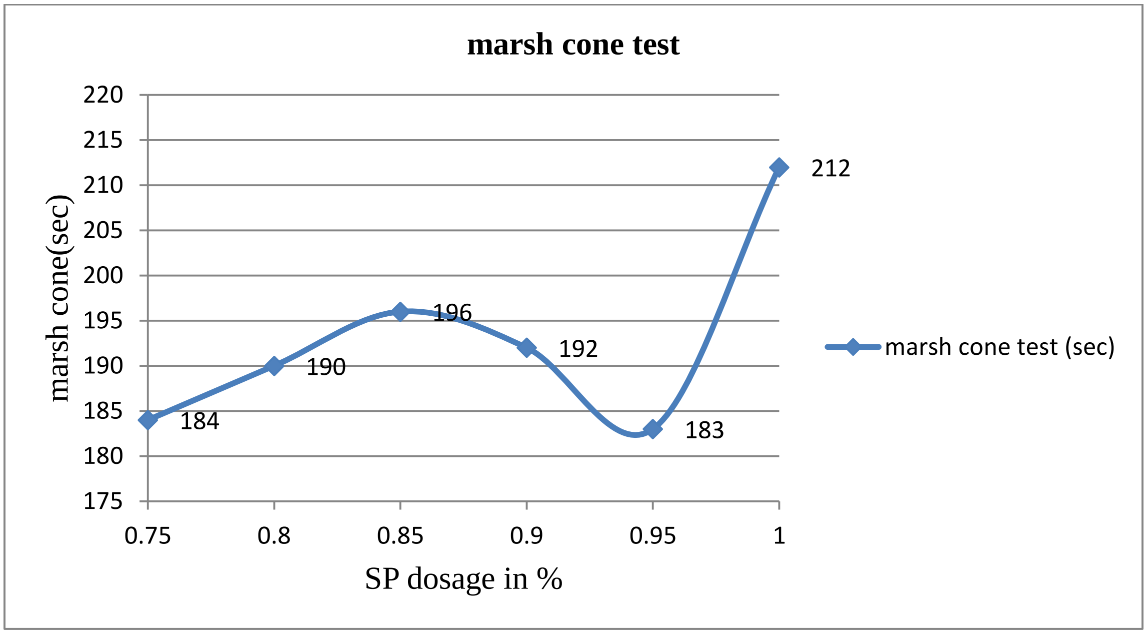


Figure 26 Marsh cone test for CMU8

Table 15 Optimization of CUF20 : Cement(75%) + UFS(12.5% + FA(12.5%)$_2$:

Total Cementitious material (g)	cement (g)	Fly Ash (gm)	UFS(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content(g)	marsh cone test (sec)
1200	900	150	150	228	0.75	0.27	9	3.24	222.24	185
1200	900	150	150	228	0.8	0.288	9.6	3.45	221.85	181
1200	900	150	150	228	0.85	0.306	10.2	3.67	221.47	180
1200	900	150	150	228	0.9	0.324	10.8	3.88	221.08	178
1200	900	150	150	228	0.95	0.342	11.4	4.10	220.70	187
1200	900	150	150	228	1	0.36	12	4.32	220.32	190

