“DEVELOPMENT OF ULTRA HIGH PERFORMANCE CONCRETE USING RELATIVE DENSITY INDEX METHOD FOR PARTICLE PACKING OF QUINARY MIX PASTE SYSTEM”

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

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Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the report titled **"DEVELOPMENT OF ULTRA HIGH PERFORMANCE CONCRETE USING RELATIVE DENSITY INDEX METHOD FOR PARTICLE PACKING OF QUINARY MIX PASTE SYSTEM"** 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 of Information Technology, Waknaghat is an authentic record of work carried out by **Ankush Saini (152665)** 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.

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ABSTRACT

Ultra High Performance Concrete (UHPC) has under been study for a considerable amount of time now. Many researchers have also yielded good strengths since the advent of this developing composite material. Past efforts of improving the concrete performance yields that, mineral additives can greatly alter the characteristics of concrete and give surprisingly higher strength and durability results.

In this study mineral additives like ultrafine slag, metakaolin, rice husk ash and fly ash will be used and concrete will be assessed for its various properties and ideal mix proportion will be figured out. The main objective of this study is to prepare the high performance concrete having the good mechanical properties by applying the concept of particle packing. The particle packing has a great influence on the properties of concrete by improving the density of the structure. More is the packing of the materials lesser will be the voids and lesser sources for the origin and propagation of the cracks.

Second most important phase of the concrete which greatly influences the properties of the concrete is the interfacial transition zone (ITZ). In the normal concrete ITZ is the potential source for the origin of cracks in the structure and it is also preventing the efficient load transfer in the matrix due to high porosity. So in order to deal with this fault, the coarse aggregates need to be eliminated from the scenario.

The water to binder ratio is also needed to be lowered by the use of superplasticizer because higher water content leads to decrease in the strength of the concrete. Also curing the concrete at the elevated temperatures results higher strengths due to the acceleration in the pozzolanic reactions and healing of the micro cracks. With the correct approach and incorporating the above discussed factors, the concrete with higher strengths can be achieved.

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β	Relative Density Index
W/B	Water to binder ratio
W/C	Water to cement ratio
SP	Superplasticizer
UTM	Universal testing machine
UFS	Ultrafine slag
RHA	Rice husk ash
FA	Fly ash
CMURF	Mix of cement + metakaolin + UFS + RHA + FA

CHAPTER - 1

INTRODUCTION

1.1 GENERAL

Traditional concrete consisted of coarse aggregates along with cement and sand and was able to provide strengths up to 40-50 MPa. But in order to achieve higher strength and durability, coarse aggregates need to be replaced by very fine aggregates of size ranging from 150-600 microns. It has been known from the past studies that coarse aggregates in the concrete turns out to be the weakest link due to the formation if interfacial transition zone and it is from where the crack propagation takes place and leads to failure at higher loads. The cement in UHPC is partially replaced by the mineral admixtures because higher cement content also affects the durability due to the release of higher heat of hydration. Also these mineral admixtures improve the quality by providing better packing density, higher pozzolanic reaction, lower water requirement, lower yield values and higher workability which adds up to the strength and durability of concrete. Low water requirement is attributed to the fact that the mineral admixtures finer than the cement particles takes up the voids between them which leads to dense packing and reduces the water requirement. Higher pozzolanic reaction results in the formation of higher quantity of C-S-H gel which provides the better matrix in the concrete lowering down the porosity too. As the porosity increases, the ingress of the foreign material into the concrete too decreases and the durability increases.

Ample information is available on the selection of the cementitious materials but what is lacking is the information on the optimum combination of these cementitious materials. Therefore, a very careful proportioning of the materials is needed to be carried out here in order to accomplish the UHPC. In order to select the combinations with maximum packing density, the trial mixes were prepared by varying the percentages of the admixtures and replacing the cement. These mixes were then experimentally tested for packing density using the Relative density method and the optimum combinations were selected of these. Particle packing of the materials plays a very decisive role in deciding the mechanical properties of the concrete. Good strength of the concrete, reduced water demand, reduction in the porosity, reduced bleeding and reduction in the permeability can be achieved by the enhanced packing density of the paste. These selected combinations with the maximum packing density values was then further checked for the effects of addition of superplasticizer(SP) on the packing density by varying the content of SP at a fixed water to binder ratios.

The further most important task was the preparation of the design mixes for the selected combination using the quartz sand, quartz powder and manufactured sand along with the mineral admixtures and SP. But before this optimization of the SP of the selected combinations using the Marsh Cone test was required in order to figure out its optimum content in the mixes. Lastly after preparing the design mix keeping the content of cement at 900 and 1100 kg/m^3, the casting of the cubes was carried out in the 7.07*7.07*7.07 cm cubes and after one day the cubes were demolded and kept for the curing at normal temperature for 28 days. After 28 days, the cubes were initially surface dried and tested for the compressive strengths.

1.2 MATERIALS

1.2.1 CEMENT

Grade 53 ordinary portland cement having 28-day minimum compressive strength of 53 MPa, (conforming to IS 12269:2016)[1] procured from Ambuja Cement, Darlaghat, Himachal Pradesh has been used.

Fig. 1.1: Cement

1.2.2 METAKAOLIN

Metakaolin (conforming to IS 1489 (Part -2): 1991)[2] is a high reactive amorphous pozzolan prepared under controlled conditions by heating kaolin at high temperatures, procured from KaoMin Industries LLP, Vadodra, Gujrat has been used.

Fig. 1.2: Metakaolin

Physical properties are as below:

Colour	Pink
Pozzolan reactivity $Ca(OH)_2$/gm	900
Average particle size (micron)	1.4
Bulk Density (gm/ltr.)	320 – 370

Table 1.1: Physical Properties of Metakaolin

1.2.3 ULTRAFINE SLAG (UFS)

Ultrafine slag (conforming to IS 12089:1987)[3] by the commercial name Alccofine1203 with high reactivity obtained by controlled granulation of slag with high glass content, from Counto Microfine Products Private Limited, Goa

Physical properties are as below:

Average Particle Size (micron)	4-6
Fineness (cm^2/gm)	12000
Bulk Density (Kg/m^3)	600-700

Table 1.2: Physical Properties of UFS

Fig. 1.3: Ultrafine Slag

1.2.4 RICE HUSK ASH (RHA)

RHA has been procured from KGR Fusions Pvt. Limited, Ludhiana, Punjab

Preparation of RHA: The RHA procured was higher on the carbon content and had a dark grey colour. Therefore, in order to make it usable the RHA was burnt more by adding diesel to it and process was repeated until it attained a light gray colur.

Fig. 1.4: Rice Husk Ash

1.2.5 FLY ASH (FA)

Fly ash of class F (conforming to IS 3812:1991)[4] from Guru Gobind Singh Super thermal power plant, Rupnagar, Punjab.

Fig. 1.5: Fly Ash

1.2.6 QUARTZ POWDER(QP)

Quartz powder was procured from Surya Min Chem, Barwala, Delhi.

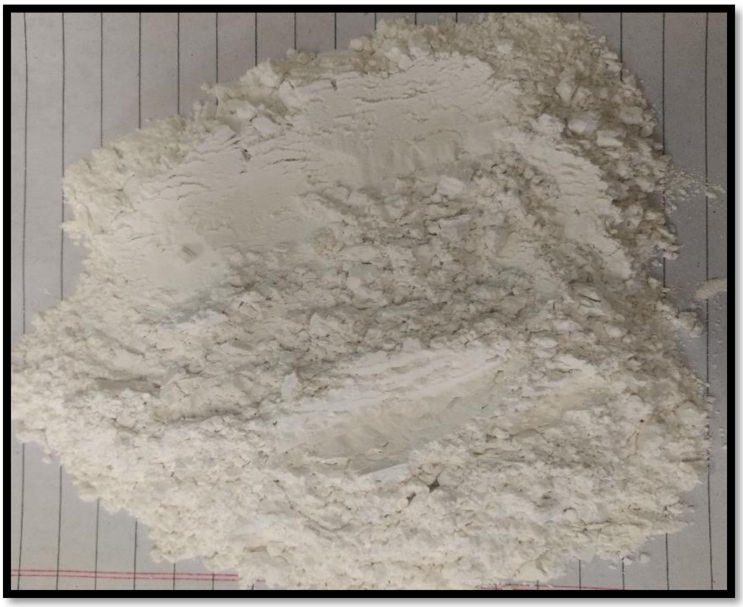


Fig. 1.6: Quartz Powder

1.2.7 QUARTZ SAND(QS)

Quartz sand too was procured from Surya Min Chem, Barwala, Delhi. The particle size of quartz sand required for our work lied in the range of 150-300 microns, therefore the material was passed from the 300-micron sieve and the material retained on the 150-micron sieve was used.

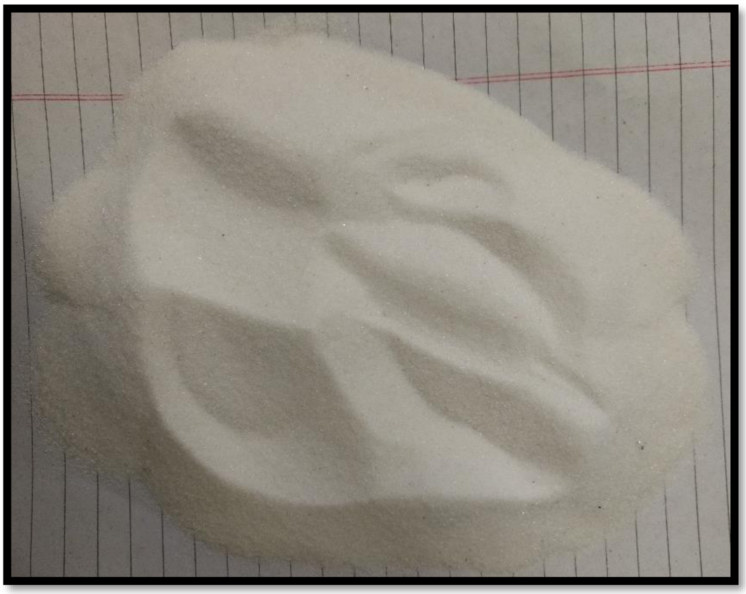


Fig. 1.7: Quartz Sand

1.2.8 MANUFACTURED SAND(MS)

The manufactured sand was procured locally from Nangal, Punjab. The particle size of quartz sand required for our work lied in the range of 300-600 microns, therefore the material was passed from the 600-micron sieve and the material retained on the 300-micron sieve was used.

Fig. 1.8: Manufactured Sand

1.2.9 SUPERPLASTICIZER (SP)

The Superplasticizer used was polycarboxylate based by the brand name CHRYSO Fluid Premia. The polycarboxylate based SPs works on the principle that it gets adsorbed on to the surface of the material grains initially and then disperses them, thereby preventing their agglomeration. As a result, the requirement of water is also reduced.

The particle size distribution for the materials using the XRD and the chemical composition test using XRF were performed at IIT Bombay. The chemical composition of all the materials is shown in Table 1.3 and the particle size distribution in Fig. 1.9

Material	Al_2O_3	SiO_2	CaO	Fe_2O_3	K_2O	Na_2O	MgO	Specific gravity
OPC 53	0.28	19.25	55.14	3.37	0.96	0.129	0.018	3.15
UFS	24.53	25.68	23.74	-	-	0	9.196	2.83
Fly Ash	17.01	33.25	0.45	5.63	1.17	0.14	1.657	2.17
Metakaolin	34.46	57.10	-	3.94	0.08	0.3	1.283	2.5
Rice Husk Ash	13.48	48.1	0.73	4.53	2.04	0.139	1.718	2.53

Table 1.3: Chemical composition of all materials

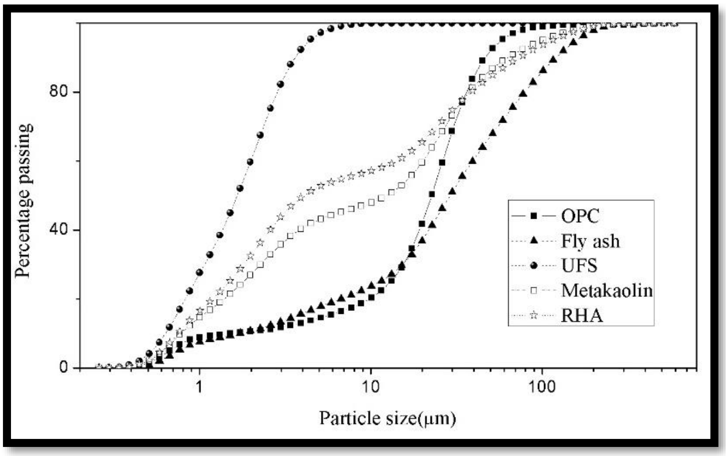


Fig. 1.9: Particle size distribution

CHAPTER - 2

2.1 LITERATURE REVIEW

1) *Pierre Richard, Marcel Cheyrezy [1995]*[5] made a development of ultra-high strength ductile concrete also called as RPC (Reactive Powder Concrete) by considering mixing, composition and heat curing post setting as set of some basic principles for the production of concrete. Two types of concretes were prepared by them as RPC 200 and RPC 800. Out of these, RPC 200 is suitable for its use under the jobsite situations which is similar to the regular high performance concrete. It can be used for constructing a no passive reinforcement prestressed structures. RPC 800 which is capable of achieving strengths up to 600 MPa are pretty much fit for precast structures. Addition of steel aggregates to the mixtures have led to yielding of strengths up to as high as 810 MPa. Certain basic principles were followed by them during their research with RPC which are as follows.

   - To exclude the use of coarse aggregates in order to improve the homogeneity.
   - Improvement in the packing density of the by the optimizing the concrete mix, and applying the pre-setting pressure and pressure during set.
   - Heat treatment after setting for refinement of microstructure.
   - Incorporation of small steel fibers for the improvement in ductility.

   With the view of preventing the interference with the cement particle of size ranging 80 - 100 microns, the largest particle size of sand is limited to 600 microns and the smallest up to 150 microns. Considering the chemical composition, lower content of C_3A in the cement provides better results with concrete. Concerning with the particle size, they made an observation that the cements which are ground more than required, increased the demand for water as the led to increase in the Blaine fineness and not required. They found an optimum silica fume to cement ratio as 0.25 for RPC. The ratio of 0.25 came out to be the one which is sufficient to fill the maximum no of voids and to completely consume the lime which is one of the products of the hydration reaction. For the reactive powder concretes which are to be subjected to the heat treatments requires crushed quartz powder as an important inclusion. The mixes which has the mean particle size lying in the range of 5-25 microns has the maximum reactivity when are treated at elevated temperatures. The characteristics of concrete were improved by providing treatments like applying presetting pressures, heat curing and inclusion of fibres.

2) *Caijun Shi and Yanzhong Wu [2005]*[6] carried out the study on design and the characteristics of self consolidating light weight concrete. While carrying out their research work they established that self consolidating concrete can be designed by combining the theories like least void volume and the excessive paste theory and using the standards of ACI mix proportioning of light weight concrete. In order to make the excessive pastes for the mix, admixtures like the powdered glass and fly ash can be used. In context of reduction of air content, the glass powder was more effective as compared to fly ash. Fly ash, very significantly increased the retarding properties as compared to powdered glass. The lime which is one of the products of the cement hydration, reacted with these powders and increased the strength of the concrete measured after 28 days, which was higher than the actual design strength. The pozzolanic reactivity of glass with lime increased with increase in its fineness. As compared to fly ash the shrinkage of concrete was more of due to the powdered glass and the remedy to this too is the higher fineness of the glass powder. The initial curing time was increased from 1-7 days but the loss of mass during drying and the drying shrinkage were not affected much. The transportation of water to the matrix from saturated porous aggregates caused a slight expansion although the powders were used but there was a negligible autogenous shrinkage. The durability properties of concrete like the reduced chloride permeability can be achieved by the inclusion of glass powder as it exhibits high pozzolonic reactivity as compared to fly ash. Adding to the durability aspect, the expansion resulting from alkali aggregate reactions can be reduced by using optimum quantities of porous light weight aggregates and the replacement of reactive aggregates by about 60% with the light weight aggregates can be effective in lowering the expansion at 14 days up to 0.1% as indicated by the results obtained by using ASTM C 1260 method.

3) *Ehab Shaheen and Nigel G. Shrive [2006]*[7] carried out an experimental work with an aim to prepare a concrete with good durability and toughness and also excellent compressive strength but with the reduced use of carbon fiber, lower heating temperatures and minimalistic pre-setting pressures. They assessed the effects of addition of carbon fibres, application of presetting pressures and the post setting heat treatments along with the assessment of their optimum quantities. Steel molds were specifically designed to cast cylindrical specimens in order to perform tests. In order to obtain higher compressive strengths, they prepared a mix design along with the treatment processes after setting. Many mixes of fiber reinforced and plain reactive powder concrete were prepared keeping the water binder ratio fixed at 0.13. The cracked specimens were subjected to freeze & thaw tests for

durability and in order to test these, ingress of water in to the specimens was made allowed by introduction of groves on their sides. The application of presetting pressures reflected that these forces must be kept in the range of 50 – 100 kN so as to achieve maximum compressive strengths. These specimens also showed that due to the rapid increase in the hydration process in concrete, the temperatures of 150-200 ^oC provided very high compressive strength values. On further increase in the heating temperatures from 15-200 ^oC, the compressive strength showed slump in the values which occurred due to the incomplete hydration as the internal water evaporated very quickly. Furthermore, the comp. strength shows the up-hill in the values again when temperature was raised from 200-300 ^oC due to formation of calcium silicate hydrate as the quartz too shows pozzolonic reaction at this range of temperature. Again if the temperature is elevated the there is a dramatic decrease in the strengths due to the decomposition of the products and also the occurrence of micro-porosity because of evaporation of HRWR admixtures. The resulting concretes has the density lying in between 1.76-2.41 kg/m^3. The density of the concretes decreases at high temperatures but increases with the increase in the pre-setting pressures. The carbon fibre added concretes reflected higher resistance to freezing and thawing as compared to the plain concrete.

4) *Prakash Nanthagopalan, Michael Haist, Manu Santhanam, Harald S. Müller [2008]*[8] made a study on the cementitious materials in order to develop the relation between the particle packing density and the flow properties. The characterization of the mixes like cement + silica fume and fly ash + cement was carried out using the packing density tests by Puntke method and the rheology tests by the use of rheometer. The study of effects of variation of water content and the particle packing on the properties of the cementitious mixes was performed. After calculating the packing density of the mixes using the Puntke test, the flow properties of the 3 compositions selected from the mixes obtained from cement + silica fume and cement + fly ash was studied. Keeping the replacement of silica fume to be constant, the yield values of the cement + silica fume mixes varied from 3-10 times as compared to those of the cement paste alone. The increase in friction between the particles and the inter-particle interactions may be the probable cause to this observed trend. As compared to the pure paste, the slump flow for the cement + silica fume was also lower. For all the 3 compositions selected which had almost the similar values of density, the yield and the plastic viscosity values increased with the increase in the silica fume replacement for all water to powder ratios. This phenomenon can be due to the fact that silica fume has high specific surface area, which results in increase in demand for water and hence the yield values. Talking about the

case of cement + fly ash mixes, the yield values decreased with increased replacement of fly ash even at constant water to binder ratios. High packing density forms the basis for the good flow properties as it is evident from test results which portrays the decrease in the yield values with increase in cement + fly ash mixes. But the plastic viscosity for cement + silica fume and cement + fly ash mixes showed uphill in values with the reduced water to powder ratios which is probably due to increase in the solids content. The increase in the cohesion in mixes led to the increase in the viscosity with the addition of fly ash and silica fume. At the constant water to binder ratios, the plastic viscosity of the mixes increased with the increase in the replacement of silica fume. Correspondingly, at the constant water to binder ratios, the plastic viscosity of the mixes decreased with the increase in the content of fly ash.

5) *Halit Yazici, Mert Yücel Yardimci, Serdar Aydin, Anil S. Karabulut [2008]*[9] carried out the study on reactive powder concrete using the class c fly ash and ground granulated blast furnace slag and worked on the mechanical properties like compressive strength, flexural and toughness and also tested it under different conditions of curing like standard, steam curing and autoclaved curing. The results of their work reflected that concrete containing higher quantity of the mineral admixtures had good mechanical properties. They were successful in producing concrete with the compressive strengths up to 200 MPa after standard curing by keeping the cement and silica fume quantity in the concrete lower than that in the conventional reactive powder concrete. The steam and autoclave curing, stood out to be effective in increasing the compressive strength in reactive powder concrete because under these curing regimes, the hydration process inside concrete improves a lot. Autoclave curing in this case achieved strengths greater than 250 MPa and steam curing too surpassed the 230 MPa mark. Addition of mineral admixtures by replacement of the cement also benefits the environment. Unlike the conventional concrete, reducing the content of cement lowers the shrinkage and heat of hydration which generally cause problems in concrete. Flip side of the shows the reduced flexural strengths on the 28th day after autoclave and steam curing as compared to normal temperature curing which may due to the reduction bond strength between fibres and the matrix. Addition of fly ash or ground granulated blast furnace slag reduced this negative impact on the concrete in both the cases and also their addition enhanced the flexural performance under all curing regimes. Going by the test results, they reflected that these two mineral admixtures can be use as the silica source and that their use increased the toughness value of concrete to a great extent. Therefore, the use of silica fume can be lowered by their incorporation in the concrete. This replacement too like that of

cement provides certain advantages like reduction in the demand for superplasticizer, lower shrinkage, lesser heat of hydration and most importantly the economy. When the replacement of the admixtures surpassed 30%, the modulus of elasticity got reduced. The SEM images for the concrete showed a dense micro-structure although there existed some pores due to air entrainment.

