"PARTICLE PACKING CONCEPT FOR ULTRA HIGH PERFORMANCE CONCRETE"

A PROJECT

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

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

Mr. Abhilash Shukla

By

Aatish Gupta (111608)

Nikhil Rathee (111643)

to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT SOLAN – 173 234

HIMACHAL PRADESH INDIA

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CERTIFICATE

This is to certify that the work which is being presented in the project title **"Particle packing concept for ultra high performance concrete"** in partial fulfillment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Aatish Gupta and Nikhil Rathee during a period from August 2014 to May 2015 under the supervision of **Mr.Abhilash Shukla** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

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

Date: - 27/05/2015

Prof. Dr. Ashok Kumar Gupta	....	....
Professor & Head of Department	Assistant Professor	External Examiner
Civil Engineering Department	Civil Engineering Department	
JUIT Waknaghat	JUIT Waknaghat	

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AATISH GUPTA(111608)

NIKHIL RATHEE(111643)

Abstract

Ultra High performance concrete (UHPC) has become more and more popular in recent years. However, the various required performance attributes of UHPC, including strength, workability, dimensional stability and durability, often impose contradictory requirements on the mix parameters to be adopted, thereby rendering the concrete mix design a very difficult task. The conventional mix design methods are no longer capable of meeting the stringent multiple requirements of UHPC. In this project we will use the concept of packing density as a fundamental principle for designing UHPC mixes. The concept is based on the belief that the performance of a concrete mix can be optimized by maximising the packing densities of the aggregate particles and the cementitious materials.

Table of Contents

PAGE NO

LIST OF TABLES

LIST OF FIGURES

Chapter - 1

1.1 INTRODUCTION

The grade of concrete is normally defined in terms of its characteristic strength.For this reason, strength has been taken as the most important performance attribute of concrete and research in concrete technology has been focusing on achieving higher strength in the last century. After decades of development, the production of highstrength concrete (HSC) up to grade 100 no longer presents any major difficulties. In fact, since further increase in concrete strength would be limited by the strength of the rock aggregate used and could drastically reduce the ductility of the concrete (Kwan *et al* 1995b), it is not advisable to specify any higher strength concrete than grade 100. On the other hand, the production of HSC generally requires the use of a low water/cementitious materials ratio and a highcementitious materials content. The use of a low water/cementitious ratio would decrease the workability of the concrete mix, while the use of a high cementitiousmaterials content would increase the thermal expansion/contraction during strength development and the drying shrinkage in the longer term, i.e. would decrease the dimensional stability of the concrete. Hence, a HSC tends to have a lower workabilityand a lower dimensional stability. Taking these attributes into consideration, a HSC is not necessarily a HPC.

Nowadays, engineers are demanding HPC that have not only high strength but also round high performance in terms of other attributes such as workability,dimensional stability and durability. Because of the conflicting requirements of these performance attribute (e.g. increase in strength often leads to decrease in workability and increases in both strength and workability may have to be achieved at the expense of lower dimensional stability etc), HPC is much more difficult to produce than HSC. High dosages of chemical and mineral admixtures may have to be added and mix optimization is needed in order to achieve all the desired properties. The conventional mix design methods are not capable of coping with such complexities and therefore a new mix design method is necessary for making HPC. In this paper, the concept of packing density, i.e. the ratio of the volume of solids to the bulk volume of the solid particles, is introduced. This concept is playing a more and more important role inmodern concrete mix design because of the increasing awareness that maximization ofpacking density by adjusting the grading of the whole range of solid particles, includingthe coarse aggregate, the fine aggregate and the cementations materials, can improve theoverall performance of the concrete mix. A preliminary mix design method called“three-tier system design” based on the concept of packing density is also proposed.Concrete is the widely used construction material. It isproduced by proper proportioning of ingredients such ascement, water, coarse aggregate and fine aggregate, so as tosatisfy the required characteristics in green and hardened state. HPChave same constituents as that of concrete along with one of thefollowing product such as organic admixture, supplementarycementitious materials, fibers etc and which are not limited to thefinal compressive strength, but include rheological properties, earlyagecharacteristics, deformability properties and durability aspects.Thus the purpose of mix proportioning is to obtain concrete that willhave suitable workability, maximum density, strength at specifiedage, dimensional stability and specified durability. Proportioning ofconcrete mixes is highly trial intensive. A purely experimental andempirical optimization could not give optimum proportion asnumber of parameters are involved as input and output as mentionedabove. But the positive aspect is no concrete technology is youngertechnology. Huge amount of experimental data and various mixproportioning methods are available for designing the concrete.Concrete proportioning is first of all the packing problem. Allexisting methods recognize this problem by suggesting themeasurement of the packing parameter of some component or byapproximating an ‘ideal’ grading curve.