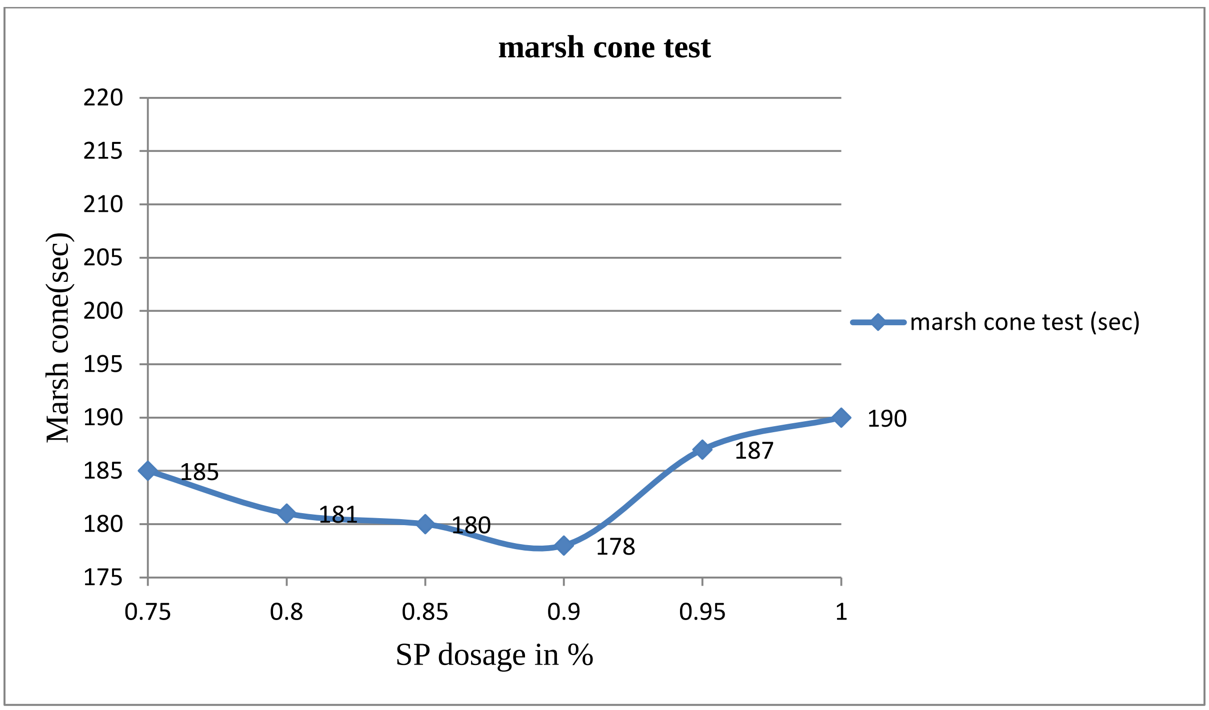


Figure 27 Marsh cone test for CUF20$_2$

Table 16 Optimization of CUF15 : Cement(85%) + UFS(7.5% + FA(7.5%)[1]:

Total Cementitious material (g)	cement (g)	Fly Ash (gm)	UFS(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content(g)	marsh cone test (sec)
1125	900	112.5	112.5	213.75	0.75	0.27	8.43	3.0375	208.35	185
1125	900	112.5	112.5	213.75	0.8	0.288	9	3.24	207.99	183
1125	900	112.5	112.5	213.75	0.85	0.306	9.56	3.4425	207.63	183
1125	900	112.5	112.5	213.75	0.9	0.324	10.12	3.645	207.27	185
1125	900	112.5	112.5	213.75	0.95	0.342	10.68	3.8475	206.91	182
1125	900	112.5	112.5	213.75	1	0.36	11.25	4.05	206.55	190