6) *Yanzhou Peng, Shuguang Hu, Qingjun Ding [2009]*[10], in terms of minimum water requirement for cement studied the effects of addition of mineral admixtures like fly-ash, slag and silica fume to the particle packing of the binary, ternary and the quaternary mixes. They carried out the investigation on the relative density of mixes at lower water to binder ratios by the addition of these admixtures and established a relation between the compressive strength and the relative density of the mixes corresponding to the hardened concrete. Here the packing density was measured by the method which determines the least amount of water which is required by the paste by measuring the spaces between the particles. Talking in other words it determined the least amount of water which can change the mixture from solid to slurry. This minimum water required includes the water adsorbed to the particle along with that required to fill in the inter-particle spaces. The maximum packing of the pastes was characterized by the minimum amount of water required for the slurry. Talking about the binary combinations, the maximum packing density obtained was 0.64 by the combination of ultra-fine fly ash and cement where the cement replacement was 15%. In case of the ternary combinations, where the cement to fly ash ratio was kept fixed at 0.85/0.15, with the mix including cement + fly ash + steel slag followed a trend in which the requirement for the water reduces while increasing the slag content upto 20% and further increase shows the uphill in the water requirement. Moving on to the quaternary mix, the cement:steel slag:fly ash ratio was fixed at 0.65:0.20:0.12 and the mix including the cement, fly ash, silica fume and the steel slag showed that with the maximum inclusion of silica fume up to 15% the requirement of water further reduces and the packing density increases to 0.666. In comparison to the inclusion of single admixture to the mixes, the mixes which had two or more admixtures showed higher values of packing density and a lower water demand and the compressive strengths too increased.

7) *Guangcheng Long, Xinyou Wang, Youjun Xie [2010]*[11], in this paper studied firstly, the compactness of ternary and binary mixes containing ultrafine mineral powders, such as Silica Fume (SF), pulverized granulated blast furnace slag (PS) or pulverized fly ash (PFA), and

the relationships between relative density and fluidity of pastes, are analyzed quantitatively. Secondly, the effects of the contents of SF, PS and PFA on the strength of VHPCs are experimentally studied. Finally, two means of improving toughness of VHPC by steel fibers and steel tubes are investigated. A very high performance concrete has been prepared with the compressive strength up to 100 MPa by the addition of ultra-fine materials and use of certain special treatments like heat treatment and proper optimization of the mineral admixtures. The relative density of the mixes as reflected by the results obtained, increases with the increment in the content of powders. Silica fume is most effective in enhancing the relative densities of binary paste systems because the average diameter of the SF particles is less than that of PFA and PS which provides the better filling effect. For the ternary paste, its relative density can further increase compared to the binary pastes due to the interfiling effect which reduces voids between particles with different sizes. W/B ratio is the key factor affecting the initial porosity. With the decrease in the W/B, the relative density of fresh pastes increases rapidly due to the reduction of water in mixtures because the distance between particles becomes shorter and the porosity of the pastes is reduced. The fluidity of the pastes decreases with the increase in the relative density. The addition of mineral admixtures into the compound pastes increase the relative density of the pastes and also compensate for the water demand and increases the fluidity of the pastes. The ternary mix samples yielded higher compressive strength as compared to the binary mix samples. The brittleness of the concrete can be overcome by adding short steel fibers and with the introduction of steel tubes, not only toughness but also the compressive strength can be enhanced.

8) *Serdar Aydin, Halit Yazici, Mert Yücel Yardimci, and Hüseyin Yigiter [2010]*[12] carried out the research work on the mechanical properties of reactive powder concrete (RPC) produced with different aggregates, such as korund, basalt, limestone, quartz, sintered bauxite, and granite. Under different regimes like atmospheric, standard and high pressure curing, the mechanical properties were studied using the different aggregated. Test results indicate that the mechanical performance of RPC can be improved by using high-strength, rough-surface aggregate. Nevertheless, a very high compressive strength of 170 to 180 MPa can also be obtained by using low-strength aggregate (limestone) or smooth-surfaced aggregate (quartz) even under standard curing conditions. In the case of strong- and rough-surface textured aggregate, the compressive strength can be increased up to 200 MPa with standard curing conditions. The compressive strength of RPC can be increased by steam curing due to an improvement in the hydration process, as expected. Compared to standard water curing, 11%

to 36% and 21% to 59% higher compressive strength can be achieved under atmospheric steam curing and high pressure steam curing (autoclaving), respectively. According to aggregate type, the values of the compressive strength of autoclaved RPC are between 218 to 285 MPa. The application of pressures during and before the setting also improves the compressive strength of RPC significantly, especially with high-strength, rough, and porous aggregate. With the exception of the granite-aggregated mixture, all mixtures showed a compressive strength over 300 MPa with pressure application and autoclaving. For sintered bauxite aggregate RPC, a compressive strength over 400 MPa was obtained. Atmospheric steam curing and autoclaving did not improve flexural performance, possibly due to the weaker bond between the fibers and matrix after these curing regimes. A rough surface textured aggregates and high strength concrete concrete is required in order to deliver high flexural strengths. There are spherical pores in RPC and these pores are generally empty in the standard or steam cured concrete but in case of autoclaved RPC, these pores are filled with tobermorite like structures. The porosity range of RPC generally lies in between 0.94% to 1.2% as compared to 20% of conventional concrete.

9) *C. M. Tam*, V. W. Y. Tam† and K. M. Ng* [2010]*[13] of City University of Hong Kong and University of Western Sydney, investigated the conditions which are optimal for producing RPC using local materials by examining the effects of material composition, curing and heating regimes on the microstructure and compressive strength of RPC. It was found that RPC with water to binder ratio of 0.2, SP dosage of 2.5%, 150 - 600 microns quartz sand cured at 27°C in water condition provided the best results in terms of mechanical and composite properties, as well as for economic and practical reasons, although a significantly high compressive strength can be achieved using the heat treatment on RPC. In too low water-to-binder ratio mixes it is difficult to achieve full compaction, whereas mixes with too high water-to-binder ratio are highly susceptible to entrain air bubbles, which then leads to formation of large air voids and thus considerable reduction in strength. Insufficient SP dosage reduces the workability owing to the friction at the increased surface area of RPC. Fine particles may easily become flocculated, resulting in voids and consequently reduction in compressive strength. However, excess SP dosage does not have a significant effect on the strength of RPC. More plate-shaped CH crystals were observed under SEM, but these do not contribute much to strength development. Quartz sand with size class of 150–300 μm displays an exceptionally low compressive strength of RPC, which may be attributable to the poor particle packing of fine particles that leads to the interference with the further larger

class of particles of cement (80 – 100 microns), whereas larger class of quartz sand ranging 600–1180 microns does not significantly reduce the compressive strength in comparison with quartz sand ranging 150–600 microns. RPC cured under 60°C in water condition and 60°C in mist condition result in a lower ultimate strength than that cured under 27°C in water condition. This is because higher temperature curing accelerates the hydration and pozzolanic reaction at the early age, which seems to produce crystals of a poor structure. Heat treatments of the RPC results in a noticeably high increase in compressive strength due to the micro-structural change which leads to the formation of xonotlite and tobermorite at 250°C and xonolite secondary particles at 100°C; whereas duration of heat treatment has small effect on compressive strength of RPC while longer durations shows little uphill in compressive strength values.

10) *Kay Wille, Antoine E. Naaman, and Gustavo J. Parra-Montesinos [2011]*[14] made a production of an ultra high performance concrete with the compressive strength values exceeding 200 MPa, which was framed using materials which are easily available in the U.S. market and without the use of any heat-treatment, pressure or special mixing. The influence of different variables such as type of cement, silica-fume, sand, and high range water reducer on compressive strength was evaluated. The initial strategy was to enhance the packing density by the proper choice of particulate materials and to improve the flowabilty, which was checked by the spread value from a simple flow cone test. The spread values were found to be a quick test which indicates the need to optimize the particle packing of the mix and therefore to decrease the effort required to generate a UHPC material. Since the higher spread values indicated a high packing density and thus a high compressive strength, the developed UHPC mixtures have the additional benefit of exhibiting high workability. They drew some conclusions for the development of a UHPC mix easily as to what products is more suitable for the same. Cement should have a moderate fineness and a C_3A content significantly lower than 8% to reduce the demand for water, which influences compressive strength. Also an optimum sand to cement ratio was determined which was approx. 1.4 for a maximum grain size of 0.8 mm. The use of sands with different grading may lead to different optimal proportions. The SF selected should have very low carbon content, preferably less than 0.5%, as was used in this research. Its optimum content was found to be 25% of the cement by weight. A median particle size of the selected SF (1.2 µm) larger than that of commonly used SF (0.5 µm) resulted in a lower surface area and a reduction in the water demand. The larger median particle size did not influence the compressive strength. The optimum amount of GP

content was found to be 25% of the cement by weight. The optimum amount of HRWR based on polycarboxylate ether was found to be ranged from 1.4 to 2.4% of cement by weight. The w/c should be such that the spread value of the paste is between 300 and 350 mm. A w/c ranging from 0.16 to 0.27 is recommended based on the test results. The optimum value was found to be approximately 0.22.

11) *G. Dhinakaran, S Thilgavathi, J. Venkataraman [2012]*[15], made an investigation in order to improve the concrete's performance with the incorporation of mineral admixture like metakaolin and improve upon the strength and increase the resistance to penetration of chloride ion. They performed a study as understand the effects of the parameters such as age of the concrete, the water to cementitious materials ratio and the different percentages of metakaolin in the mix. Different ratios of the water to cementitious materials was considered like 0.32, 0.35, 0.4 and 0.5 for the study. The experiments were performed considering the metakaolin proportions from 0 to 15% in the increments of 5% and the different ages of concrete from 3-90 days. The results of the various performance parameters like pH of concrete, workability, chloride permeability, depth of ingress of chloride ions and compressive strength, considering the above mentioned concrete were investigated and the results of this metakaolin introduced concrete were compared to the conventional concrete. These results reflected that for higher water to binder ratios like 0.5 and 0.4, greater strengths were achieved and the resistance to the chloride ion penetration for all the water to binder ratios was almost consistent and the incorporation of optimum amount of metakaolin resulted in the significant reduction of chloride penetration. Statistical model was prepared using multiple non-linear regression analysis in order to predict the strengths were found to be in good correlation with the predicted and observed values.

12) *R.S Deotale, S.H. Sathawne, A.R. Narde [2012]*[16] carried out research work in detail to make a study on the effects of addition of mineral admixtures like rice husk ash and fly ash by replacing the cement and with the incorporation of steel fibres on the concrete. The percentages of these admixtures was varied as decrease in the fly ash in steps of 5% and increase in the percentage of rice husk ash in the increments of 5% as well. The percentages therefor varied from fly ah being 30% to 15% and the rice husk ash from 0% to 15% simultaneously. To improve upon the strength values, the steel fibres were incorporated with their variations in the increments of 0.25% from 0 to 1% and the percentages of the fly ash and rice husk ash being kept fixed at 20 and 10% respectively. The main aim of this study

was to see the effects on the parameters of concrete like compressive strength, workability, split tensile, flexural strength and the durability of the concrete with the addition of steel fibres to it. Compressive strength increases with the addition of these materials and the optimum value of these materials stands at 22.5% for fly ash and 7.5% for rice husk ash. RHA addition has significantly improved upon the tensile and the flexural strengths of the concrete and the compressive strength values didn’t show any changes with the incorporation of steel fibres.

13) *Dilip Kumar Singh Roy, Amitava Sil [2012]*[17], made a study on the concrete properties with the addition of silica fume as replacement to the cement. They prepared a number of mix combinations and tested these for the properties like split-tensile, compression strength and flexural strengths and these results were compared to the results for the conventional concrete. When the cement is replaced with the silica fume, the cylindrical strengths (maximum values of the strength) at the 7 and 28 days was observed to be 4.32% and 16.82% higher than the conventional concrete. The particle packing of the materials greatly improved with the increase in the percentage of incorporation of silica fume which further led to the enhancement in the interfacial bonds between the cement matrix and the cement and this improved the tensile strength to the great extent. With only the 10% replacement of the cement with silica fume led to the maximum flexural strength at 28 days to be 21.13% higher than the control concrete.

14) *Counto Microfine Products Pvt. Ltd.*[18] made a comparison through experimental work of the addition of Alccofine 1203 in the concrete to the addition of silica fume in concrete mix on the basis of their effects on strength, durability, requirement of admixture, workability and the requirement of water. The results obtained reflected clearly that the mix designs which incorporated the Alccofine 1203 judiciously, developed higher properties as compared to silica fume. The mix designs with the addition of Alccofine 1203 were prepared such that they provide the good advantage as far as the economic as well as technical benefits are concerned. The compared results of the Alccofine 1203 were way better than that of the silica fume for addition of equal amounts of water reducers and water to binder ratios as per the carried out methodologies. And the other 2 methodologies too presented the same results. The Alccofine exhibits a good chemical composition and the Particle size distribution is optimized too which helps in the reduction in requirement of water reducers and development of high strengths as compared to silica fume. The particle size distribution and chemical

composition of Alccofine 1203 owes to the pozzolonic reactivity for the longer term. The dense pore structure was observed in the case of Alccofine 1203 addition which was mainly due to the presense of CaO content which provides secondary hydrated products and results in higher strengths even at the early and the later stage of the concrete. These products helps with the filling of the pores in the hardened concrete. The permeability of these hydrated products is reduced to the great extent the concrete is protected from the chemical attacks.

2.2 RESEARCH GAP

According to the literature review carried out it can be inferred that:

1. With the increase in the no of fine pozzolanic materials added to the paste, the packing density increases and the studies up to "Quaternary" paste system have been carried out but the effect of the "Quinary" compound paste system on the mechanical properties of concrete have not been studies yet.
2. Not much research has been carried out by considering the jobsite conditions i.e. without special treatments like presetting pressures, higher curing temperatures and working with concrete at low temperatures.

2.3 OBJECTIVES

Following are the objectives which were fulfilled during the course of the project.

1. To determine the ideal combination for high strength concrete by particle packing method.
   - The method used for the particle packing was Relative Density Index Method (d/d_o)
2. Optimization of the combinations by the third generation superplasticizer.
   - Marsh Cone test was performed for the optimization.
3. To study the effect of curing at low temperature on strength of concrete.
   - Curing at low temperatures of about 5-10^{o}C was carried out.
4. Compressive strength tests were performed at the end of the curing period.

CHAPTER - 3

EXPERIMENTAL WORK

3.1 TESTS ON MATERIALS

Certain tests were carried out on the materials used which are discussed below.

3.1.1 CEMENT

Following tests were performed on the cement.

3.1.1.1 Normal Consistency

Normal consistency of the cement is that percentage of water by weight of the cement added at which the plunger of 10 mm dia penetrates up to the depth 5-7 mm from the base of the plate.

Apparatus used: Vicat Apparatus with 10 mm plunger, balance and measuring cylinder

Fig. 3.1: Vicat Apparatus

Procedure:

1. 100 gms of cement was taken in a tray and initially 30 % water of the weight of the cement was added and mixed thoroughly for about 3-5 minutes to obtain a paste.

2. Vicat mould, kept on the glass plate, was then filled with the paste prepared and the surface was levelled properly.
3. The mould was then placed under the plunger, the plunger is then lowered to the surface of the paste and then released quickly, allowing it to penetrate the paste.
4. Depth of the penetration was measured and noted down.
5. Similarly, the test was performed for other percentages of water too until the depth of penetration lies between 5-7 mm from the base of the plate.

Result: The normal consistency of the cement obtained was 36%

3.1.1.2 Initial setting time

Initial setting time is the time period from the preparation of paste of cement by adding 0.85P of water to the time when the paste resists the penetration of the 1 mm^2 cross-section needle, where P is the normal consistency of the cement.

Apparatus: Vicat Apparatus (with 1 mm^2 cross-section needle), balance and measuring cylinder

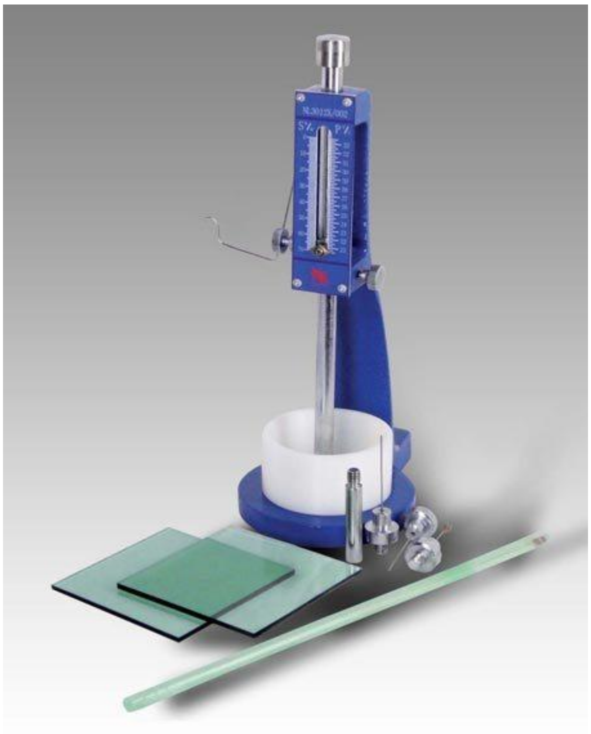


Fig. 3.2: Vicat apparatus (Initial and Final Setting time)

Procedure:

1. 100 gms. of cement was taken and 0.85P of water was added to make the paste.
2. Very moment the water is added, the time is noted down.
3. Further the prepared paste is added to the mold with surface levelled and placed under the needle of the apparatus.
4. The needle is then lowered to the surface of the paste and quickly released.
5. Initially the needle pierces the paste completely to the surface, therefore this procedure is repeated until the needle after penetrating stops at 5mm from the base of the plate. The time is noted again and the total time taken is calculated.

Result: The initial setting time of the cement was 110 minutes.

3.1.1.3 Final setting time

Final setting time is the time period from the preparation of paste of cement by adding 0.85P of water to the time when the 1 mm dia needle makes an impression on the surface but the 5 mm attachment fails to do so, where P is the normal consistency of the cement.

Apparatus: Vicat Apparatus (with an attachment having 1 mm dia needle and outer 5 mm dia attachment), balance and measuring cylinder.

Procedure:

1. 100 gms. of cement was taken and 0.85P of water was added to make the paste.
2. Very moment the water is added, the time is noted down.
3. Further the prepared paste is added to the mould with surface levelled and placed under the needle of the apparatus.
4. The needle is then lowered to the surface of the paste and quickly released.
5. Initially both the 1mm needle and outer 5mm dia attachment makes an impression, therefore this step is repeated until 1 mm dia needle makes an impression on the surface but the 5 mm attachment fails to do so.
6. The time is noted down and the time taken is calculated.

Result: The final setting time of the cement was 225 minutes

3.1.1.4 Fineness of cement

Fineness of the cement was measured by passing it through the 90 micron sieve. The weight of cement retained on the sieve represented as the percentage of the initial weight taken is taken as the fineness of the cement.

Apparatus: 90 micron sieve and balance

Fig. 3.3: 90 micron sieve

Procedure:

1. 10 gms. of the cement was weighed and poured on to the sieve which had a pan attached to the bottom and was covered with the lid.
2. The cement in the pan was shaken in various motions until no more material passed through the sieve.
3. The material retained on the sieve was then weighed and the calculation for the percentage retained on the sieve was carried out.

Result: The fineness of cement came out to be 0.5%

3.1.1.5 Soundness of cement

In the soundness test a specimen of hardened cement paste is boiled for a fixed time so that any tendency to expand is speeded up and can be detected. Soundness means the ability to resist volume expansion.

Apparatus: Le- Chatlier apparatus, water bath and balance

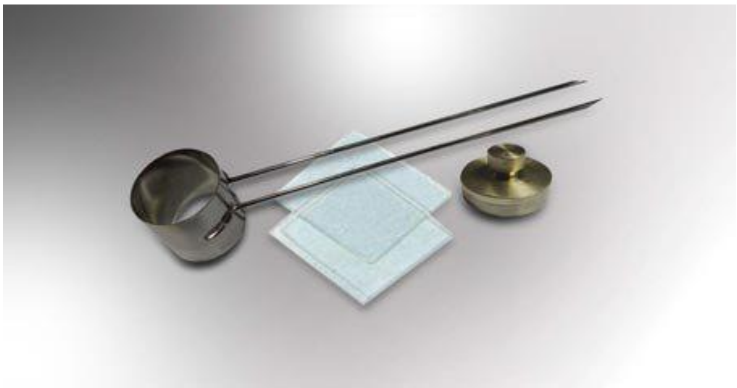


Fig. 3.4: Le-Chatlier Apparatus

<u>Procedure:</u>

1. A paste was prepared by adding 0.78 times the water required to give a paste of standard consistency.
2. The mould was then filled with the prepared cement paste and was covered with a glass sheet and a small weight placed on this covering glass sheet.
3. Whole assembly was submerged in water at a temperature of 27 ± 2^0 C for 24 hours and then removed from water bath to measure the distance separating the indicator points (L1).
4. Again the whole assembly was submerged in water bath at 100 ^{o}C for a period of 3 hours.
5. Measure the distance between the two indicator points after removal from the water bath (L2).
6. Calculate the soundness of cement as L2 - L1.

<u>Result:</u> The soundness of the cement was 2 mm.

3.1.2 Metakaolin

The Metakaolin was tested for the specific gravity using the same procedure as mentioned in 3.1.1 and the specific gravity was found to be 2.5.

3.1.3 Ultrafine Slag

The Ultrafine Slag was tested for the specific gravity using the same procedure as mentioned in 3.1.1 and the specific gravity was found to be 2.86.

3.1.4 Rice Husk Ash

The Rice Husk Ash was tested for the specific gravity using the same procedure as mentioned in 3.1.1 and the specific gravity was found to be 2.53.

3.1.5 Fly Ash

The Fly Ash was tested for the specific gravity using the same procedure as mentioned in 3.1.1 and the specific gravity was found to be 2.17.

3.2 MIX PROPORTIONS

The mix proportions for the trials of the particle packing have been decided according to the inferences from the literature review.