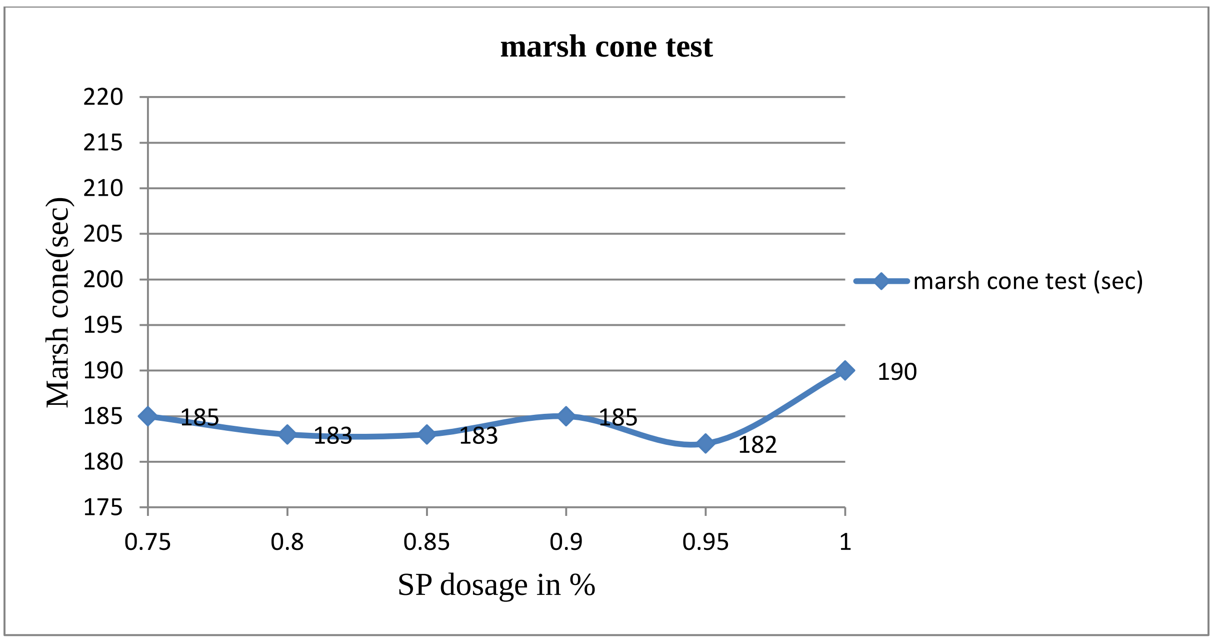


Figure 28 Marsh cone test for CUF15[2]

Table 17 Optimization of CMU8 : Cement(85%) + RHA(7.5% + FA(7.5%)$_3$:

Total Cementitious material (g)	cement (g)	RHA(gm)	FA(gm)	water(g)	SP (%)	solid content of SP in %	SP in ml	Solid content BWOC	modified water content(g)	marsh cone test (sec)
1194	900	195	99	226.86	0.75	0.27	8.955	3.22	221.12	197
1194	900	195	99	226.86	0.8	0.288	9.552	3.43	220.74	195
1194	900	195	99	226.86	0.85	0.306	10.149	3.65	220.36	212
1194	900	195	99	226.86	0.9	0.324	10.746	3.86	219.98	191
1194	900	195	99	226.86	0.95	0.342	11.343	4.08	219.60	194
1194	900	195	99	226.86	1	0.36	11.94	4.29	219.21	205
1194	900	195	99	226.86	1.25	0.45	14.925	5.37	217.30	192
1194	900	195	99	226.86	1.5	0.54	17.91	6.44	215.39	190

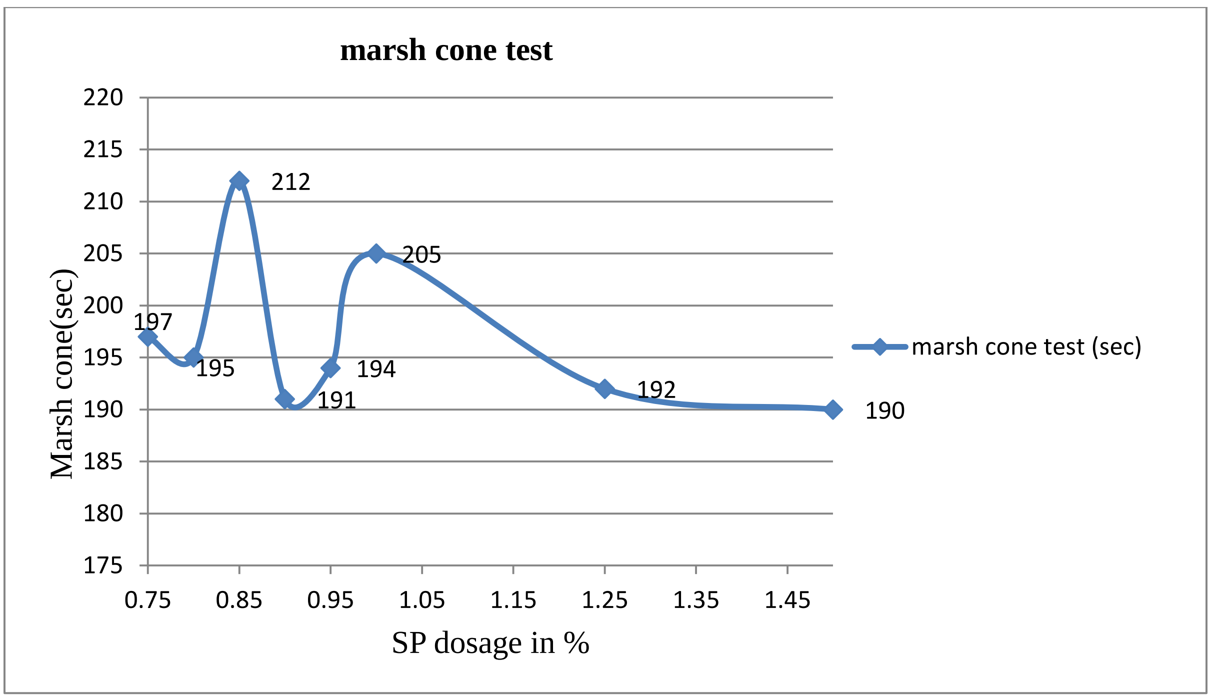


Figure 29 Marsh cone test for CRF8$_2$

From the Tables optimum dosage of superplasticizer when cement= 1100kg/m^3gm are:

- 0.75 % for CUF 20 at 0.18 w/b ratio
- 0.8% for CUF15 at 0.19% w/b ratio
- 1.25% for CRF20 at 0.19%
- 1 % for CRU8 at 0.19%
- 0.95% for CMU8 at 0.19%

  When cement content is 900kg/m^3
- 0.9 % for CUF 20 at 0.19 w/c ratio
- 0.95% for CUF15 at 0.19%
- 1.5% for CMU8 at 0.19%

3.9 .Test setup for compressive strength:

For compressive strength check cubes (7.06cm * 7.06cm) were casted for the combinations shown in section 3.7. Before the casting of the cubes moulds were cleaned and oiled properly. Moulds were properly tightened accurately. Procedure followed in the casting of cubes was:

- Cement and two other mineral admixtures were weighted on weighing machine.
- Then dry mixing was done in Planetary mixer (Hobart) for 2 minutes
- After that 70 % of calculated water and superplasticizer was added in the mix and was mixed for 2 minutes
- Remaining 30 % of water and superplasticizer was then added and mixing was done for 2 minutes.
- Then three moulds were filled for each combination with the paste and compaction was done on vibration table.
- Cubes were kept in water basin for curing for 28 days for curing. Total 24 cubes were casted.
- After 28 days of normal curing cubes were demoulded and after surface drying, were tested for compressive strength.

- Cubes were tested for compressive strength in Universal testing machine (UTM) of capacity 2000KN and loading rate of UTM is 1.2KN/mm_2/min.

3.9.1 Mix design for casting of cubes:

Casting calculations are based on total volume of concrete for three cubes which was 0.0010290 m^3(for $1m^3$). Then according to the percentages of other materials their values were calculated. Also Superplasticizer's dosage was decided according to the values obtained from marsh cone test. Water absorption corrections for quartz sand were 0.004 and 0.01 for manufactured sand. Casting calculation are shown here in Tables when cement contents 1100kg/m^3 and 900kg/m^3 respectively.

Table 18 Casting calculations for CUF20 (75 % OPC53 + 12.5% UFS + 12.5% FA), w/b = 0.18, Aggregate Vol. = 0.24 m^3

TCM	Cement	UFS	FA	QS (50%)	MS (50%)	QP (10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1459.33	1100.00	183.33	183.33	251.76	279.74	63.36	11	3.96	260.76
Weight(gm)									
1660.12	1245.09	207.52	207.52	284.94	316.63	71.72	12.45		295.16

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Table 19 Casting calculations for CUF15 (80 % OPC53 + 10% UFS + 10% FA), w/b = 0.19, Aggregate Vol. = 0.28 m^3

TCM	Cement	FA	UFS	QS (50%)	MS (50%)	QP (10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1294.12	1100.00	137.5	137.5	293.55	326.16	73.87	11	3.96	258.65
Weight(gm)									
1556.36	1245.09	155.64	155.64	332.26	369.18	83.62	12.45		292.76

.**Table 20** Casting calculations for CRF20 (75 % OPC53 + 16.25% RHA + 8.75% FA), w/b = 0.19, Aggregate Vol. = 0.22 m^3

TCM	Cement	RHA	FA	QS(50%)	MS(50%)	QP(10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1459.33	1100.0	238.3	121.00	233.73	259.70	58.82	18.24	6.57	269.13
Weight(gm)									
1651.82	1245.0	269.7	136.96	264.56	293.95	66.58	20.65		304.63

Table 21 Casting calculations for CRU8 (85% OPC53 + 7.5% RHA +7.5% UFS), w/b = 0.19, Aggregate Vol. = 0.33 m^3 w/b = 0.19

TCM	Cement	RHA	UFS	QS(50%)	MS(50%)	QP(10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1294.12	1100.00	97.06	97.06	344.03	382.26	86.58	13.59	4.89	242.38
Weight(gm)									
1464.48	1245.09	109.86	109.86	389.41	432.68	98	15.38		273.36

Table 22 Casting calculations for CMU8 (90% OPC53 + 2.5% MK +7.5% UFS), w/b = 0.19, Aggregate Vol. = 0.37 m^3

TCM	Cement	MK	UFS	QS(50%)	MS(50%)	QP(10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1222.22	1100.00	30.56	91.67	392.64	436.27	98.81	16.61	4.18	230.72
Weight(gm)									
1383.43	1245.09	34.59	103.76	443.43	493.82	11.85	13.14		261.16

Table 23 Casting calculations for CUF20 (75%OPC53 + 12.5% UFS +12.5% FA), w/b = 0.19, Aggregate Vol. = 0.37 m^3

TCM	Cement	FA	UFS	QS(50%)	MS(50%)	QP(10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1200.00	900.00	150.00	150.00	384.81	427.56	96.84	10.80	3.89	226.90
Weight(gm)									
1358.28	1018.71	169.79	169.79	435.56	483.96	109.61	12.22		256.83

Table 24 Casting calculations for CUF15 (80%OPC53 + 10% UFS +10% FA), w/b = 0.19, Aggregate Vol. = 0.41 m^3

TCM	Cement	FA	UFS	QS (50%)	MS(50%)	QP(10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1125.00	900.00	112.50	112.50	431.62	479.58	108.62	10.97	3.95	213.25
Weight(gm)									
1273.39	1018.71	127.34	127.34	488.56	542.84	122.95	12.42		241.381

Table 25 Casting calculations for CRF20 (75%OPC53 + 16.25% RHA +8.75% FA), w/b = 0.19, Aggregate Vol. = 0.36 m^3

TCM	Cement	RHA	FA	QS(50%)	MS(50%)	QP(10%)	SP	BWOC	corrected water
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
1194.00	1100.00	195.00	99.00	382.69	425.21	96.31	17.91	6.45	221.18
Weight(gm)									
1351.49	1018.71	220.72	112.06	433.16	481.92	109.01	20.27		250.35

Figure 30 Casting of cubes

3.9.2 Curing of cubes:

Curing plays an important and prominent role in the development of microstructure and strength in concrete. It increases the hydration rate, controls crack development and increases durability in concrete. Therefore after the demoulding of the cubes (after 24 hours), cubes were placed in water basin for 28 days at normal room temperature.

Figure 31 Curing of cubes$_1$

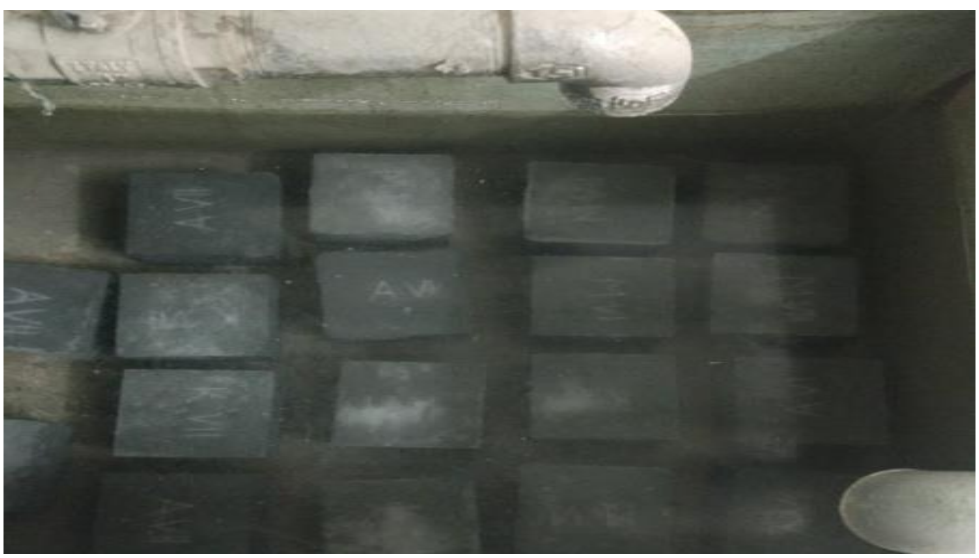

Figure 32 Curing of cubes$_2$

Chapter 4. Results and Discussions

4.1. Testing of the cubes:

Compressive strength basically is a compressive stress concrete can withstand. After 28 days of normal cold water curing, cubes were tested for compressive strength in Universal Testing Machine (UTM) of capacity 2000KN and loading rate is 1.2KN/mm^2/min. Dimension of the cubes were noticed. As the dimensions changed a little bit due to the imperfection in the moulds, therefore dimensions of the two faces were recorded and average of those two dimensions was taken as the cross section of the respective cube.