Combinations	Cement : Metakaolin : UFS : RHA : Fly Ash
CMURF 1	90 : 2.5 : 2.5 : 2.5 : 2.5
CMURF 2	90 : 2.5 : 3.5 : 2 : 2
CMURF 3	90 : 3 : 3 : 2 : 2
CMURF 4	90 : 3.5 : 2.5 : 2 : 2
CMURF 5	85 : 3.75 : 3.75 : 3.75 : 3.75
CMURF 6	85 : 4 : 4 : 4 : 3
CMURF 7	85 : 4 : 5 : 3 : 3
CMURF 8	85 : 4 : 7 : 2 : 2
CMURF 9	85 : 5 : 4 : 3 : 3
CMURF 10	85 : 5 : 5 : 3 : 2
CMURF 11	85 : 5 : 6 : 2 : 2
CMURF 12	85 : 5.5 : 5.5 : 2 : 2
CMURF 13	85 : 6 : 4 : 3 : 2
CMURF 14	85 : 6 : 5 : 2 : 2
CMURF 15	85 : 7 : 4 : 2 : 2
CMURF 16	80 : 5 : 5 : 5 : 5
CMURF 17	80 : 5 : 6 : 5 : 4
CMURF 18	80 : 5 : 7 : 4 : 4
CMURF 19	80 : 6 : 5 : 5 : 4
CMURF 20	80 : 6 : 7 : 4 : 3
CMURF 21	80 : 6 : 8 : 3 : 3
CMURF 22	80 : 6 : 8 : 4 : 2
CMURF 23	80 : 7 : 5 : 4 : 4
CMURF 24	80 : 7 : 5 : 5 : 3
CMURF 25	80 : 7 : 6 : 4 : 3
CMURF 26	80 : 8 : 6 : 3 : 3
CMURF 27	80 : 8 : 6 : 4 : 2
CMURF 28	75 : 7 : 7 : 6 : 5
CMURF 29	75 : 7 : 8 : 5 : 5

CMURF 30	75 : 7 : 8 : 6 : 4
CMURF 31	75 : 7 : 9 : 5 : 4
CMURF 32	75 : 7 : 10 : 5 : 3
CMURF 33	75 : 8 : 7 : 5 : 5
CMURF 34	75 : 8 : 7 : 6 : 4
CMURF 35	75 : 8 : 8 : 5 : 4
CMURF 36	75 : 8 : 9 : 4 : 4
CMURF 37	75 : 8 : 9 : 5 : 3
CMURF 38	75 : 9 : 7 : 5 : 4
CMURF 39	75 : 9 : 8 : 4 : 4
CMURF 40	75 : 9 : 8 : 5 : 3
CMURF 41	75 : 9 : 9 : 4 : 3
CMURF 42	75 : 10 : 7 : 5 : 3
CMURF 43	70 : 8 : 8 : 7 : 7
CMURF 44	70 : 8 : 9 : 7 : 6
CMURF 45	70 : 8 : 10 : 7 : 5
CMURF 46	70 : 8 : 11 : 6 : 5
CMURF 47	70 : 8 : 11 : 7 : 4
CMURF 48	70 : 8 : 9 : 7 : 6
CMURF 49	70 : 9 : 10 : 6 : 5
CMURF 50	70 : 9 : 10 : 7 : 4
CMURF 51	70 : 9 : 11 : 5 : 5
CMURF 52	70 : 9 : 11 : 6 : 4
CMURF 53	70 : 10 : 9 : 6 : 5
CMURF 54	70 : 10 : 10 : 5 : 5
CMURF 55	70 : 10 : 10 : 6 : 4
CMURF 56	70 : 11 : 8 : 6 : 5
CMURF 57	70 : 11 : 8 : 7 : 4
CMURF 58	70 : 11 : 9 : 6 : 4
CMURF 59	65 : 10 : 10 : 8 : 7
CMURF 60	65 : 10 : 11 : 8 : 6
CMURF 61	65 : 10 : 12 : 7 : 6
CMURF 62	65 : 10 : 13 : 7 : 5
CMURF 63	65 : 11 : 11 : 7 : 6
CMURF 64	65 : 11 : 12 : 6 : 6
CMURF 65	65 : 12 : 10 : 7 : 6
CMURF 66	65 : 12 : 11 : 6 : 6
CMURF 67	60 : 12 : 12 : 9 : 7
CMURF 68	60 : 12 : 13 : 9 : 6
CMURF 69	60 : 13 12 : 8 : 7
CMURF 70	60 : 14 : 12 : 8 : 6

Table 3.1: Mix Proportions

3.3 PARTICLE PACKING OF MATERIALS

Amongst the experimental works carried out in this semester was the particle packing of the pozzolanic materials using the Relative Density Index (d/d_o). d mixture which is supposed to be compact. The relative density (β) of paste is defined as:

$$\beta = \frac{d}{d_o}, \qquad (i)$$

where d denotes the density of the compacted paste, and d_o, the density of the dry mixtures which are supposed to be compacted.

To determine the value of d, initially the cup with the known weight and volume is taken. The prepared paste is then added to the cup and compacted on the vibrating table and then weighed. Then, d and d_o are calculated as:

$$d = \frac{W - W_o}{V}, \qquad (ii)$$

$$do = \frac{\sum W_i}{\sum W_i / d_i}, \qquad (iii)$$

where W_o and V respectively are the weight and volume of the empty cup and W is the weight of the cup and paste, and W_i and d_i respectively are the weights and densities of the cementitious materials.

The procedure adopted is as:

1. The materials are weighed and dry mixed according to the mix proportion selected. (Refer Fig. 3.4).
2. Then the water is to added as calculated from the decided w/b ratio and materials are mixed for 3 minutes forming a uniform paste. (Refer Fig. 3.6)
3. The prepared paste is then added to the cup gradually up to the brim while compacting it on the vibrating table for 4 minutes to expel out the entrapped air in the paste. (Refer Fig. 3.7)
4. After the compaction is done, the excess material above the brim of the cup is then scrapped off using the steel ruler from the upper face of the cup from one side of the cup to the other side so that the surface is levelled. (Refer Fig. 3.8)
5. The compacted material is then weighed and taken as W. (Refer Fig. 3.9)

6. The paste is then emptied from the cup and extra amount of water required as per the next w/b ratio is added to the paste and is again mixed thoroughly following the same procedure as above until the value of β once ascends and then descends.

Fig. 3.5: Dry mixed materials

Fig. 3.6: Prepared paste

Fig. 3.7: Compacting on vibrating table

Fig. 3.8: Levelling paste surface

Fig. 3.9: Weighing the compacted paste

3.4 EFFECT OF ADDITION OF SP ON THE RELATIVE DENSITY

After the particle packing tests had been performed, the effect of addition of the superplasticizer on the mixes was studied. The content of the SP was varied from 0.65% in the increments of 0.05% and its effect on the particle packing was studied. The water to the binder ratio here was kept constant at 0.19.

The procedure for the preparation of the mix was same as discussed in 3.3 except that the additional SP was added along with the water and the mixing time was kept at 5 minutes.

3.5 MARSH CONE TEST

In order to make a study on the rheological properties of the cement pastes, marsh cone test is performed. It provides us with the optimum dosage of the superplasticizer for a specific combination of cement and SP. The marsh cone test works by providing that quantity of SP beyond which the reduction in the flow time is not significant. Basically it provides that minimum dosage of the SP at which the workability of the paste is maximum. Marsh cone test was performed the 5 mix combinations which yielded the maximum packing density.

The test procedure followed was as below:

a) The amount of the cement for the test was fixed at 1100 gms.
b) The other cementitious materials were taken in the proportions as reflected by the selected mix combinations.
c) Superplasticizer by the weight of the total cementitious materials was taken with the increments of 0.5%.
d) The water content was taken at 0.19 of the total cementitious material.
e) The materials along with the water and superplasticizer were mixed thoroughly in the planetarium mixer for about 6 minutes till the thick slurry is formed. (Fig. 4.71)
f) The slurry formed was then transferred to the marsh cone by blocking the hole below with the help of the finger. (Fig. 4.72)
g) Once the whole mix was transferred, the hole was released and time as “Marsh Cone Time” was noted up till the cone was emptied. (Fig. 4.73)
h) The above procedure was then repeated for the increased value of the superplasticizer up till the decrease in the time was not significant.

Fig. 3.10 : Planetarium mixer

Fig. 3.11 : Material slurry

Fig. 3.12 : Test setup

3.6 CASTING

The mix design for the combinations was first prepared as presented in the chapter 4 and then further the casting of the combinations was carried out. The procedure for mixing of the materials followed was as follows.

1. The materials were weighed according to the mix design prepared.
2. The water required for the mix was measured in the graduated cylinder along with the SP.
3. The materials were poured into the bowl of the mixer (Planetarium mixer of the make Hobart) and the materials were dry mixed for 1.5 minutes at the first gear. (Refer Fig. 3.13)
4. Then about 70% of the water and the SP was poured into the mixer and the mixing was done for about 2 minutes at the first gear.
5. Then the remaining water and SP was added to the mix and the mixing was done for 2 minutes at the second gear.
6. Further again the gear was shifted to first and mixing was carried out for about 1.5 minutes.

Fig. 3.13: Mixing in Planetarium mixer

At this point of time the thick slurry was formed which was ready to be casted. The molds used for the casting were 7.07*7.07*7.07 cm. The nuts in the molds were properly tightened in order to ensure the correct dimensions. The molds were then properly oiled on the inner sides. Three cubes for the single mix were casted. The molds were placed on the vibration table and while vibrating, the material was added gradually in to the molds up till they are full to their brims. The total vibration time was kept at 4-5 minutes.

After all the cubes were casted, they were kept to set at the room temperature (5-10^{o}C) for 24 hrs and then demolded to be kept in the curing tank for the curing of cubes for 28 days.

3.7 COMPRESSIVE STRENGTH TEST

Casting of 8 mix designs was carried out and 3 cubes were casted for each combination in order to get the average of three. Therefore, a total of 24 cubes were tested for the compressive strength. The compression testing was performed on universal testing machine with the load rating of 2.5 $kN/mm^2/min$. Before carrying out the compression test, the cubes were removed from the curing tank and kept in the open until they get surface dried. After drying, the top and the bottom dimensions of the cubes were taken with ruler. In order to get the area, the average of the top and bottom surface was considered. The cubes were placed one by one on the bearing of the UTM and the load application was continued till the cubes failed.

The compressive strength was calculated as:

$$\text{Compressive Strength} = \frac{\text{Load}}{\text{Average area}}\ \text{MPa}$$

Fig. 3.14: Compression testing in UTM

CHAPTER 4

MIX DESIGN

4.1 CEMENT CONTENT FIXED AT 1100 KG/M^3

4.1.1 MIX DESIGN OF CMURF 44

Conditions:

1. Quantity of cement = 1100 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 0.95
4. Mix proportion = 70:8:9:7:6

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}
   = 0.001132 mm^3
2. Weight of Cement = 1100*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}
   = 1245.1 gm
3. Weight of Metakaolin = 1100/70*8 = 125.71 kg/m^3
   = 125.71*0.001132*1000 = 142.3 gm
4. Weight of Ultrafine slag = 1100/70*9 = 141.43 kg/m^3
   = 141.43*0.001132*1000 = 160.1 gm
5. Weight of Rice Husk Ash = 1100/70*7 = 110 kg/m^3
   = 110*0.001132*1000 = 124.5 gm
6. Weight of Fly Ash = 1100/70*6 = 94.29 kg/m^3
   = 94.29*0.001132*1000 = 106.7 gm
7. Total cementitious materials (TCM) = 1245.1+142.3+160.1+124.5+106.7 = 1778.7 gm
8. Quantity of SP = 0.95*1778.7/100 = 14.93 {95% of TCM}
   = 14.93*0.001132*1000 = 16.9 gm
9. Weight of water = 0.19*1778.7 = 298.57 kg/m^3
10. Total volume of fine aggregates = 1-(((1100/3.15) + (125.71/2.5) + (141.43/2.86) +
    (110/2.53) + (94.29/2.17) + 298.57)/1000) = 0.1656 m^3
    {1 m^3- volume of TCM}
11. Weight of QP = 5/100*0.1656*2.65*1000 = 21.94 kg/m^3
    {5% QP of tot. vol. * Sp. gr. of QP * 1000}
    = 21.94*0.001132*1000 = 24.8 gm

12. Volume of QS+MS = 0.1656-(21.94/(2.6*1000)) = 0.1571 m^3

{Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}

13. Weight of QS (50%) = 50/100*0.1571*2.34*1000 = 183.83 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 183.83*0.001132*1000 = 208.1 gm

14. Weight of MS (50%) = 50/100*0.1571*2.65*1000 = 204.26 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 204.26*0.001132*1000 = 231.2 gm

15. Corrected weight of water = 298.57 - (14.93*64/100) + (0.004*183.83) + (0.01*204.26)

= 291.80 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 291.8*0.001132*1000 = 330.3 ml

4.1.2 MIX DESIGN OF CMURF 45

Conditions:

1. Quantity of cement = 1100 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 0.95
4. Mix proportion = 70:8:10:7:5

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}

   = 0.001132 mm^3

2. Weight of Cement = 1100*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}

   = 1245.1 gm

3. Weight of Metakaolin = 1100/70*8 = 125.71 kg/m^3

   = 125.71*0.001132*1000 = 142.3 gm

4. Weight of Ultrafine slag = 1100/70*10 = 157.14 kg/m^3

   = 157.14*0.001132*1000 = 177.9 gm

5. Weight of Rice Husk Ash = 1100/70*7 = 110 kg/m^3

   = 110*0.001132*1000 = 124.5 gm

6. Weight of Fly Ash = 1100/70*5 = 78.57 kg/m^3

   = 78.57*0.001132*1000 = 88.9 gm

7. Total cementitious materials (TCM) = 1245.1+142.3+177.9+124.5+88.9 = 1778.7 gm

8. Quantity of SP = 0.95*1778.7/100 = 14.93 {95% of TCM}

= 14.93*0.001132*1000 = 16.9 gm

9. Weight of water = 0.19*1778.7 = 298.57 kg/m^3

10. Total volume of fine aggregates = 1-(((1100/3.15) + (125.71/2.5) + (157.14/2.86) + (110/2.53) + (78.57/2.17) + 298.57)/1000) = 0.1673 m^3

{1 m^3- volume of TCM}

11. Weight of QP = 5/100*0.1673*2.65*1000 = 22.17 kg/m^3

{5% QP of tot. vol. * Sp. gr. of QP * 1000}

= 22.17 *0.001132*1000 = 25.1 gm

12. Volume of QS+MS = 0.1673-(22.17/(2.6*1000)) = 0.1588 m^3

{Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}

13. Weight of QS (50%) = 50/100*0.1588*2.34*1000 = 185.77 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 183.83*0.001132*1000 = 210.3 gm

14. Weight of MS (50%) = 50/100*0.1588*2.65*1000 = 206.41 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 204.26*0.001132*1000 = 233.6 gm

15. Corrected weight of water = 298.57 - (14.93*64/100) + (0.004*185.77) + (0.01*210.3)

= 291.82 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 291.82*0.001132*1000 = 330.3 ml

4.1.3 MIX DESIGN OF CMURF 46

Conditions:

1. Quantity of cement = 1100 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 0.95
4. Mix proportion = 70:8:11:6:5

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}

= 0.001132 mm^3

2. Weight of Cement = 1100*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}

= 1245.1 gm

3. Weight of Metakaolin = 1100/70*8 = 125.71 kg/m^3

= 125.71*0.001132*1000 = 142.3 gm

4. Weight of Ultrafine slag = 1100/70*11 = 172.86 kg/m^3

= 172.86*0.001132*1000 = 195.66 gm

5. Weight of Rice Husk Ash = 1100/70*6 = 94.29 kg/m^3

= 94.29*0.001132*1000 = 106.72 gm

6. Weight of Fly Ash = 1100/70*5 = 78.57 kg/m^3

= 78.57*0.001132*1000 = 88.9 gm

7. Total cementitious materials (TCM) = 1245.1+142.3+195.66+106.72+88.9 = 1778.7 gm

8. Quantity of SP = 0.95*1778.7/100 = 14.93 {95% of TCM}

= 14.93*0.001132*1000 = 16.9 gm

9. Weight of water = 0.19*1778.7 = 298.57 kg/m^3

10. Total volume of fine aggregates = 1-(((1100/3.15) + (125.71/2.5) + (172.86/2.86) + (94.29/2.53) + (78.57/2.17) + 186.57)/1000) = 0.1680 m^3

{1 m^3- volume of TCM}

11. Weight of QP = 5/100*0.1680*2.65*1000 = 22.26 kg/m^3

{5% QP of tot. vol. * Sp. gr. of QP * 1000}

= 22.26*0.001132*1000 = 25.2 gm

12. Volume of QS+MS = 0.1680-(22.26/(2.6*1000)) = 0.1595 m^3

{Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}

13. Weight of QS (50%) = 50/100*0.1595*2.34*1000 = 186.57 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 183.83*0.001132*1000 = 211.18 gm

14. Weight of MS (50%) = 50/100*0.1595*2.65*1000 = 207.3 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 207.3*0.001132*1000 = 234.64 gm

15. Corrected weight of water = 298.57 - (14.93*64/100) + (0.004*186.57) + (0.01*207.3)

= 291.84 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 291.84*0.001132*1000 = 330.33 ml

4.1.4 MIX DESIGN OF CMURF 58

Conditions:

1. Quantity of cement = 1100 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 0.9%
4. Mix proportion = 70:11:9:6:4

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}
   = 0.001132 mm^3
2. Weight of Cement = 1100*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}
   = 1245.1 gm
3. Weight of Metakaolin = 1100/70*11 = 172.86 kg/m^3
   = 172.86*0.001132*1000 = 195.66 gm
4. Weight of Ultrafine slag = 1100/70*9 = 141.43 kg/m^3
   = 141.43*0.001132*1000 = 160.1 gm
5. Weight of Rice Husk Ash = 1100/70*6 = 94.29 kg/m^3
   = 94.29*0.001132*1000 = 106.72 gm
6. Weight of Fly Ash = 1100/70*4 = 62.86 kg/m^3
   = 62.86*0.001132*1000 = 71.15 gm
7. Total cementitious materials (TCM) = 1245.1+195.66+160.1+106.72+71.15 = 1778.7 gm
8. Quantity of SP = 0.9*1778.7/100 = 14.1 {90% of TCM}
   = 14.1*0.001132*1000 = 16.01 gm
9. Weight of water = 0.19*1778.7 = 298.57 kg/m^3
10. Total volume of fine aggregates = 1-(((1100/3.15) + (172.86/2.5) + (141.43/2.86) +
    (94.29/2.53) + (62.86/2.17) + 298.57)/1000) = 0.1674 m^3
    {1 m^3- volume of TCM}
11. Weight of QP = 5/100*0.1673*2.65*1000 = 22.17 kg/m^3
    {5% QP of tot. vol. * Sp. gr. of QP * 1000}
    = 22.17*0.001132*1000 = 25.11 gm
12. Volume of QS+MS = 0.1673-(22.17/(2.6*1000)) = 0.1589 m^3
    {Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}
13. Weight of QS (50%) = 50/100*0.1589*2.34*1000 = 185.87 kg/m^3
    {50% QP*Vol in 12*Sp. gr. of QP*1000}
    = 185.87*0.001132*1000 = 210.39 gm

14. Weight of MS (50%) = 50/100*0.1589*2.65*1000 = 206.52 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 204.52*0.001132*1000 = 233.76 gm

15. Corrected weight of water = 298.57 - (14.14*64/100) + (0.004*185.87) + (0.01*206.52)

= 292.33 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 292.33*0.001132*1000 = 330.89 ml

4.1.5 MIX DESIGN OF CMURF 65

Conditions:

1. Quantity of cement = 1100 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 0.9%
4. Mix proportion = 65:11:11:7:6

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}

   = 0.001132 mm^3
2. Weight of Cement = 1100*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}

   = 1245.1 gm
3. Weight of Metakaolin = 1100/65*11 = 186.15 kg/m^3

   = 186.15*0.001132*1000 = 186.15 gm
4. Weight of Ultrafine slag = 1100/65*11 = 141.43 kg/m^3

   = 186.15*0.001132*1000 = 186.15 gm
5. Weight of Rice Husk Ash = 1100/65*7 = 118.46 kg/m^3

   = 118.46*0.001132*1000 = 134.09 gm
6. Weight of Fly Ash = 1100/65*6 = 101.54 kg/m^3

   = 101.54*0.001132*1000 = 114.93 gm
7. Total cementitious materials (TCM) = 1245.1+186.15+141.43+118.46+101.54 = 1915.52 gm
8. Quantity of SP = 0.9*1915.52/100 = 15.23 {90% of TCM}

   = 15.23*0.001132*1000 = 17.24 gm
9. Weight of water = 0.19*1915.52 = 321.54 kg/m^3

10. Total volume of fine aggregates = 1-(((1100/3.15) + (186.15/2.5) + (141.43/2.86) + (118.46/2.53) + (101.54/2.17) + 298.57)/1000) = 0.0961 m^3

{1 m^3- volume of TCM}

11. Weight of QP = 5/100*0.0961*2.65*1000 = 12.73 kg/m^3

{5% QP of tot. vol. * Sp. gr. of QP * 1000}

= 12.73*0.001132*1000 = 14.41 gm

12. Volume of QS+MS = 0.0961-(14.41/(2.6*1000)) = 0.0912 m^3

{Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}

13. Weight of QS (50%) = 50/100*0.0912*2.34*1000 = 106.7 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 106.7*0.001132*1000 = 120.77 gm

14. Weight of MS (50%) = 50/100*0.0912*2.65*1000 = 118.55 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 118.55*0.001132*1000 = 134.19 gm

15. Corrected weight of water = 321.54 - (15.23*64/100) + (0.004*106.7) + (0.01*118.55)

= 313.4 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 313.4*0.001132*1000 = 354.74 ml

4.2 CEMENT CONTENT FIXED AT 900 KG/M^3

4.2.1 MIX DESIGN OF CMURF 44

Conditions:

1. Quantity of cement = 900 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 1.05%
4. Mix proportion = 70:8:9:7:6

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}

= 0.001132 mm^3

2. Weight of Cement = 900*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}

= 1018.71 gm

3. Weight of Metakaolin = 900/70*8 = 102.86 kg/m^3

= 102.86*0.001132*1000 = 116.42 gm

4. Weight of Ultrafine slag = 900/70*9 = 115.71 kg/m^3

= 115.71*0.001132*1000 = 130.98 gm

5. Weight of Rice Husk Ash = 900/70*7 = 90 kg/m^3

= 90*0.001132*1000 = 101.87 gm

6. Weight of Fly Ash = 900/70*6 = 77.14 kg/m^3

= 77.14*0.001132*1000 = 87.32 gm

7. Total cementitious materials (TCM) = 1018.71+116.42+130.98+101.87+87.32 = 1455.30 gm

8. Quantity of SP = 1.05*1455.3/100 = 13.5 {1.05% of TCM}

= 13.5*0.001132*1000 = 15.28 gm

9. Weight of water = 0.19*1455.3 = 244.29 kg/m^3

10. Total volume of fine aggregates = 1-(((900/3.15) + (102.86/2.5) + (115.71/2.86) + (90/2.53)

+ (77.14/2.17) + 244.29)/1000) = 0.3173 m^3

{1 m^3- volume of TCM}

11. Weight of QP = 5/100*0.3173*2.65*1000 = 42.04 kg/m^3

{5% QP of tot. vol. * Sp. gr. of QP * 1000}

= 42.04*0.001132*1000 = 47.58 gm

12. Volume of QS+MS = 0.3173-(42.04/(2.6*1000)) = 0.3011 m^3

{Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}

13. Weight of QS (50%) = 50/100*0.3011*2.34*1000 = 352.29 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 352.29*0.001132*1000 = 398.76 gm

14. Weight of MS (50%) = 50/100*0.3011*2.65*1000 = 391.44 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 391.44*0.001132*1000 = 443.07 gm

15. Corrected weight of water = 244.29 - (13.5*64/100) + (0.004*352.29) + (0.01*391.44)

= 240.97 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 240.97*0.001132*1000 = 272.75 ml

1.2.2 MIX DESIGN OF CMURF 45

Conditions:

1. Quantity of cement = 900 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 1.05%
4. Mix proportion = 70:8:10:7:5

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}
   = 0.001132 mm^3
2. Weight of Cement = 900*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}
   = 1018.71 gm
3. Weight of Metakaolin = 900/70*8 = 102.86 kg/m^3
   = 102.86*0.001132*1000 = 116.42 gm
4. Weight of Ultrafine slag = 900/70*10 = 128.57 kg/m^3
   = 128.57*0.001132*1000 = 145.5 gm
5. Weight of Rice Husk Ash = 900/70*7 = 90 kg/m^3
   = 90*0.001132*1000 = 101.87 gm
6. Weight of Fly Ash = 900/70*5 = 64.29 kg/m^3
   = 64.29*0.001132*1000 = 72.8 gm
7. Total cementitious materials (TCM) = 1018.71+116.42+145.5+101.87+72.8 = 1455.30 gm
8. Quantity of SP = 1.05*1455.3/100 = 13.5 {1.05% of TCM}
   = 13.5*0.001132*1000 = 15.28 gm
9. Weight of water = 0.19*1455.3 = 244.29 kg/m^3
10. Total volume of fine aggregates = 1-(((900/3.15) + (102.86/2.5) + (128.57/2.86) + (90/2.53)
    + (64.29/2.17) + 244.29)/1000) = 0.3187 m^3
    {1 m^3- volume of TCM}
11. Weight of QP = 5/100*0.3187*2.65*1000 = 42.23 kg/m^3
    {5% QP of tot. vol. * Sp. gr. of QP * 1000}
    = 42.23*0.001132*1000 = 47.8 gm
12. Volume of QS+MS = 0.3187-(42.23/(2.6*1000)) = 0.3025 m^3
    {Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}
13. Weight of QS (50%) = 50/100*0.3025*2.34*1000 = 353.88 kg/m^3
    {50% QP*Vol in 12*Sp. gr. of QP*1000}
    = 353.88*0.001132*1000 = 400.6 gm

14. Weight of MS (50%) = 50/100*0.3025*2.65*1000 = 393.2 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 393.2*0.001132*1000 = 445.1 gm

15. Corrected weight of water = 244.29 - (13.5*64/100) + (0.004*400.6) + (0.01*393.2)

= 240.99 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 240.99*0.001132*1000 = 272.8 ml

1.2.3 MIX DESIGN OF CMURF 46

Conditions:

1. Quantity of cement = 900 kg/m^3
2. Water to binder ratio = 0.19
3. Content of superplasticizer = 1.1%
4. Mix proportion = 70:8:11:6:5

Mix Calculations:

1. Volume of 3 cubes = (0.07*0.07*0.07) *3*1.1 {considering 10% extra}

   = 0.001132 mm^3
2. Weight of Cement = 900*0.001132*1000 {cement per m^3 * volume of 3 cubes * 1000}

   = 1018.71 gm
3. Weight of Metakaolin = 900/70*8 = 102.86 kg/m^3

   = 102.86*0.001132*1000 = 116.42 gm
4. Weight of Ultrafine slag = 900/70*11 = 141.43 kg/m^3

   = 141.43*0.001132*1000 = 160.08 gm
5. Weight of Rice Husk Ash = 900/70*6 = 77.14 kg/m^3

   = 77.14*0.001132*1000 = 87.32 gm
6. Weight of Fly Ash = 900/70*5 = 64.29 kg/m^3

   = 64.29*0.001132*1000 = 72.77 gm
7. Total cementitious materials (TCM) = 1018.71+116.42+160.08+87.32+72.77 = 1455.30 gm
8. Quantity of SP = 1.1*1455.3/100 = 14.14 {1.1% of TCM}

   = 14.14*0.001132*1000 = 16.01 gm
9. Weight of water = 0.19*1455.3 = 244.29 kg/m^3
10. Total volume of fine aggregates = 1-(((900/3.15) + (102.86/2.5) + (141.43/2.86) + (77.14/2.53) + (64.29/2.17) + 244.29)/1000) = 0.3193 m^3

{1 m^3- volume of TCM}

11. Weight of QP = 5/100*0.3193*2.65*1000 = 42.31 kg/m^3

{5% QP of tot. vol. * Sp. gr. of QP * 1000}

= 42.31*0.001132*1000 = 47.89 gm

12. Volume of QS+MS = 0.3193-(42.31/(2.6*1000)) = 0.3030 m^3

{Vol of fine agg. - (Wt. of QP/Sp. gr. of QP*1000)}

13. Weight of QS (50%) = 50/100*0.3030*2.34*1000 = 354.53 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 354.53*0.001132*1000 = 401.3 gm

14. Weight of MS (50%) = 50/100*0.3030*2.65*1000 = 393.92 kg/m^3

{50% QP*Vol in 12*Sp. gr. of QP*1000}

= 393.92*0.001132*1000 = 445.88 gm

15. Corrected weight of water = 244.29 - (14.14*64/100) + (0.004*354.53) + (0.01*393.92)

= 240.59 kg/m^3

{Wt. of water – (Water content of SP + Water absorption of QS + Water absorption of MS)}

= 240.59*0.001132*1000 = 272.33 ml

CHAPTER 5

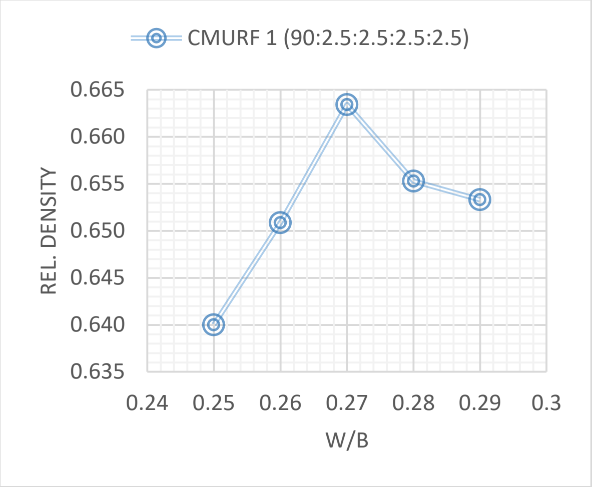
RESULTS AND DISCUSSIONS

5.1 PACKING DENSITY RESULTS

The trial mixes prepared as discussed in the chapter 3 were tested for the particle packing of the cementitious materials and calculations were done and the results of the same were compared. The results for the calculation of Relative Density are presented below:

Table 5.1
Relative Density of combinations 1-6

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative density, β
CMURF 1 (90:2.5:2.5:2.5:2.5)	1	0.25	374.25	259.25	0.640
	2	0.26	378.65	263.65	0.651
	3	0.27	383.75	268.75	0.663
	4	0.28	380.45	265.45	0.655
	5	0.29	379.65	264.65	0.653
CMURF 2 (90:2.5:3.5:2:2)	6	0.25	381.7	266.7	0.657
	7	0.26	386.1	271.1	0.668
	8	0.27	388.2	273.2	0.673
	9	0.28	389.2	274.2	0.675
	10	0.29	386.2	271.2	0.668
CMURF 3 (90:3:3:2:2)	11	0.26	384.8	269.8	0.665
	12	0.27	389.6	274.6	0.677
	13	0.28	389.85	274.85	0.677
	14	0.29	392.1	277.1	0.683
	15	0.3	388.5	273.5	0.674
CMURF 4 (90:3.5:2.5:2:2)	16	0.26	384.4	269.4	0.664
	17	0.27	388.5	273.5	0.675
	18	0.28	385.3	270.3	0.667
	19	0.29	385.2	270.2	0.666
CMURF 5 (85:3.75:3.75:3.75:3.75)	20	0.25	389.75	274.75	0.687
	21	0.26	391.8	276.8	0.692
	22	0.27	394.5	279.5	0.699
	23	0.28	391.65	276.65	0.692
CMURF 6 (85:4:4:4:3)	24	0.25	388.15	273.15	0.684
	25	0.26	395	280	0.702
	26	0.27	396.45	281.45	0.705
	27	0.28	394.2	279.2	0.700



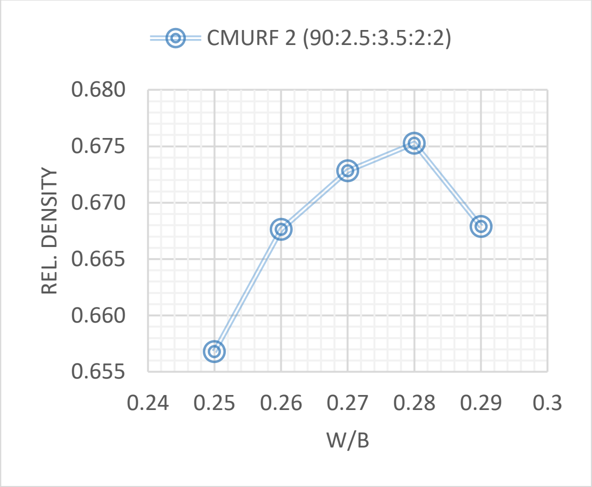
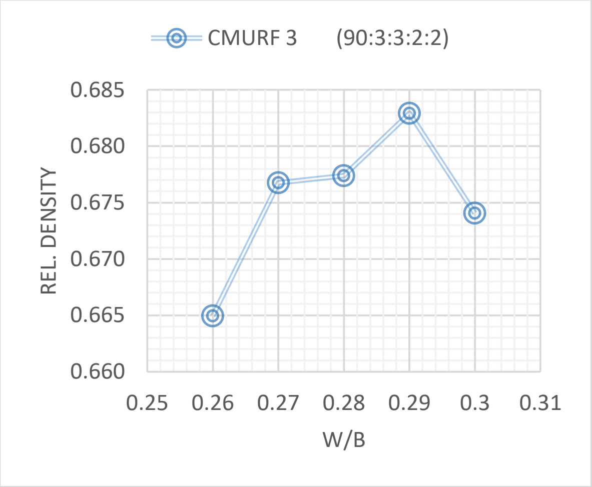


Fig. 5.1: Graph for combination 1

Fig. 5.2: Graph for combination 2



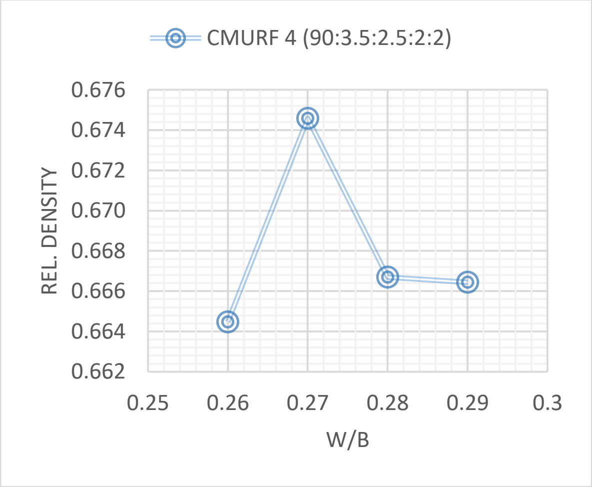
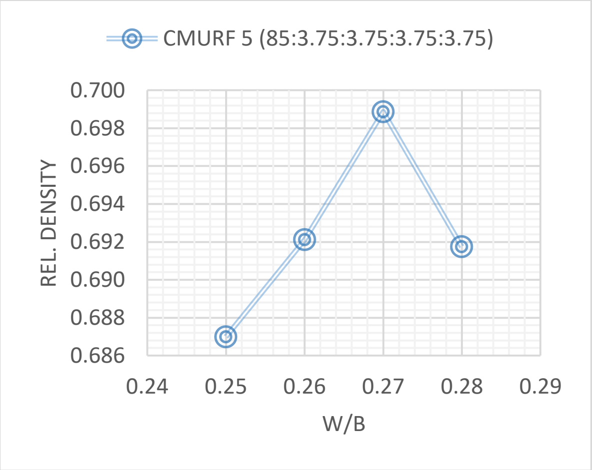


Fig. 5.3: Graph for combination 3

Fig. 5.4: Graph for combination 4



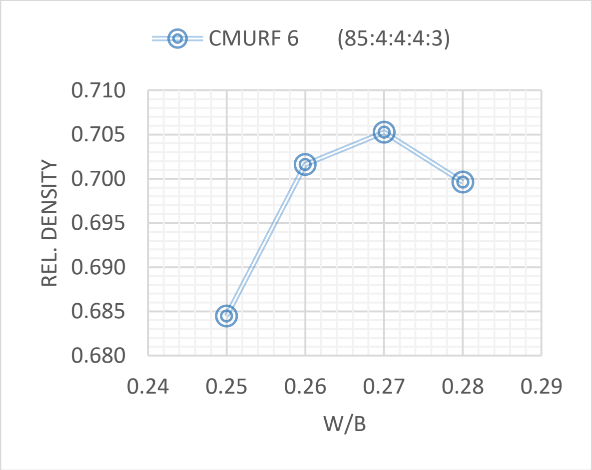


Fig. 5.5: Graph for combination 5

Fig. 5.6: Graph for combination 6

Table 5.2
Relative Density of combinations 7-12

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative density, β
CMURF 7 (85:4:5:3:3)	28	0.25	389.75	274.75	0.685
	29	0.26	394.65	279.65	0.697
	30	0.27	395.15	280.15	0.698
	31	0.28	394.4	279.4	0.696
CMURF 8 (85:4:7:2:2)	32	0.25	392.6	277.6	0.689
	33	0.26	395.5	280.5	0.696
	34	0.27	394.85	279.85	0.694
	35	0.28	393.7	278.7	0.691
CMURF 9 (85:5:4:3:3)	36	0.25	390.9	275.9	0.689
	37	0.26	393.8	278.8	0.696
	38	0.27	395	280	0.699
	39	0.28	394.2	279.2	0.697
CMURF 10 (85:5:5:3:2)	40	0.25	390.9	275.9	0.686
	41	0.26	394.25	279.25	0.695
	42	0.27	396	281	0.699
	43	0.28	393.15	278.15	0.692
CMURF 11 (85:5:6:2:2)	44	0.25	390.65	275.65	0.685
	45	0.26	393.7	278.7	0.692
	46	0.27	395.3	280.3	0.696
	47	0.28	393.55	278.55	0.692
CMURF 12 (85:5.5:5.5:2:2)	48	0.25	390.3	275.3	0.684
	49	0.26	393.7	278.7	0.693
	50	0.27	395.3	280.3	0.697
	51	0.28	393.55	278.55	0.693

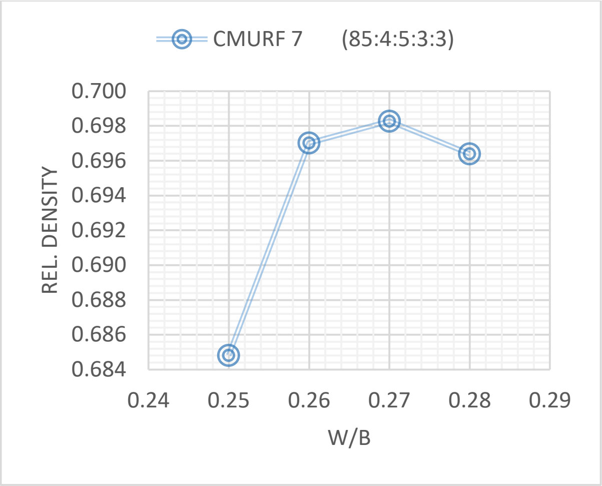


Fig. 5.7: Graph for combination 7

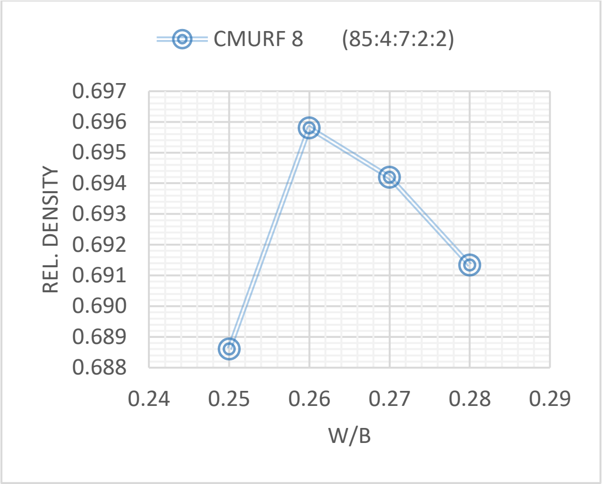


Fig. 5.8: Graph for combination 8

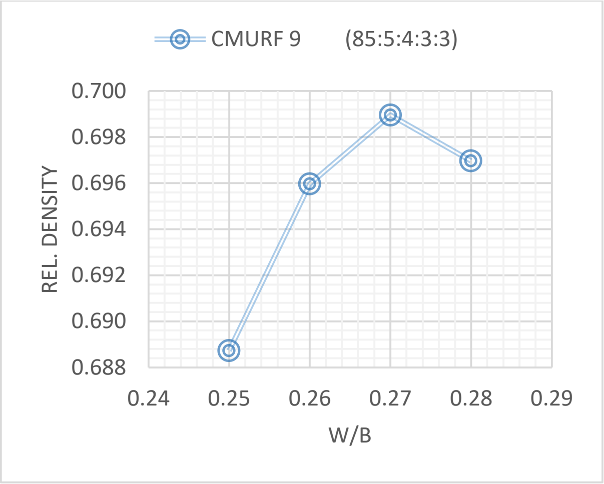


Fig. 5.9: Graph for combination 9

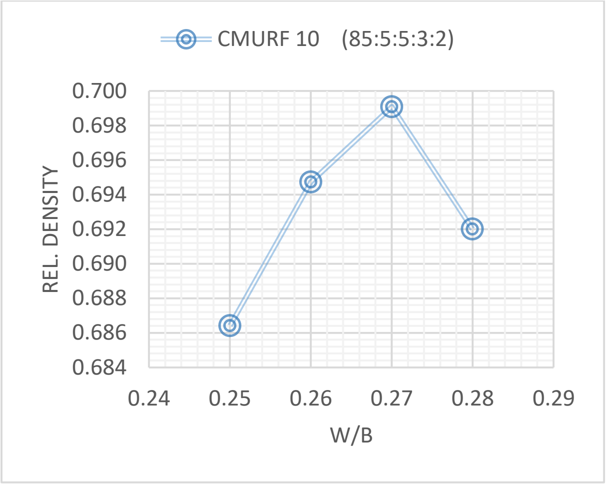


Fig. 5.10: Graph for combination 10

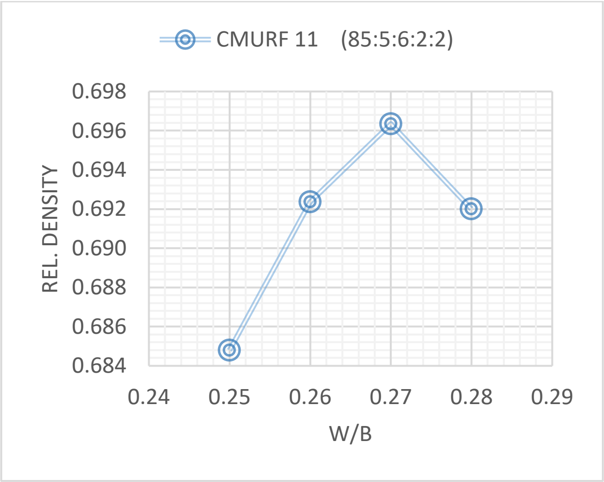


Fig. 5.11: Graph for combination 11

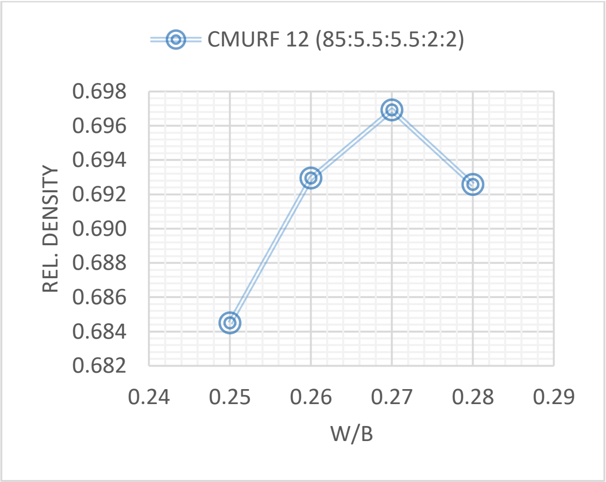


Fig. 5.12: Graph for combination 12

Table 5.3
Relative Density of combinations 13-18

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 13 (85:6:4:3:2)	52	0.26	389.2	274.2	0.684
	53	0.27	392.1	277.1	0.691
	54	0.28	393.2	278.2	0.694
	55	0.29	393	278	0.693
CMURF 14 (85:6:5:2:2)	56	0.26	393.25	278.25	0.692
	57	0.27	395.45	280.45	0.698
	58	0.28	397.45	282.45	0.703
	59	0.29	395.75	280.75	0.699
CMURF 15 (85:7:4:2:2)	60	0.26	390.9	275.9	0.688
	61	0.27	395.1	280.1	0.698
	62	0.28	393.85	278.85	0.695
	63	0.29	392.1	277.1	0.691
CMURF 16 (80:5:5:5:5)	64	0.26	389.05	274.05	0.694
	65	0.27	392.6	277.6	0.703
	66	0.28	391.2	276.2	0.699
CMURF 17 (80:5:6:5:4)	67	0.26	389.7	274.7	0.693
	68	0.27	390.95	275.95	0.696
	69	0.28	392.55	277.55	0.700
	70	0.29	391.9	276.9	0.699
CMURF 18 (80:5:7:4:4)	71	0.26	391.25	276.25	0.696
	72	0.27	393.35	278.35	0.702
	73	0.28	394.5	279.5	0.704
	74	0.29	393.3	278.3	0.701