Figure 33 Testing of cubes in UTM

4.2 Results:

Table 26 Compressive strength results for ternary combinations when cement = 1100Kg/m^3:

Sample name	Area(top) mm^2	Area (bottom) mm^2	Area (avg.) mm^2	Weight (gm)	Load (KN)	Stress (MPa)	Avg. Stresses(MPa)
CUF20	5184	5112	51.48	799.2	423.1	82.18	77.0233
	5041	5005.5	50.232	769	390	77.63	
	5112	5147.5	51.29	783.3	365.5	71.26	
CUF15	5112.25	5148	5130.125	809.7	378.5	73.779	76.989
	5219.5	5040	5129.75	812	388.1	75.65	
	5148	5183	5165.5	809.5	421.2	81.54	
CRF20	4935	5148	5041.5	758.7	365.2	72.43	74.671
	5112	5112.25	5112.125	771.8	395	77.267	
	5076.5	5112.25	5094.375	777.2	378.6	74.317	
CRF8	5041	5184	5112.5	807.9	433.4	84.772	
	5112	5112	5112	822.3	416.9	81.553	
	5041	5076.5	5058.75	827.4	378.4	74.801	80.375
CMU8	4935	5112.25	5023.625	814	422.7	84.142	
	5184	5148	5166	851	430.8	83.391	
	5076.5	5112	5094.25	813.5	441.3	86.627	84.72

Maximum compressive strength = 84.72Mpa in CMU8 (90% cement + 2.5% MK + 2.5% UFS)

Table 27 Compressive strength results for ternary combinations when cement = 900kg/m^3

Sample name	Area(top) mm^2	Area(bottom) mm^2	Area(avg.) mm^2	Weight (gm)	Load (KN)	Stress (MPa)	average stresses (MPa)
CUF20	5076.5	5076.5	5076.5	825.5	431.3	84.960	83.147
	5076.5	5076.5	5076.5	814	418.8	82.497	
	5184	5076.5	5130.25	814.5	420.6	81.984	
CUF15	5040.75	5112	5076.375	817	463.5	91.305	90.755
	5148	5148	5148	828	471	91.491	
	5076.5	5040.75	5058.625	813.5	452.6	89.470	
CRF20	5076.5	5148	5112.25	809	398.6	77.969	76.104
	5005	5076.5	5040.75	805.5	387.3	76.833	
	5291	5147.5	5254.75	820.5	378.4	73.511	

Due to restriction of time only these 24 cubes were casted and maximum compressive strength of 90.755Mpa was obtained in combination CUF15 on 15 % replacement of cement with UFS and FA.