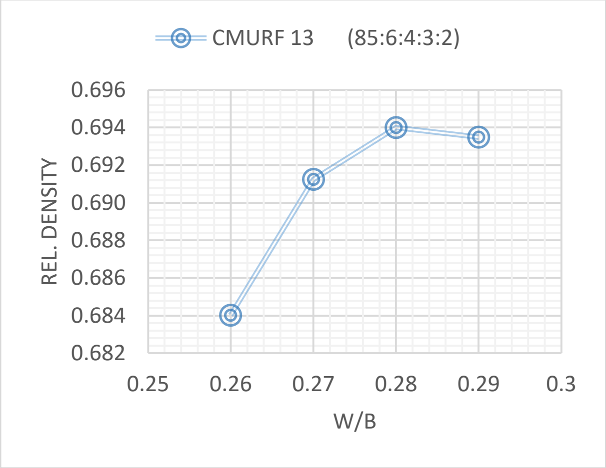


Fig. 5.13: Graph for combination 13

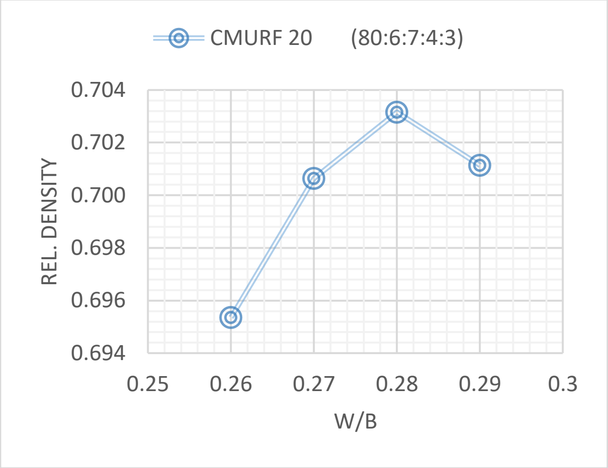


Fig. 5.14: Graph for combination 14

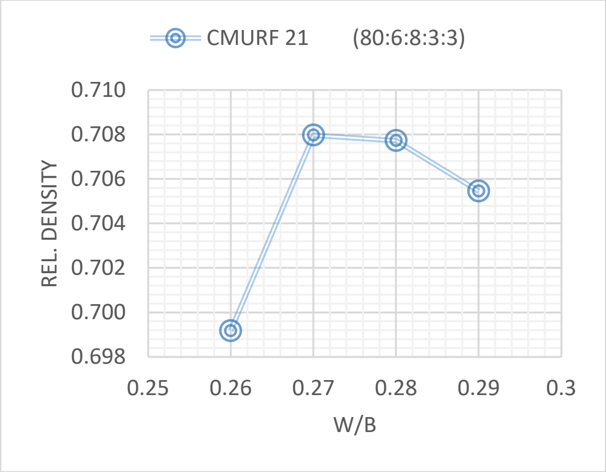


Fig. 5.15: Graph for combination 15

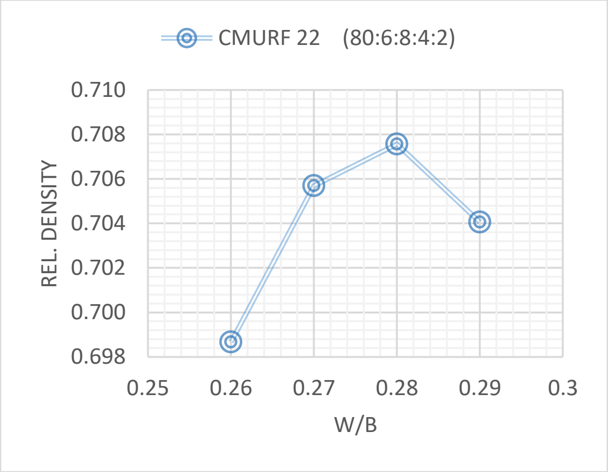


Fig. 5.16: Graph for combination 16

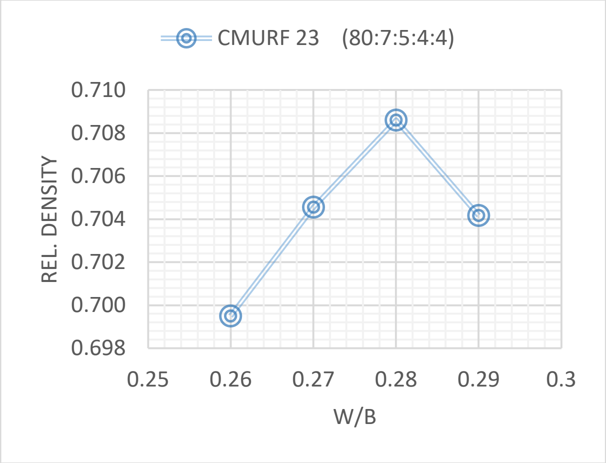


Fig. 5.17: Graph for combination 17

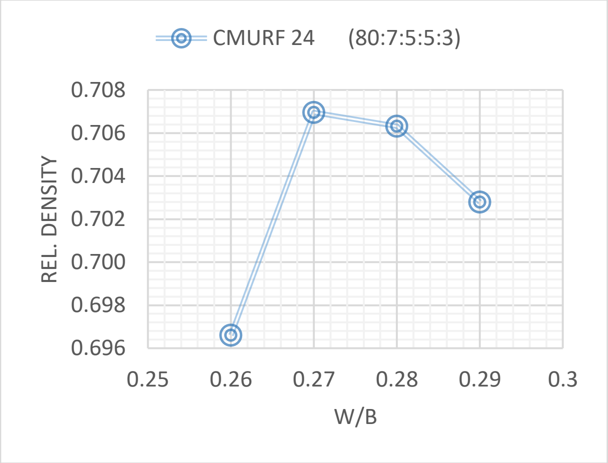
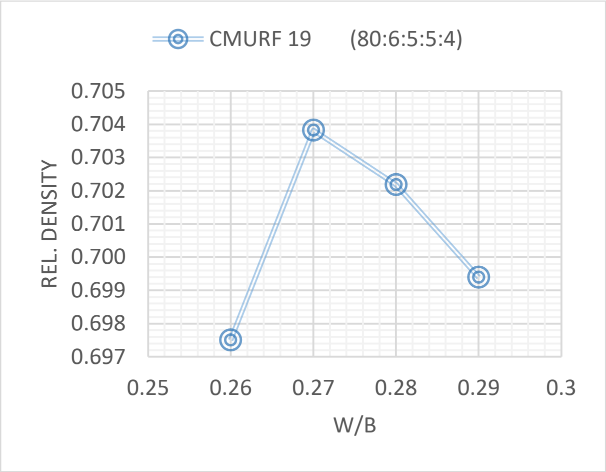


Fig. 5.18: Graph for combination 18

Table 5.4

Relative Density of combinations 19-24

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 19 (80:6:5:5:4)	75	0.26	390.95	275.95	0.697
	76	0.27	393.45	278.45	0.704
	77	0.28	392.8	277.8	0.702
	78	0.29	391.7	276.7	0.699
CMURF 20 (80:6:7:4:3)	79	0.26	391.4	276.4	0.695
	80	0.27	393.5	278.5	0.701
	81	0.28	394.5	279.5	0.703
	82	0.29	393.7	278.7	0.701
CMURF 21 (80:6:8:3:3)	83	0.26	393.3	278.3	0.699
	84	0.27	396.8	281.8	0.708
	85	0.28	396.7	281.7	0.708
	86	0.29	395.8	280.8	0.705
CMURF 22 (80:6:8:4:2)	87	0.26	393.65	278.65	0.699
	88	0.27	396.45	281.45	0.706
	89	0.28	397.2	282.2	0.708
	90	0.29	395.8	280.8	0.704
CMURF 23 (80:7:5:4:4)	91	0.26	391.7	276.7	0.699
	92	0.27	393.7	278.7	0.705
	93	0.28	395.3	280.3	0.709
	94	0.29	393.55	278.55	0.704
CMURF 24 (80:7:5:5:3)	95	0.26	391.1	276.1	0.697
	96	0.27	395.2	280.2	0.707
	97	0.28	394.95	279.95	0.706
	98	0.29	393.55	278.55	0.703



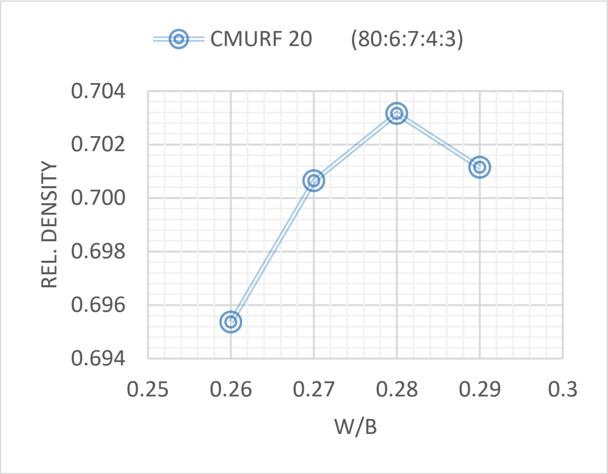
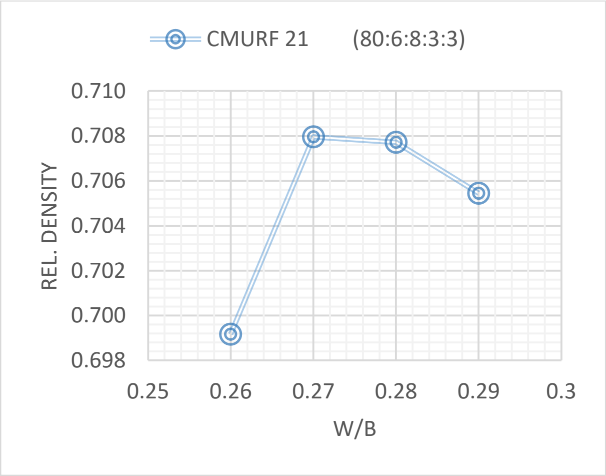


Fig. 5.19: Graph for combination 19

Fig. 5.20: Graph for combination 20



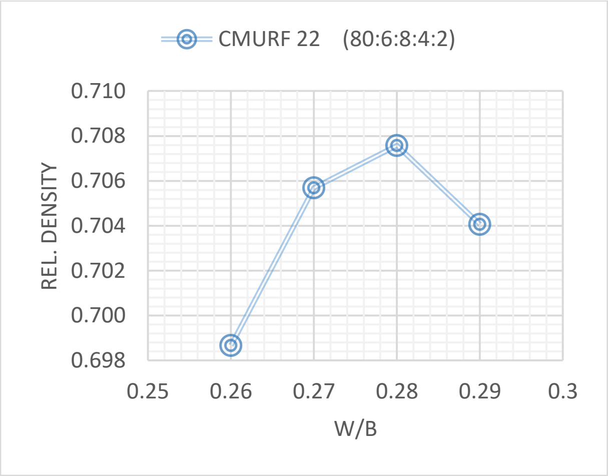
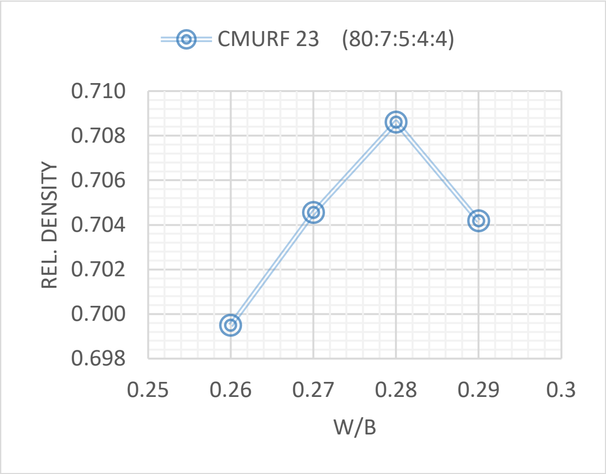


Fig. 5.21: Graph for combination 21

Fig. 5.22: Graph for combination 22



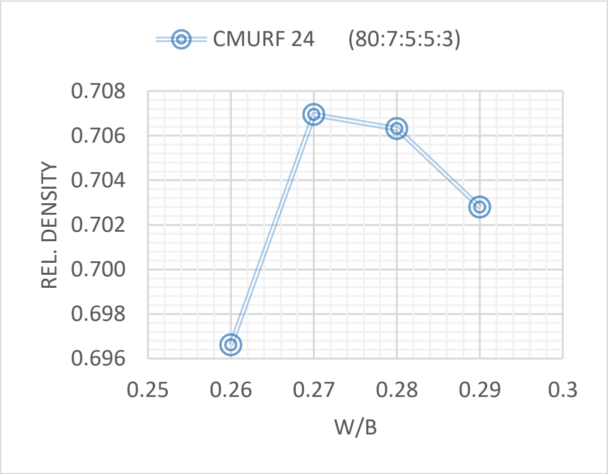
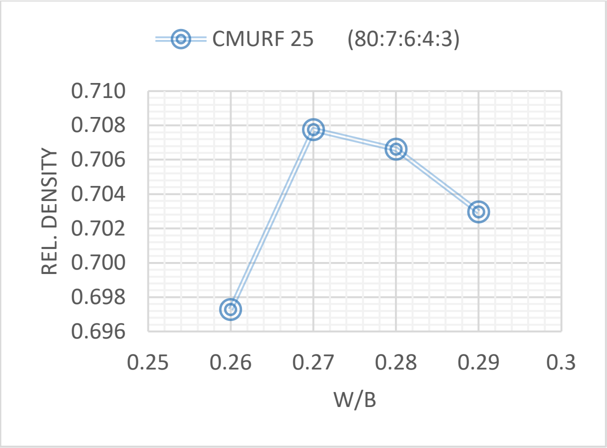


Fig. 5.23: Graph for combination 23

Fig. 5.24: Graph for combination 24

Table 5.5
Relative Density of combinations 25-30

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 25 (80:7:6:4:3)	99	0.26	391.75	276.75	0.697
	100	0.27	395.9	280.9	0.708
	101	0.28	395.45	280.45	0.707
	102	0.29	394	279	0.703
CMURF 26 (80:8:6:3:3)	103	0.26	391	276	0.695
	104	0.27	395.2	280.2	0.706
	105	0.28	394.45	279.45	0.704
	106	0.29	393.85	278.85	0.703
CMURF 27 (80:8:6:4:2)	107	0.26	386.4	271.4	0.683
	108	0.27	396.1	281.1	0.707
	109	0.28	396.8	281.8	0.709
	110	0.29	395.9	280.9	0.706
CMURF 28 (75:7:7:6:5)	111	0.26	390	275	0.703
	112	0.27	393.85	278.85	0.713
	113	0.28	393.4	278.4	0.711
	114	0.29	392.7	277.7	0.710
CMURF 29 (75:7:8:5:5)	115	0.26	390.75	275.75	0.704
	116	0.27	394.6	279.6	0.714
	117	0.28	395.3	280.3	0.715
	118	0.29	393.8	278.8	0.712
CMURF 30 (75:7:8:6:4)	119	0.26	393.45	278.45	0.709
	120	0.27	395	280	0.713
	121	0.28	395.6	280.6	0.715
	122	0.29	394.8	279.8	0.713



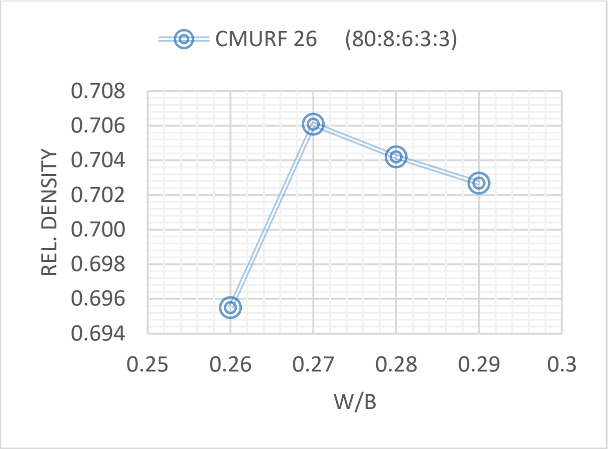
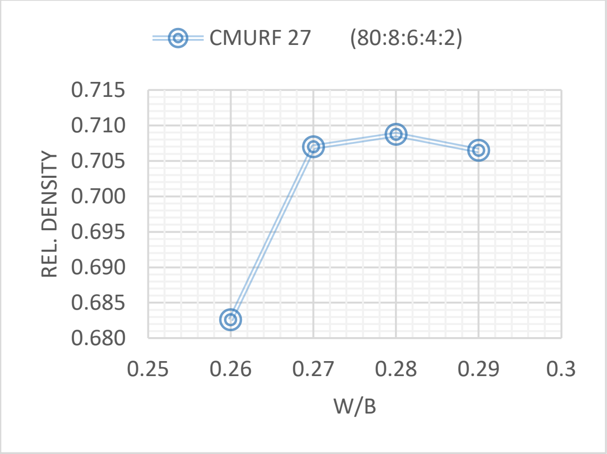


Fig. 5.25: Graph for combination 25

Fig. 5.26: Graph for combination 26



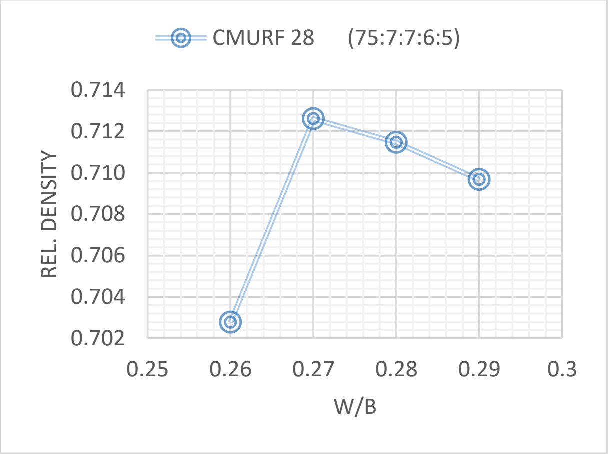
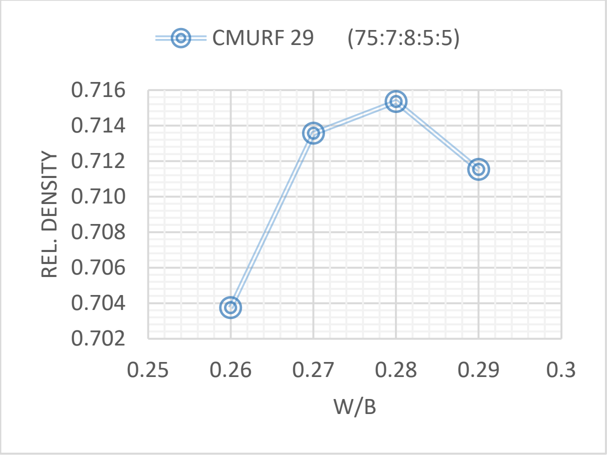


Fig. 5.27: Graph for combination 27

Fig. 5.28: Graph for combination 28



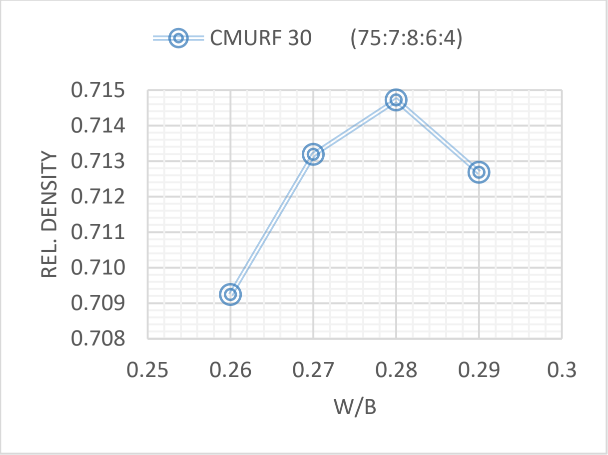
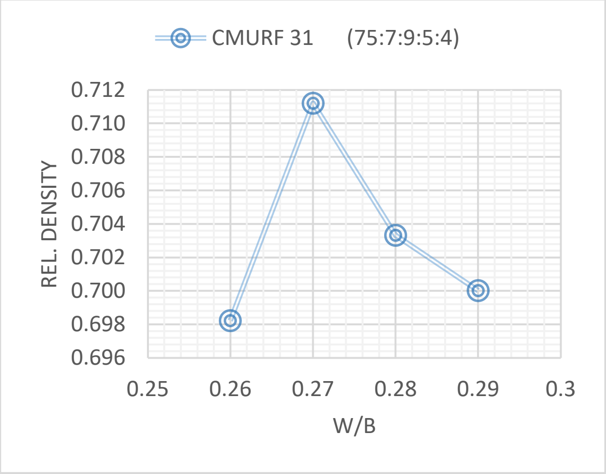


Fig. 5.29: Graph for combination 29

Fig. 5.30: Graph for combination 30

Table 5.6
Relative Density of combinations 31-36

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 31 (75:7:9:5:4)	123	0.26	389.5	274.5	0.698
	124	0.27	394.6	279.6	0.711
	125	0.28	391.5	276.5	0.703
	126	0.29	390.2	275.2	0.700
CMURF 32 (75:7:10:5:3)	127	0.26	392.8	277.8	0.704
	128	0.27	395.5	280.5	0.711
	129	0.28	394.15	279.15	0.708
	130	0.29	393.85	278.85	0.707
CMURF 33 (75:8:7:5:5)	131	0.26	389	274	0.700
	132	0.27	393	278	0.711
	133	0.28	393.9	278.9	0.713
	134	0.29	390.3	275.3	0.704
CMURF 34 (75:8:7:6:4)	135	0.26	390.2	275.2	0.702
	136	0.27	393.35	278.35	0.710
	137	0.28	394	279	0.712
	138	0.29	393.8	278.8	0.711
CMURF 35 (75:8:8:5:4)	139	0.26	392.8	277.8	0.708
	140	0.27	393.7	278.7	0.710
	141	0.28	394.5	279.5	0.712
	142	0.29	392.6	277.6	0.707
CMURF 36 (75:8:8:4:4)	143	0.26	390	275	0.700
	144	0.27	393.8	278.8	0.709
	145	0.28	394.6	279.6	0.711
	146	0.29	393.6	278.6	0.709



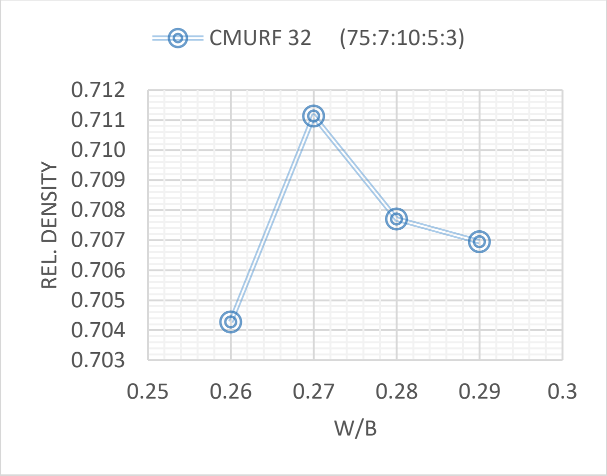
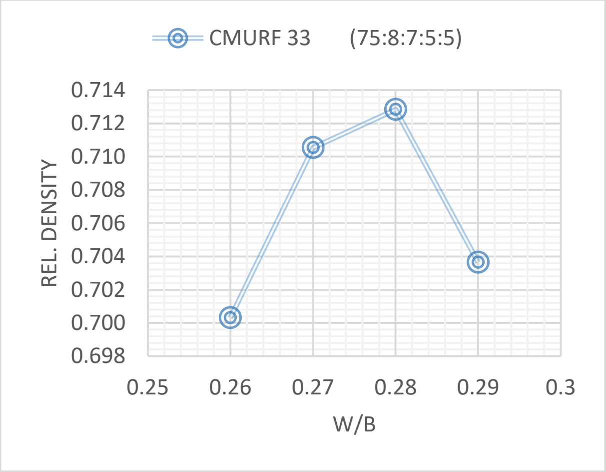


Fig. 5.31: Graph for combination 31

Fig. 5.32: Graph for combination 32



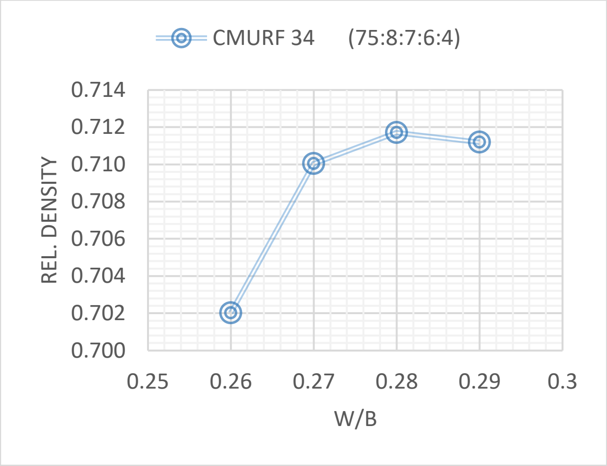
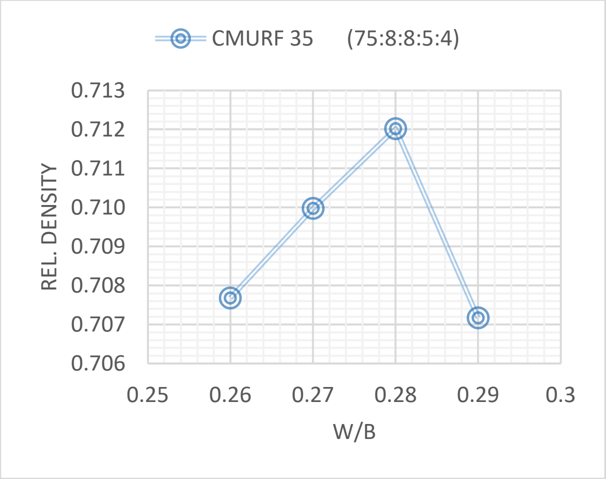


Fig. 5.33: Graph for combination 33

Fig. 5.34: Graph for combination 34



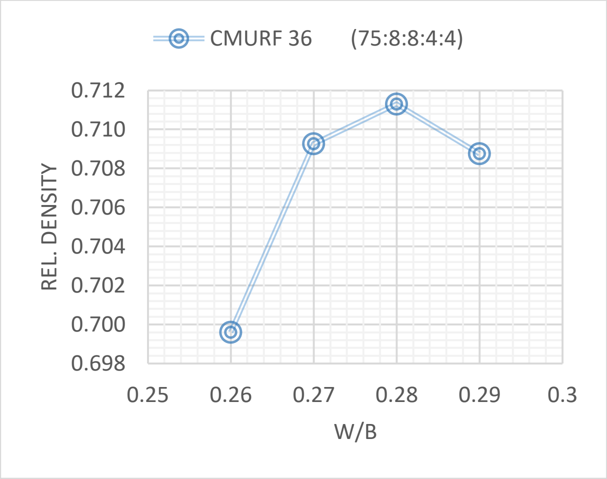


Fig. 5.35: Graph for combination 35

Fig. 5.36: Graph for combination 36

Table 5.7

Relative Density of combinations 37-42

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 37 (75:8:9:5:3)	147	0.26	392.3	277.3	0.704
	148	0.27	393	278	0.706
	149	0.28	395.2	280.2	0.711
	150	0.29	393.1	278.1	0.706
CMURF 38 (75:9:7:5:4)	151	0.26	392.8	277.8	0.709
	152	0.27	394	279	0.712
	153	0.28	394.7	279.7	0.714
	154	0.29	393.8	278.8	0.711
CMURF 39 (75:9:8:4:4)	155	0.26	390	275	0.701
	156	0.27	392	277	0.706
	157	0.28	394.3	279.3	0.712
	158	0.29	394	279	0.711
CMURF 40 (75:9:8:5:3)	159	0.26	389	274	0.697
	160	0.27	390.4	275.4	0.700
	161	0.28	394	279	0.709
	162	0.29	393.25	278.25	0.708
CMURF 41 (75:9:9:4:3)	163	0.26	392.7	277.7	0.705
	164	0.27	396.1	281.1	0.714
	165	0.28	397.3	282.3	0.717
	166	0.29	395	280	0.711
CMURF 42 (75:10:7:5:3)	167	0.26	392.4	277.4	0.706
	168	0.27	394.1	279.1	0.711
	169	0.28	395.1	280.1	0.713
	170	0.29	393.25	278.25	0.709

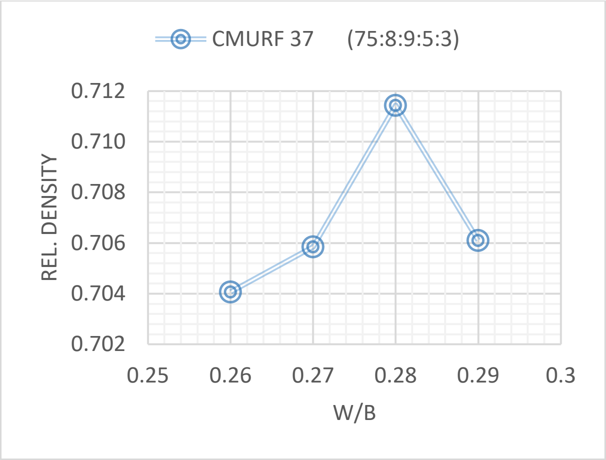


Fig. 5.37: Graph for combination 37

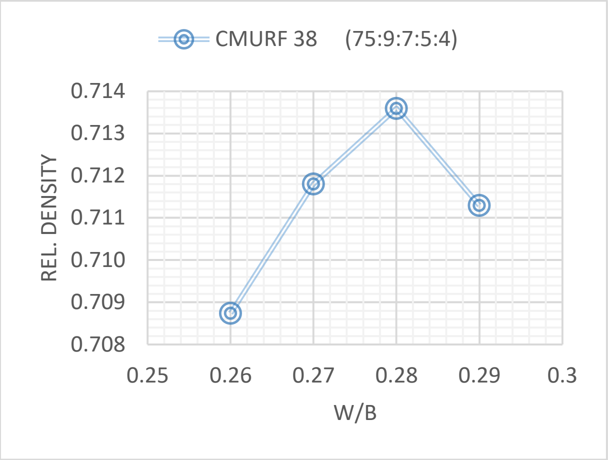


Fig. 5.38: Graph for combination 38

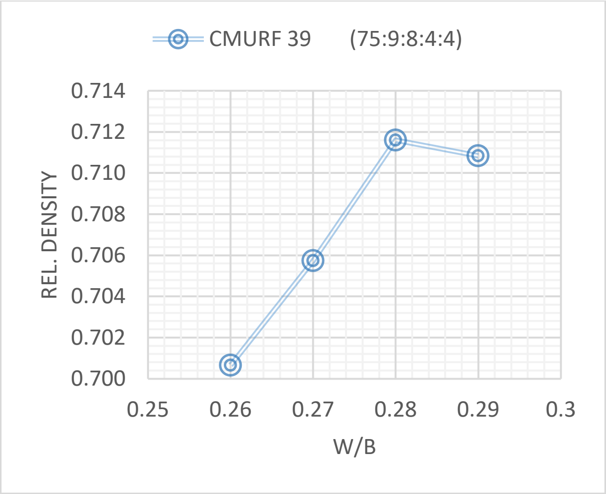


Fig. 5.39: Graph for combination 39

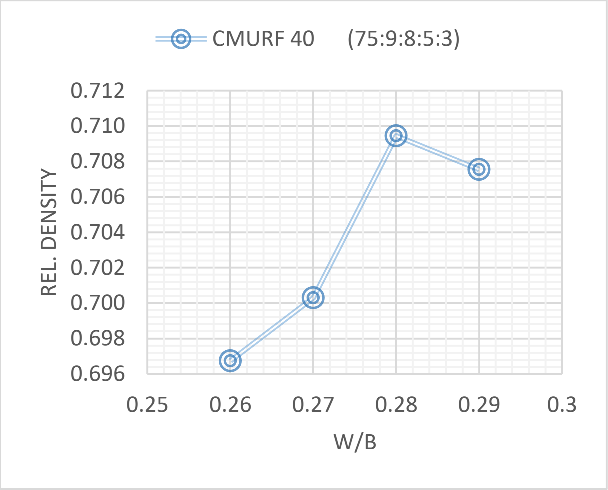


Fig. 5.40: Graph for combination 40

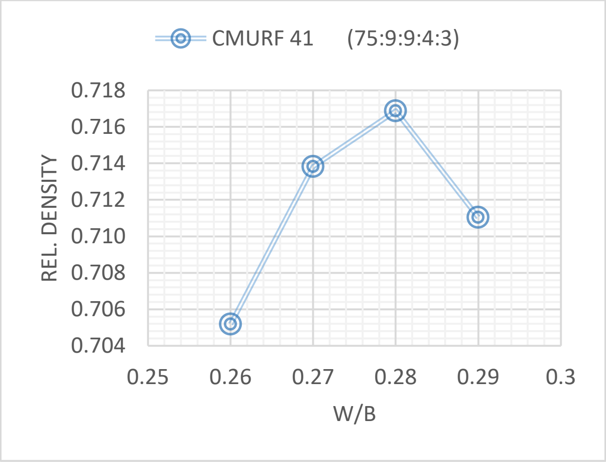


Fig. 5.41: Graph for combination 41

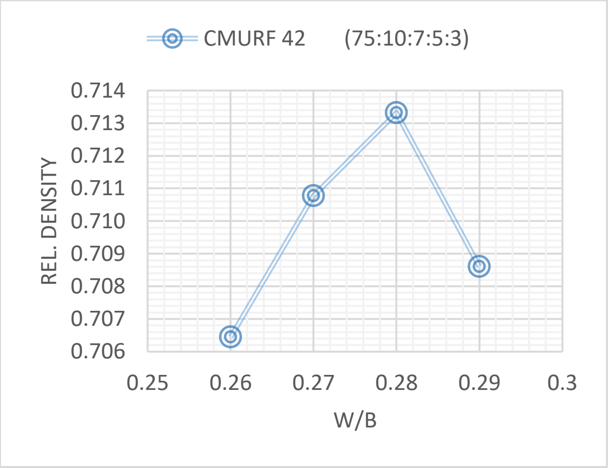


Fig. 5.42: Graph for combination 42

Table 5.8

Relative Density of combinations 43-48

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 43 (70:8:8:7:7)	171	0.26	390.8	275.8	0.715
	172	0.27	391.35	276.35	0.716
	173	0.28	392.05	277.05	0.718
	174	0.29	391.45	276.45	0.717
CMURF 44 (70:8:9:7:6)	175	0.26	391.5	276.5	0.714
	176	0.27	392.7	277.7	0.717
	177	0.28	393.8	278.8	0.720
	178	0.29	392.4	277.4	0.717
CMURF 45 (70:8:10:7:5)	179	0.26	392.9	277.9	0.716
	180	0.27	394.35	279.35	0.719
	181	0.28	394.45	279.45	0.720
	182	0.29	393.2	278.2	0.716
CMURF 46 (70:8:11:6:5)	183	0.26	393.9	278.9	0.717
	184	0.27	394.45	279.45	0.719
	185	0.28	394.25	279.25	0.718
	186	0.29	393.8	278.8	0.717
CMURF 47 (70:8:11:7:4)	187	0.26	393.2	278.2	0.714
	188	0.27	394.35	279.35	0.717
	189	0.28	394	279	0.716
	190	0.29	393.5	278.5	0.715
CMURF 48 (75:8:9:7:6)	191	0.26	391.9	276.9	0.715
	192	0.27	392.6	277.6	0.717
	193	0.28	392.4	277.4	0.717
	194	0.29	391.85	276.85	0.715

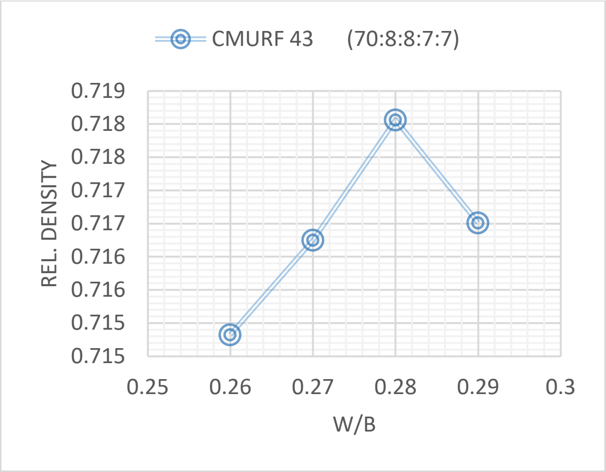


Fig. 5.43: Graph for combination 43

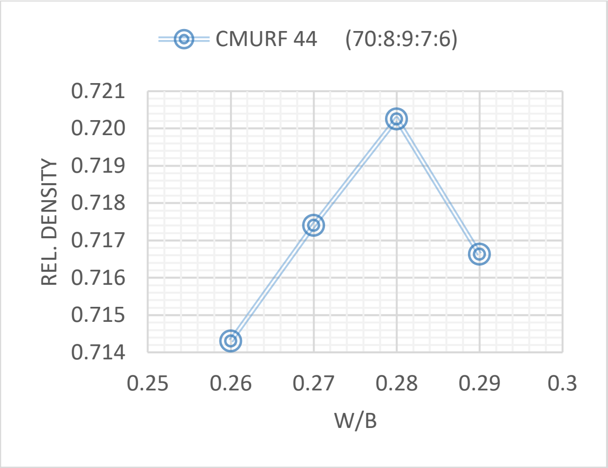


Fig. 5.44: Graph for combination 44

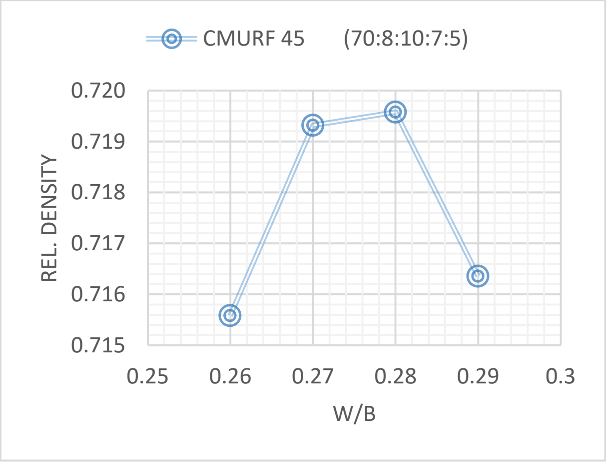


Fig. 5.45: Graph for combination 45

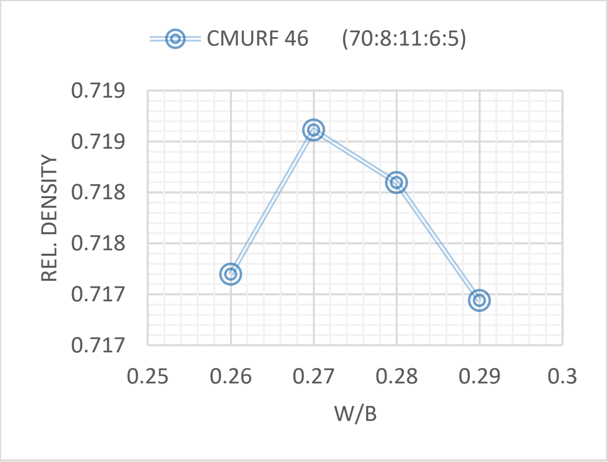


Fig. 5.46: Graph for combination 46

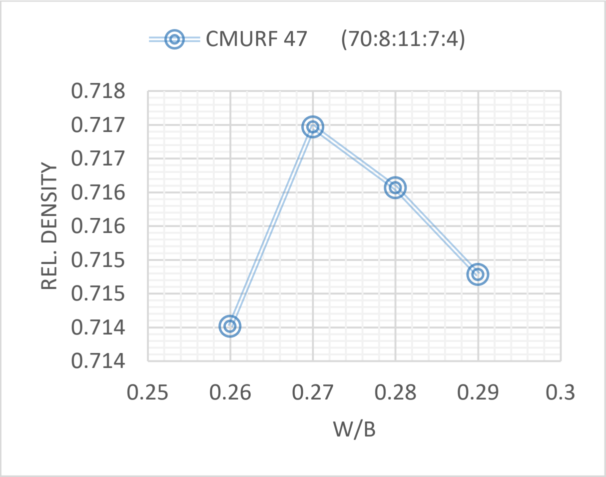


Fig. 5.47: Graph for combination 47

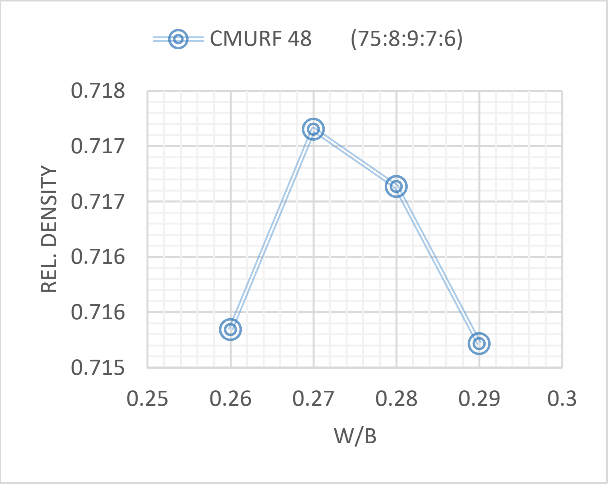
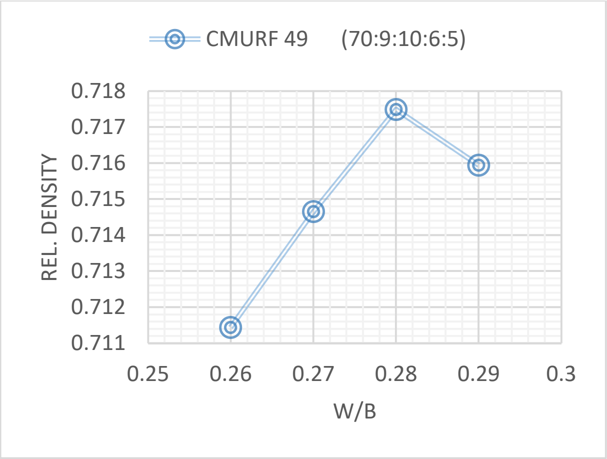


Fig. 5.48: Graph for combination 48

Table 5.9
Relative Density of combinations 49-54

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 49 (70:9:10:6:5)	195	0.26	391.25	276.25	0.711
	196	0.27	392.5	277.5	0.715
	197	0.28	393.6	278.6	0.717
	198	0.29	393	278	0.716
CMURF 50 (70:9:10:7:4)	199	0.27	390.7	275.7	0.709
	200	0.28	392.5	277.5	0.713
	201	0.29	392.6	277.6	0.714
	202	0.3	392	277	0.712
CMURF 51 (70:9:11:5:5)	203	0.26	392	277	0.712
	204	0.27	392.65	277.65	0.714
	205	0.28	392.55	277.55	0.714
	206	0.29	392.1	277.1	0.713
CMURF 52 (70:9:11:6:4)	207	0.26	392.8	277.8	0.713
	208	0.27	394	279	0.716
	209	0.28	393.2	278.2	0.714
	210	0.29	392.6	277.6	0.713
CMURF 53 (70:10:9:6:5)	211	0.26	391.9	276.9	0.714
	212	0.27	393	278	0.717
	213	0.28	392.4	277.4	0.715
	214	0.29	391.5	276.5	0.713
CMURF 54 (70:10:10:5:5)	215	0.26	390.2	275.2	0.709
	216	0.27	392.5	277.5	0.715
	217	0.28	392.9	277.9	0.716
	218	0.29	392	277	0.713