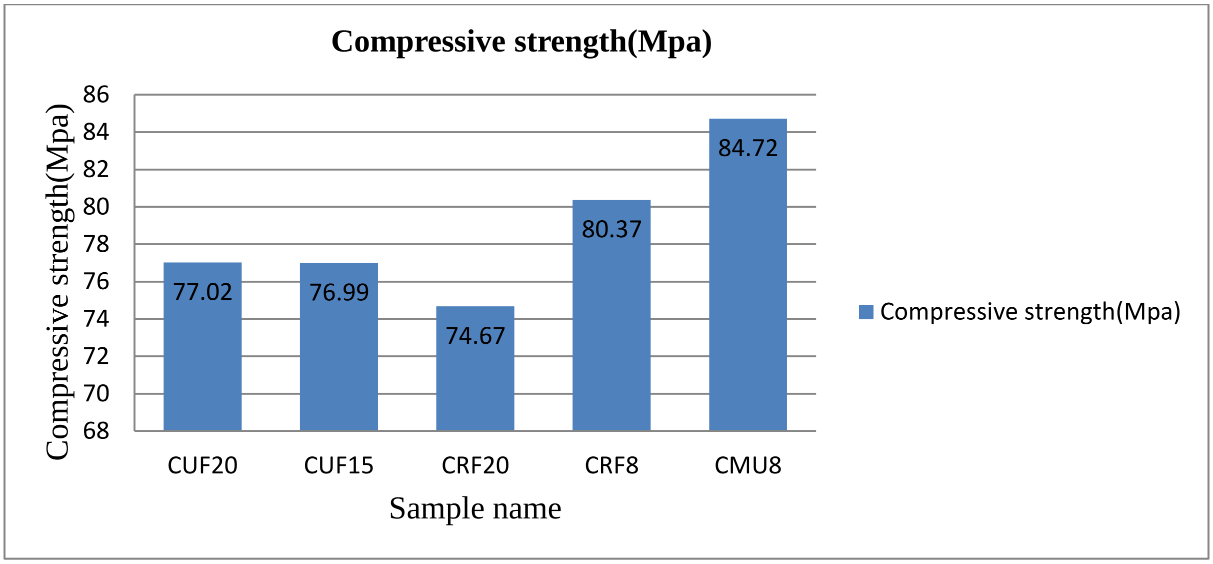

Figure 34 Compressive strength of different samples1

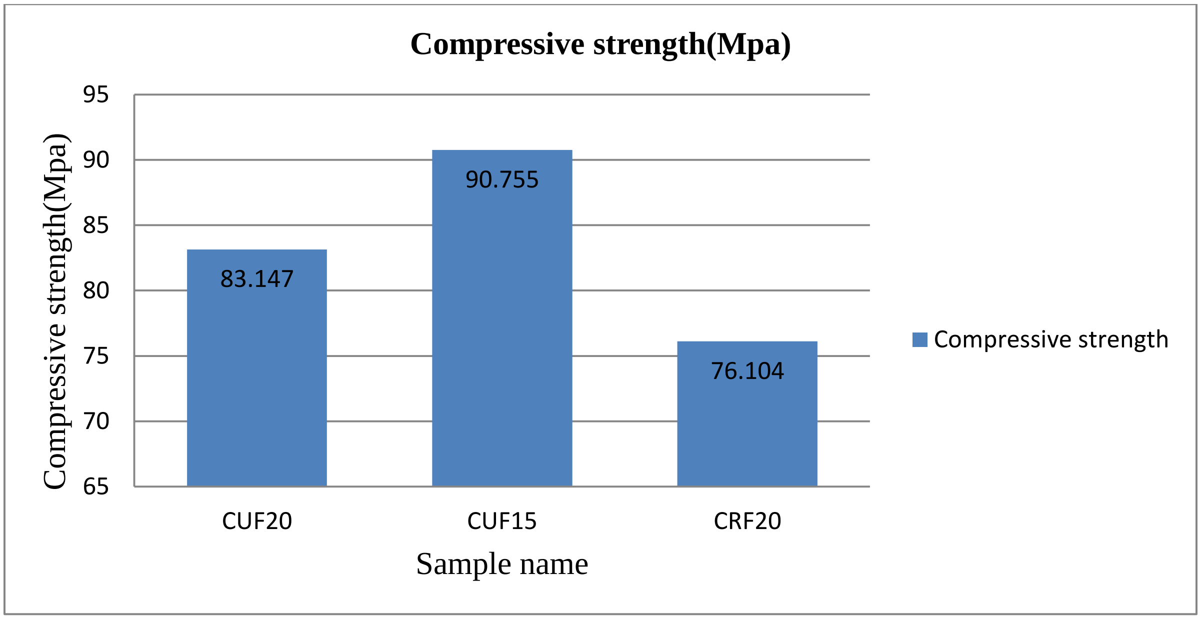

Figure 35 Compressive strength of different combinations2

4.3 Discussions:

The compressive strength obtained is less than the range of Ultra High Strength Concrete. The reasons for this drop could be:

- Imperfection in the dimensions of the mould can be one reason of less compressive strength.
- Normal cold water curing was done for 28 days. If accelerated curing was done, compressive strength would definitely have maximum value. As accelerated curing is done at 100^0c and therefore rate of reaction is fast in this case which is the reason of high strength. If autoclave curing was done, compressive strength would have been increased. Because in this type of curing pressure is being applied on the cubes which results in high compressive strength.
- The temperature recorded in the water basin was about 15^0c which is very less than the room temperature. At such low temperature rate of reaction is slower and this results in less compressive strength. Proper hydration can't be completed which results in less compressive strength.
- Also compaction in some cubes was less than as required. This can be justified with the voids which appeared in the cubes and further gave less compressive strength.
- Due to the addition of superplasticizer, pores increased and therefore compressive strength decreased.
- If steel fiber has been used, compressive strength would be more as fibers arrest the cracks in concrete.
- Also in ternary blend only two cementitious materials have been added. If one or two more admixtures would have been added packing density will be more and definitely compressive strength of that mix will be more.

Figure 36 Pores in cube due to less compaction

Figure 37 Brittle failure of $cube_1$

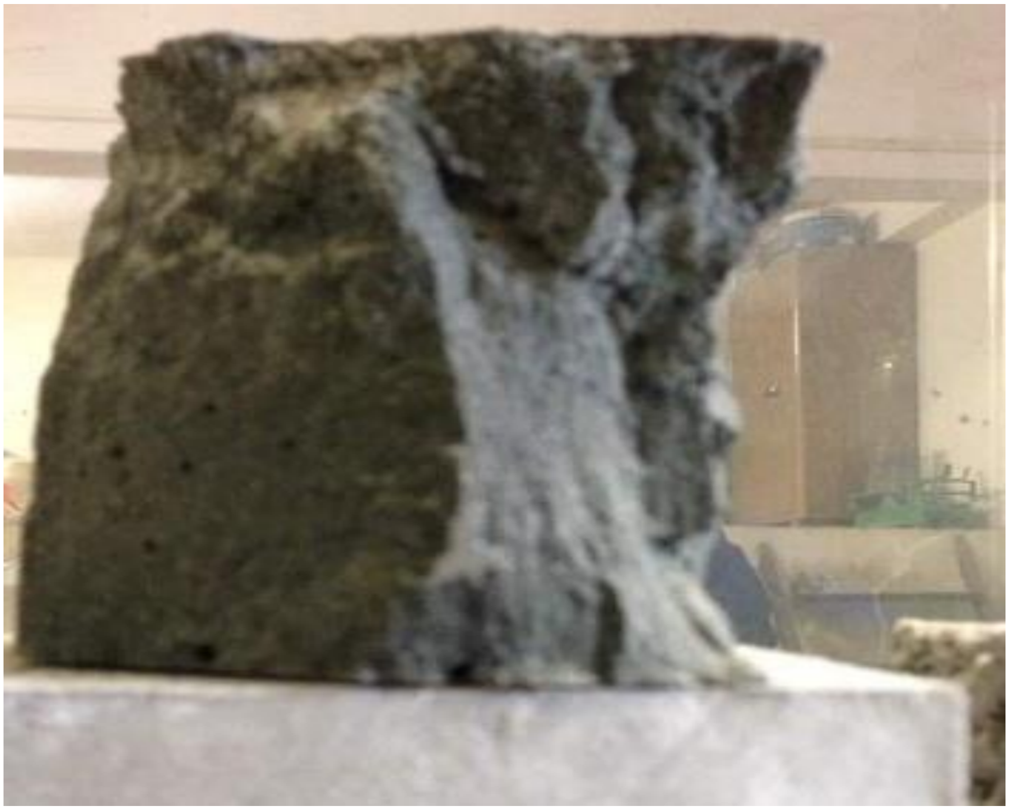

Figure 38 Brittle failure in $cube_2$

Chapter 5. Conclusion

5.1 Conclusion

As the demand of high strength concrete is increasing day by day for heavy construction, long span bridges, high rise buildings. Therefore there should be some easier way for its development. Our research was aimed to achieve maximum compressive strength for ternary blend using Puntke method of particle packing. After using four types of mineral admixture (FA, UFS, MK,RHA) for cement replacement , it can be concluded that as cement replacement increases packing density increases and further compressive strength increases. Also it can be concluded that for high compressive strength proportions of fine materials, dosage of superplasticizer, rate of compaction should be optimum. Further compressive strength can be increased by addition of more fine materials; addition of steel fibers. Also curing type affects the compressive strength. Autoclave, Accelerated curing and autoclave curing will provide better results as compare to normal cold water curing.

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