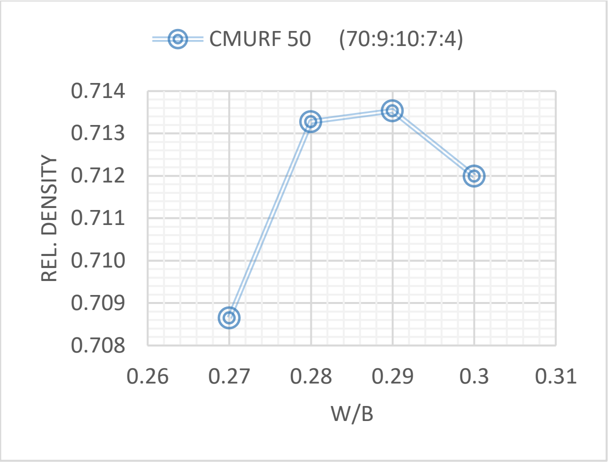
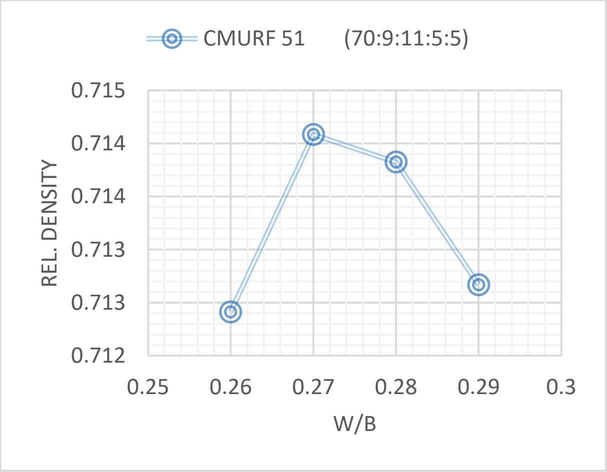


Fig. 5.49: Graph for combination 49

Fig. 5.50: Graph for combination 50



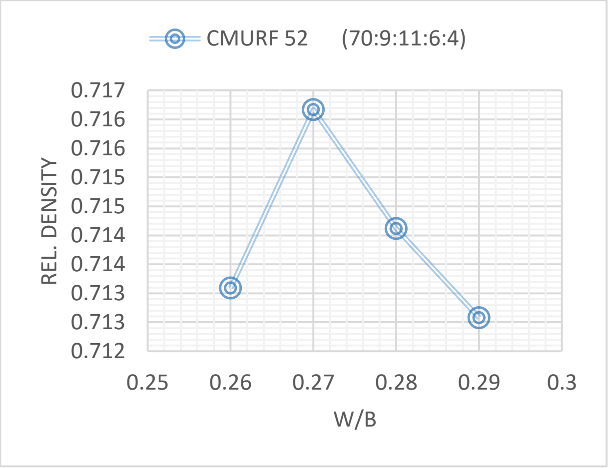
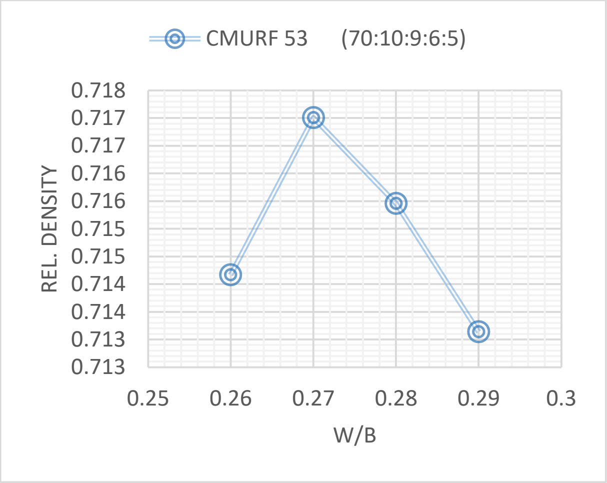


Fig. 5.51: Graph for combination 51

Fig. 5.52: Graph for combination 52



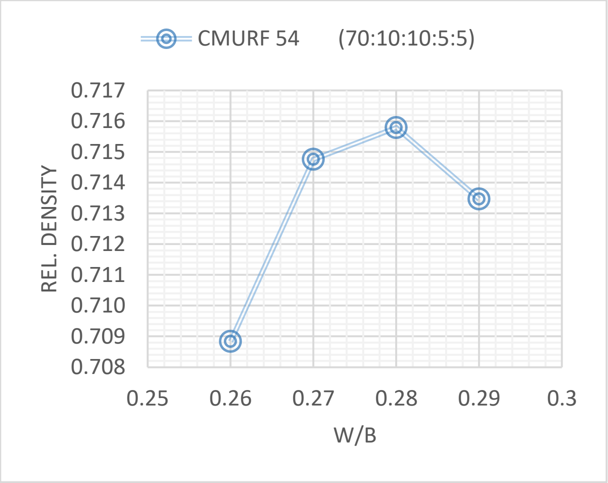


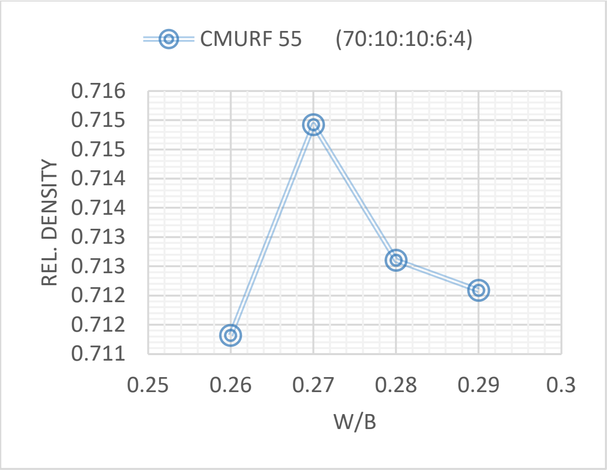
Fig. 5.53: Graph for combination 53

Fig. 5.54: Graph for combination 54

Table 5.10

Relative Density of combinations 55-60

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 55 (70:10:10:6:4)	219	0.26	391.7	276.7	0.711
	220	0.27	393.1	278.1	0.715
	221	0.28	392.2	277.2	0.713
	222	0.29	392	277	0.712
CMURF 56 (70:11:8:6:5)	223	0.27	390.7	275.7	0.712
	224	0.28	392	277	0.715
	225	0.29	390.9	275.9	0.713
	226	0.3	390.1	275.1	0.711
CMURF 57 (70:11:8:7:4)	227	0.26	392.1	277.1	0.714
	228	0.27	393.3	278.3	0.717
	229	0.28	392.4	277.4	0.715
	230	0.29	391.8	276.8	0.714
CMURF 58 (70:11:9:6:4)	231	0.26	392.8	277.8	0.715
	232	0.27	393.75	278.75	0.718
	233	0.28	392.5	277.5	0.714
	234	0.29	392	277	0.713
CMURF 59 (65:10:10:8:7)	235	0.26	389.1	274.1	0.717
	236	0.27	389.25	274.25	0.717
	237	0.28	389.05	274.05	0.717
	238	0.29	388.75	273.75	0.716
CMURF 60 (65:10:11:8:6)	239	0.27	387.3	272.3	0.710
	240	0.28	388.8	273.8	0.714
	241	0.29	387.85	272.85	0.711
	242	0.3	387.4	272.4	0.710



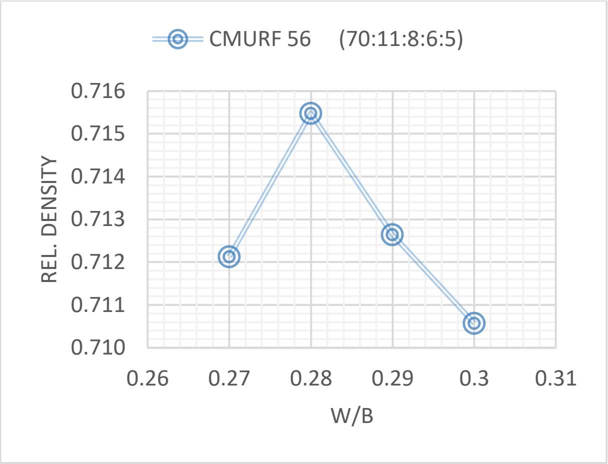
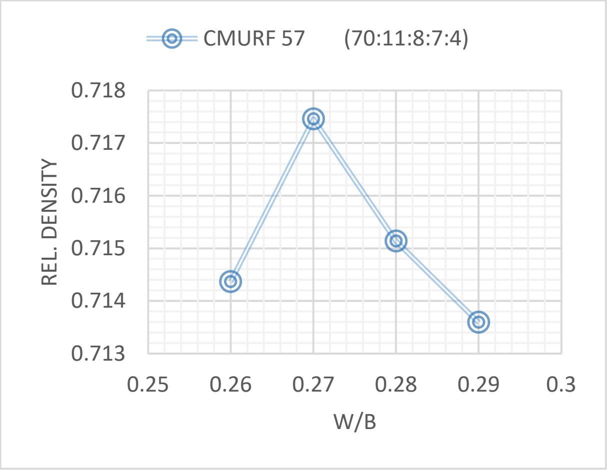


Fig. 5.55: Graph for combination 55

Fig. 5.56: Graph for combination 56



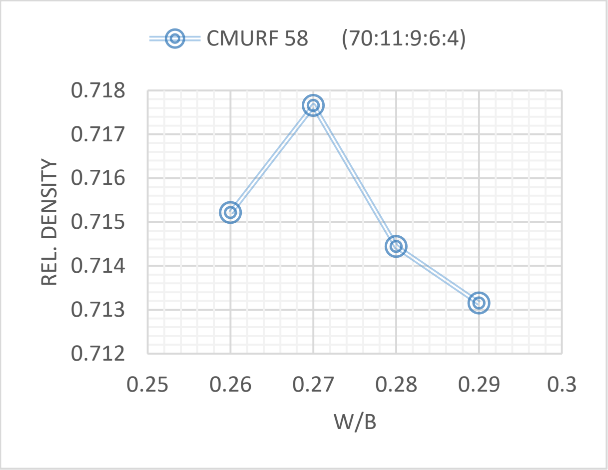
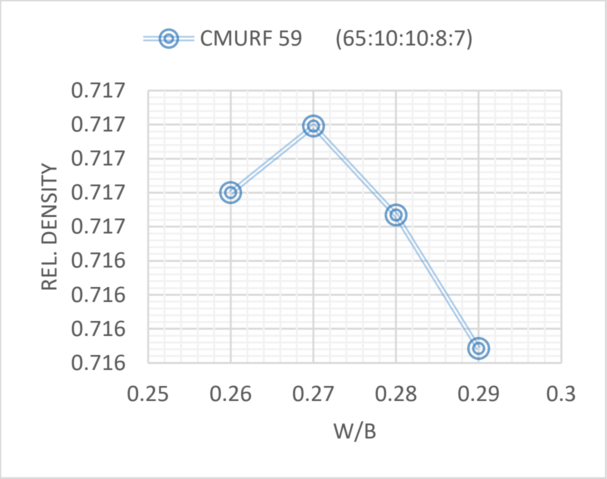


Fig. 5.57: Graph for combination 57

Fig. 5.58: Graph for combination 58



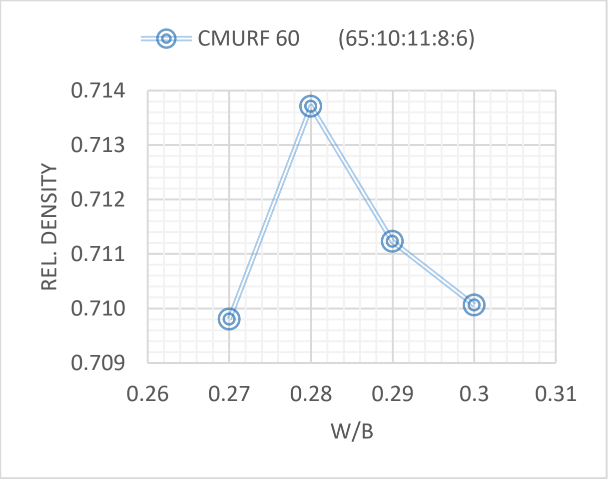


Fig. 5.59: Graph for combination 59

Fig. 5.60: Graph for combination 60

Table 5.11
Relative Density of combinations 61-66

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt., *W* (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative Density, β
CMURF 61 (65:10:12:7:6)	243	0.26	386.65	271.65	0.707
	244	0.27	389.1	274.1	0.714
	245	0.28	390.25	275.25	0.717
	246	0.29	389.2	274.2	0.714
CMURF 62 (65:10:13:7:5)	247	0.27	387.75	272.75	0.708
	248	0.28	388.9	273.9	0.711
	249	0.29	390.3	275.3	0.714
	250	0.3	390.15	275.15	0.714
CMURF 63 (65:11:11:7:6)	251	0.26	389.2	274.2	0.715
	252	0.27	390.35	275.35	0.718
	253	0.28	389.55	274.55	0.716
	254	0.29	389.1	274.1	0.715
CMURF 64 (65:11:12:6:6)	255	0.27	385.25	270.25	0.704
	256	0.28	389.75	274.75	0.715
	257	0.29	389.45	274.45	0.715
	258	0.3	389	274	0.713
CMURF 65 (65:12:10:7:6)	259	0.27	387.05	272.05	0.710
	260	0.28	389.55	274.55	0.717
	261	0.29	387.75	272.75	0.712
	262	0.3	387.25	272.25	0.711
CMURF 66 (65:12:11:6:6)	263	0.27	386.1	271.1	0.707
	264	0.28	388.8	273.8	0.714
	265	0.29	390.15	275.15	0.717
	266	0.3	389.2	274.2	0.715

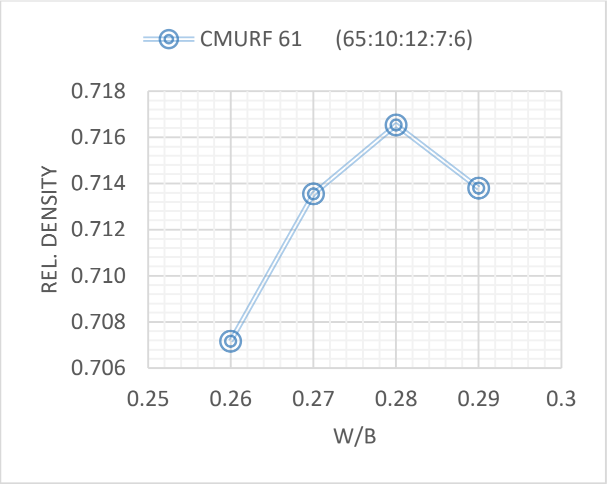


Fig. 5.61: Graph for combination 61

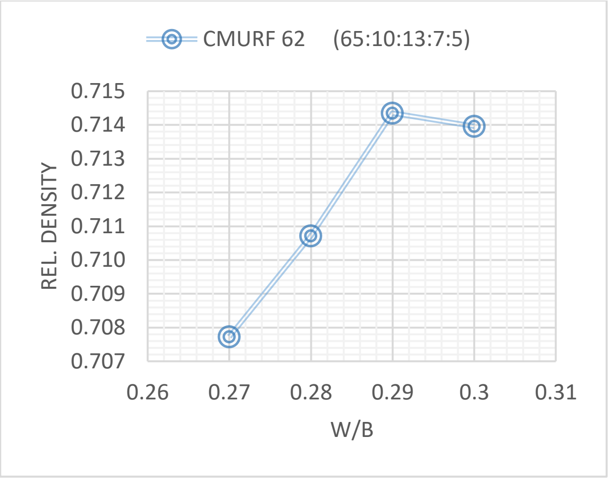


Fig. 5.62: Graph for combination 62

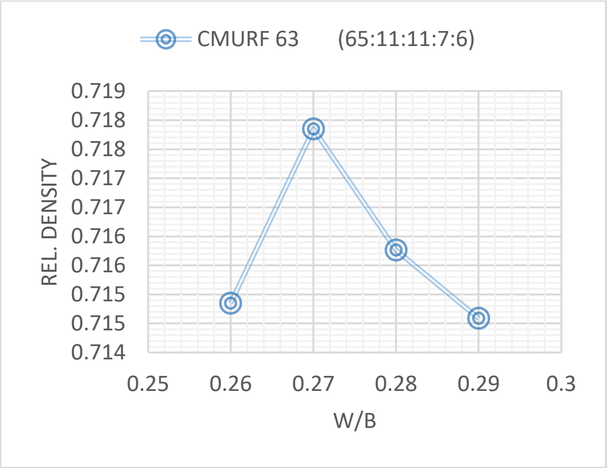


Fig. 5.63: Graph for combination 63

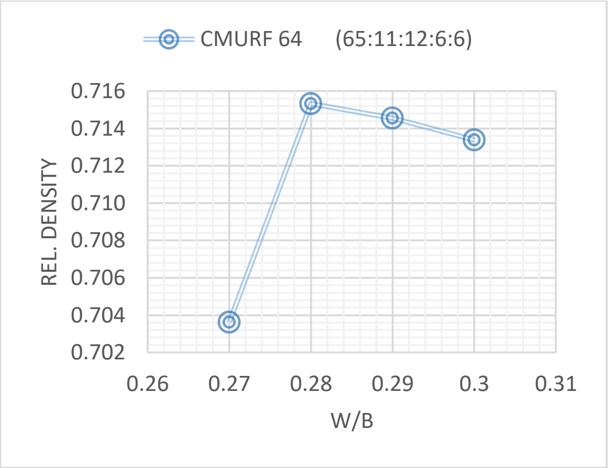


Fig. 5.64: Graph for combination 64

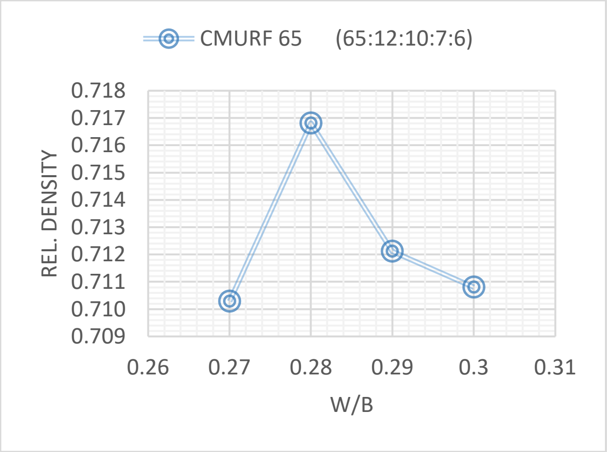


Fig. 5.65: Graph for combination 65

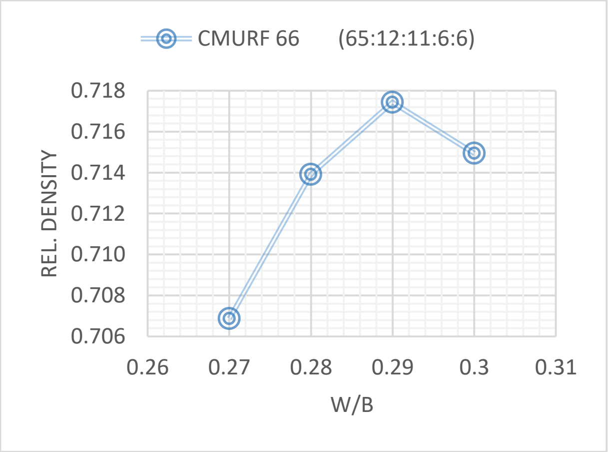


Fig. 5.66: Graph for combination 66

Table 5.12

Relative Density of combinations 67-70

Mix Combination (Ratios)	Sr. No	w/b ratio	Wt. (c+p) (gms.)	Wt. of compacted paste (gms.)	Relative density
CMURF 67 (60:12:12:9:7)	267	0.26	380.7	265.7	0.701
	268	0.27	383.6	268.6	0.709
	269	0.28	384.5	269.5	0.711
	270	0.29	383.8	268.8	0.709
CMURF 68 (60:12:13:9:6)	271	0.27	381.4	266.4	0.701
	272	0.28	383.8	268.8	0.707
	273	0.29	383.4	268.4	0.706
	274	0.3	382.3	267.3	0.703
CMURF 69 (60:13:12:8:7)	275	0.26	381.9	266.9	0.704
	276	0.27	383.9	268.9	0.710
	277	0.28	385.7	270.7	0.714
	278	0.29	384.2	269.2	0.710
CMURF 70 (60:13:13:8:6)	279	0.27	381.1	266.1	0.700
	280	0.28	383.9	268.9	0.707
	281	0.29	384.8	269.8	0.710
	282	0.3	383.6	268.6	0.707

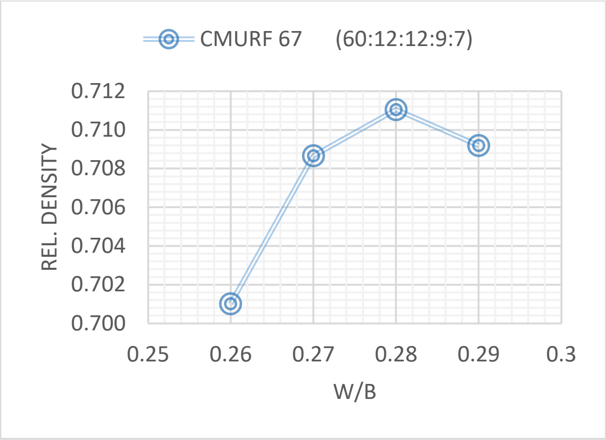


Fig. 5.67: Graph for combination 67

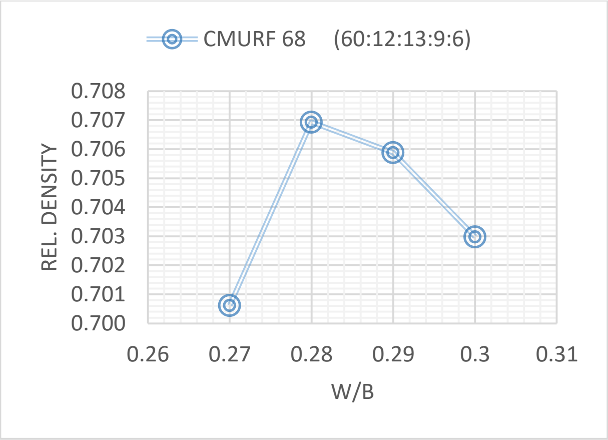


Fig. 5.68: Graph for combination 68

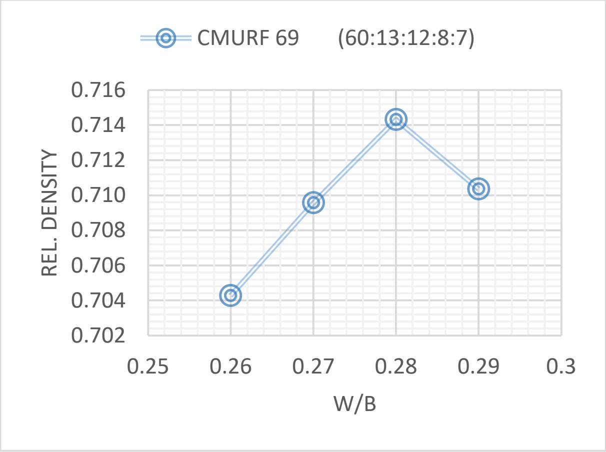


Fig. 5.69: Graph for combination 69

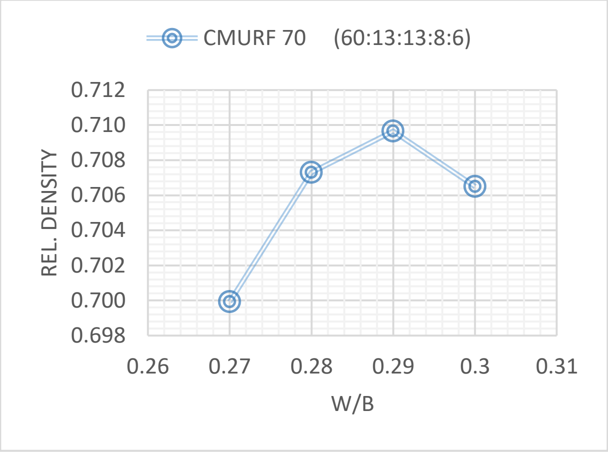


Fig. 5.70: Graph for combination 70

Various trial mixes were tested for the relative density of the paste by changing the proportions of the materials in the mixes and certain observations were made. These trial mixes were obtained on the basis of the literature review carried out. The replacement of the cement was done starting from the 10% up till 40% with the gradual decrease in cement content by 5%. The other cementitious material used were Metakaolin, Ultrafine Slag, Rice Husk Ash and Fly Ash, whose percentages in the mixes were also varied gradually. The contents of Metakaolin and Ultrafine Slag were varied by same amounts, keeping the content of the RHA less than these, followed by that of the Fly Ash.

Following observations were made during the tests:

- The water requirement increased slightly with the increase in the quantity of the fines in the combinations corresponding to the maximum relative density for a combination.

- The major and the most important observation of interest was that as the percentage of cement replacement kept on increasing, the relative density of the paste first increased up to 30% cement replacement and then further decreased. Fig 4.74 shows the comparison of the relative density values of all combinations and Fig. 4.75 shows the variation of relative density with the % cement replacement.
- The maximum value of the relative density obtained was 0.72 for the mix CMURF 44. In this mix the cement content is 70%, metakaolin is 8%, ultrafine slag is 9%, RHA is 7% and fly ash is 6%.
- With the increase in the fine content, the requirement of water too increased by small amount.

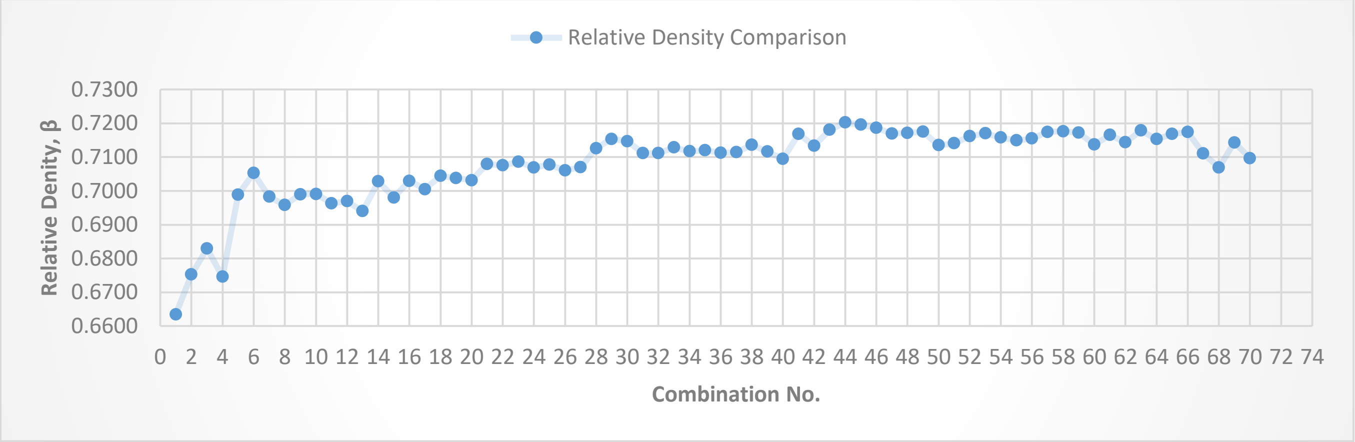


Fig. 5.74: Relative Density Comparison

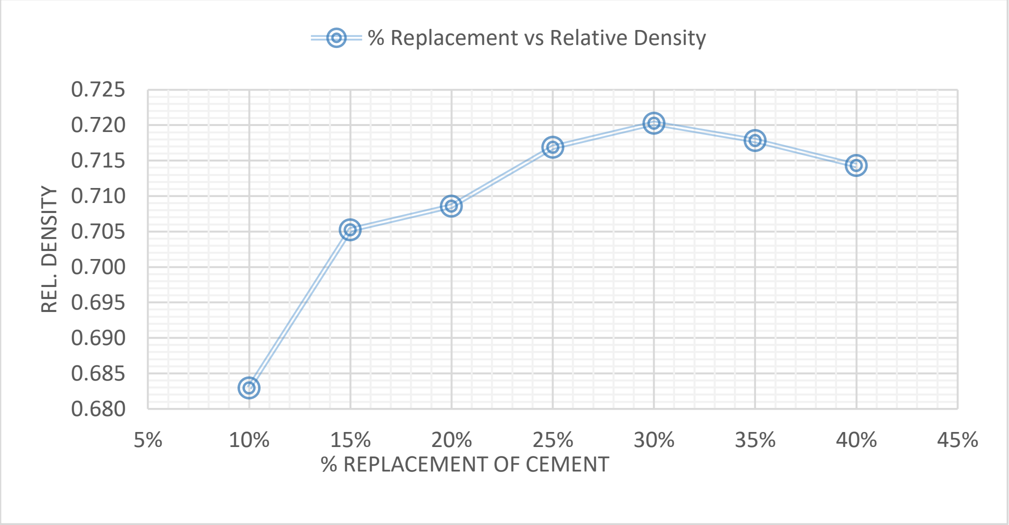


Fig. 5.75: % Replacement vs Relative Density

5.2 EFFECT OF ADDITION OF SP ON RELATIVE DENSITY

The variation of the relative density with the change in the dosage of superplasticizer yielded the following results.

Table 5.13
Variation of packing density with SP

Sr. No.	% of SP	CMURF 44	CMURF 45	CMURF 46	CMURF 58	CMURF 65
1	0.6	0.721	0.723	0.7205	0.7223	0.7208
2	0.65	0.72878	0.7273	0.7276	0.7269	0.7256
3	0.7	0.73201	0.7311	0.7302	0.7294	0.7289
4	0.75	0.72955	0.72825	0.7277	0.7263	0.7253
5	0.8	0.724	0.725	0.721	0.722	0.723

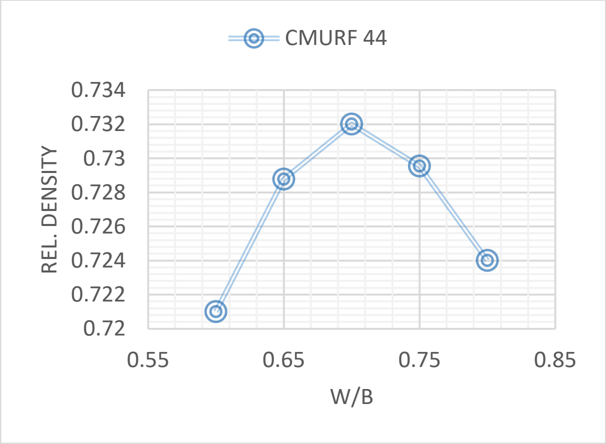


Fig. 5.76: SP vs Rel. density for CMURF 44

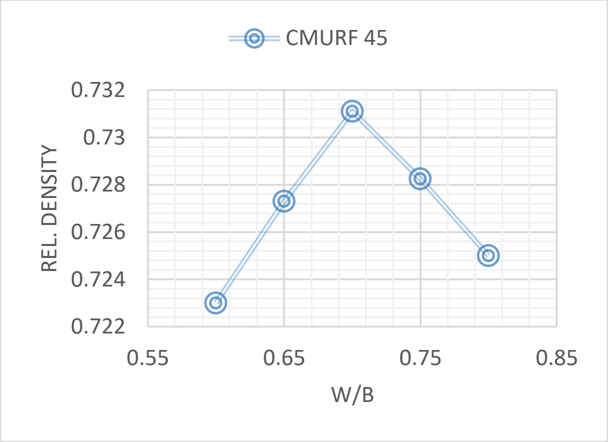


Fig. 5.77: SP vs Rel. density for CMURF 45

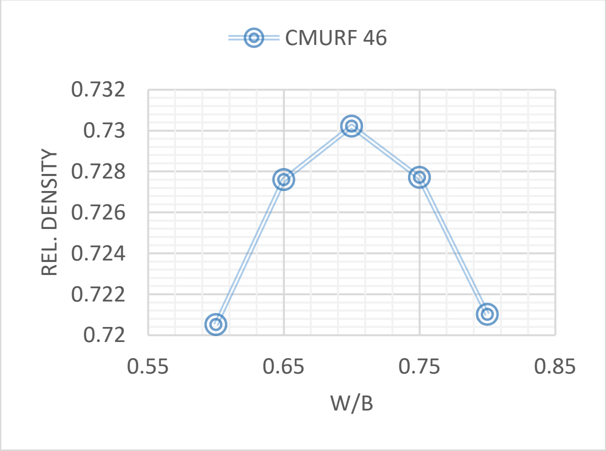


Fig. 5.78: SP vs Rel. density for CMURF 46

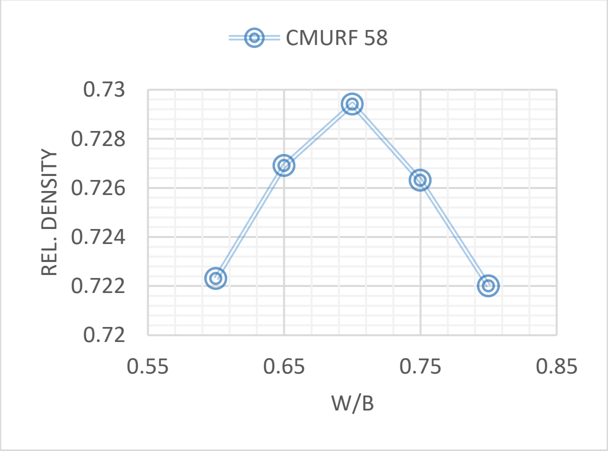


Fig. 5.79: SP vs Rel. density for CMURF 58

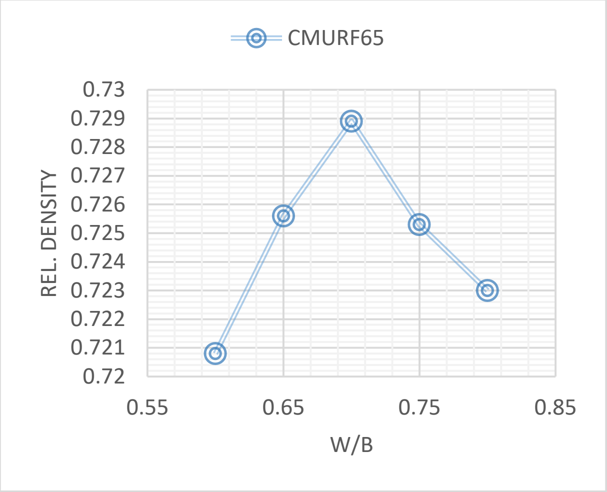


Fig. 5.80: SP vs Rel. density for CMURF 65

5.3 MARSH CONE TEST

The marsh cone test was performed on the mixes and following results were yielded.

Table 5.14
Optimization of CMURF 44

Sr. No.	Cement (g) (70%)	Metakaolin (8%)	Alccofine (9%)	RHA (7%)	FA (6%)	SP (%)	Water content(g)	Marsh cone time (sec)
1	1100	125.7	141.4	110	94.3	0.85	290.0	120
2	1100	125.7	141.4	110	94.3	0.9	289.5	95
3	1100	125.7	141.4	110	94.3	0.95	289.0	76
4	1100	125.7	141.4	110	94.3	1	288.5	62
5	1100	125.7	141.4	110	94.3	1.05	288.0	58
6	1100	125.7	141.4	110	94.3	1.1	287.5	57
7	1100	125.7	141.4	110	94.3	1.15	287.0	56

Table 5.15
Optimization of CMURF 45

Sr. No.	Cement (g) (70%)	Metakaolin (8%)	Alccofine (10%)	RHA (7%)	FA (5%)	SP (%)	Water content(g)	Marsh cone time (sec)
1	1100.0	125.7	157.1	110.0	78.6	0.8	306.2	115
2	1100.0	125.7	157.1	110.0	78.6	0.85	305.7	102
3	1100.0	125.7	157.1	110.0	78.6	0.9	305.2	89
4	1100.0	125.7	157.1	110.0	78.6	0.95	304.7	75
5	1100.0	125.7	157.1	110.0	78.6	1	304.2	72
6	1100.0	125.7	157.1	110.0	78.6	1.05	303.7	71

Table 5.16

Optimization of CMURF 46

Sr. No.	Cement (g) (70%)	Metakaolin (8%)	Alccofine (11%)	RHA (6%)	FA (5%)	SP (%)	Water content(g)	Marsh cone time (sec)
1	1100	125.7	141.4	110	94.3	0.8	290.5	108
2	1100	125.7	141.4	110	94.3	0.85	290.0	110
3	1100	125.7	141.4	110	94.3	0.9	289.5	97
4	1100	125.7	141.4	110	94.3	0.95	289.0	91
5	1100	125.7	141.4	110	94.3	1	288.5	83
6	1100	125.7	141.4	110	94.3	1.05	288.0	80
7	1100	125.7	141.4	110	94.3	1.1	287.5	79

Table 5.17

Optimization of CMURF 58

Sr. No.	Cement (g) (70%)	Metakaolin (11%)	Alccofine (9%)	RHA (6%)	FA (4%)	SP (%)	Water content(g)	Marsh cone time (sec)
1	1100.0	125.7	157.1	110.0	78.6	0.8	306.2	129
2	1100.0	125.7	157.1	110.0	78.6	0.85	305.7	117
3	1100.0	125.7	157.1	110.0	78.6	0.9	305.2	111
4	1100.0	125.7	157.1	110.0	78.6	0.95	304.7	105
5	1100.0	125.7	157.1	110.0	78.6	1	304.2	96
6	1100.0	125.7	157.1	110.0	78.6	1.05	303.7	93
7	1100.0	125.7	157.1	110.0	78.6	1.1	303.2	92

Table 5.18

Optimization of CMURF 63

Sr. No.	Cement (g) (65%)	Metakaolin (11%)	Alccofine (11%)	RHA (7%)	FA (6%)	SP (%)	Water content(g)	Marsh cone time (sec)
1	1100	125.7	141.4	110	94.3	0.9	289.5	136
2	1100	125.7	141.4	110	94.3	0.95	289.0	124
3	1100	125.7	141.4	110	94.3	1	288.5	115
4	1100	125.7	141.4	110	94.3	1.05	288.0	112
5	1100	125.7	141.4	110	94.3	1.1	287.5	109

The marsh cone test was carried out for the 5 combinations and the following observations were made:

a) The combination CMURF 44, CMURF 45, CMURF 46 yielded the optimum dosage of the superplasticizer as 0.95%.

b) The combination CMURF 58 and CMURF 63 yielded the optimum dosage of the superplasticizer as 1%.

5.4 COMPRESSIVE STRENGTH TEST

The casting was carried out for same mix combinations in 2 sets, one with the mix design having 1100 kg/m^3 of cement and the other with the 900 kg/m^3. The compressive strength results for the same are presented below.

Table 4.19

Compressive strength results for cement with 1100 kg/m^3

Sr. No	**Mix Combination**	**Compressive Strength for 3 cubes (N/mm^2)**	**Average Compressive Strength (N/mm^2)**
1	CMURF 44	89.08	94.96
		96.30	
		99.51	
2	CMURF 45	98.31	100.45
		100.51	
		102.52	
3	CMURF 46	90.28	93.61
		93.83	
		96.70	
4	CMURF 58	80.25	87.27
		88.28	
		93.29	
5	CMURF 65	82.26	84.00
		84.26	
		85.47	

Table 4.20
Compressive strength results for cement with 900 kg/m^3

Sr. No	Mix Combination	Compressive Strength for 3 cubes (N/mm^2)	Average Compressive Strength (N/mm^2)
1	CMURF 44	78.24	80.65
		83.46	
		80.25	
2	CMURF 45	82.30	83.19
		84.46	
		82.82	
3	CMURF 46	84.16	85.10
		86.87	
		84.26	

The maximum compressive strength of 100.45 MPa was achieved by the combination CMURF 45 with 1100 kg/m^3 of cement. The strength achieved was satisfactory considering some reasons which affected the strength of concrete. Firstly, the molds available in the lab were not perfectly in the square shape due to which the resulting cubes too presented a deformed shape and when placed in between the plates of the UTM, the surface of the cubes was not parallel to the plated which resulted in the early development of cracks. Secondly, the temperature of the water in which 28 days curing was carried out, was way below 24°C and was at about 5-10°C resulting in incomplete hydration and underutilized potential of the mineral admixtures as lower the hydration of the cement, lower is the production of $Ca(OH)_2$ which is necessary for the pozzolanic reactions of mineral admixtures. Having considered all these factors, the strength of 100 MPa achieved is considerably good.

The failure of the cubes observed was more of a brittle failure than the D shaped failure as observed in the conventional concrete. The brittle failure of cubes is shown in Fig. 5.81.

Further if the curing of the concrete would have been carried out at the elevated temperatures of about 90°C, higher compressive strengths would have been achieved.

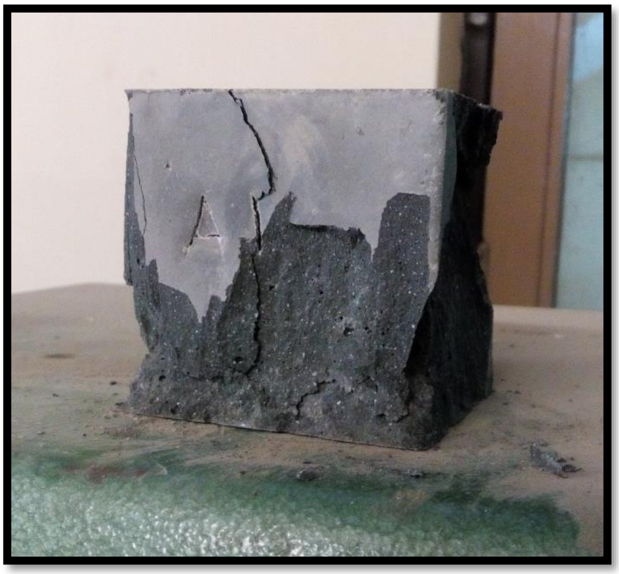


Fig. 5.81: Failure of concrete

CONCLUSIONS

The literature review carried out concluded that with the increase in the quantity of the fines as a replacement to the cement and the results of the tests supports this conclusion to a great extent.

- The cement was replaced by certain percentages of metakaolin, ultrafine slag, RHA and fly ash and amongst the mix combinations tested, the one with 30% replacement of the cement yielded the maximum relative density of 0.72.
- The another observation made was that the mix combinations with the amount of fines such that they cover the wide range of the particle sizes achieved the maximum packing.
- The particle packing of the materials followed a trend in which initially the packing increased with the increase in the replacement of the cement up to 30% and the further the packing density showed a slight slump. It concludes that 30% fines added to the mix are sufficient to fill the maximum voids and the further increase or decrease results in the lower packing.
- As the percentage of fine content kept on increasing, the water demand increased slightly owing to the fact that the surface area of the materials increased which increased the water demand in turn.
- Certain observations were made by changing the percentages of the materials in the mixes as the other materials being kept constant, the packing density increased with the increase in the fly ash content. Keeping the maximum percentages of Metakaolin and UFS in the mix too led to the uphill in density values.
- With the use of the superplasticizer, the water to binder ratio was brought down to 0.19 with the optimum value of the superplasticizer being 0.95% for 3 combinations and 1% for the other 2. It was observed that the superplasticizer yielded a remarkable workability at the lower values of the water to binder ratios.
- The compressive strength results yielded the strength up to 100 MPa, which is quite satisfactory owing to certain reasons like the deformed shape of the cubes casted because of the defected molds and the curing of the cubes at low temperatures ranging from 5-10^{o}C which is quite low than the normal room temperature of 24^{o}C, resulting in the incomplete hydration
- Further if the curing of the specimens is carried out at elevated temperatures, these concrete mixes are expected to provide higher strengths.

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