1.2 OBJECTIVE-

The objective of our project is to optimize the Packing density of concrete using different blend of materials available and compare this optimum density with a ideal graph available in EMMA(Elkem material mix analyser) software until the curve using practical method fits with ideal curve that we got with the help of EMMA software.At last for that proportion of materials we will prepare a High Performance Concrete using the method proposed.

1.3 An Introduction to EMMA(Elkem Material Mix Analyser)…

EMMA is an application that calculates and displays the particle size distribution of a mixture of components. It was originally developed for designing self-flowing refractory castable c-ompositions at Elkem AS. Today particle size distribution analysis of different building products, concrete etc. are investigated by this tool.

EMMA uses the Andreassen model of particle-packing and calculates the composite particle size distribution.It has been developed by Elkem materials.

HOW TO USE IT:

1-It simply requires the details of material which we have used in our analysis.

2-There are some default materials available in software , we can also create a materials by providing the relevant details about it if it is not available in default list.

3-After adding all the materials used it will give a ideal curve which shows the optimum proportion of materials used to prepare a High Performance Concrete.

4-It will require some general details about materials like its particle size distribution , particle density etc.

Chapter -2

LITERATURE REVIEW

2.1 Powder Processing and Packing of Powders:

Powder processing has a wide scope, meaning preparing powder by size reduction, giving a green shape etc. The use of powder may end in the form of powder itself, such as polishing powders. Mostly, the powders are utilized for making shapes, which are strong and made useful for many applications. Powders are used for being melted and given shape, as in glass making orthe green shape may be treated at high temperature for developing strength such as is done in most other ceramic industries. Here we have chosen to deal with principles of packing, as dense packing is desirable in many cases.

What ordinarily one can hold in hand as discrete particles is called pebbles. Lesser than that size may be called powders.

2.2 Significance of Particle Packing Concept:

The porosity as well as the pore characteristics of compacted mass consisting of solid particulate system is the manifestation of the packing of the particles. Flow of fluids through a tower packed with a solid particulate material, filtration of a slurry containing fine solids, passage of combustion gases through a shaft kiln charged with solid lumps, rate of drying of moist cakes and crystals, sintering of pressed items of ceramic and metallic systems are all governed by the total porosity of the bed and also the size, shape and distribution of the pores.

Even though there is a growing attractiveness for HPC, a systematic and simple mix design procedure is still lacking. Extensive study on the mechanical and durability aspects of HPC is very much essential for instilling confidence in the construction industry. The production of HPC requires the careful proportioning of the paste and mortar materials. Properties of concrete are highly influenced by the optimization of ingredients. Particle packing concept was selected for optimizing the ingredients. The basic concept adopted for the current study is that, performance of the concrete mix can be improved by maximizing the packing densities of the aggregate particles and the cementitious materials. In this study, an attempt has been made to design the paste and mortar phase which will enable to produce a high quality HPC, both in fresh and hardened state. Few studies were conducted for plain HPC and fibre reinforced HPC but limited studies were conducted with flyashand slag. The significance of current study lies in understanding the fresh and hardened properties of paste and mortar phase with slag and flyash.

2.2.1-Some definitions:-

Packing of particles: Packing of particles may be defined as the selection of proper size, shape and proportions of particulate material as well as the compaction device so as to obtain a system with the desired porosity**.**

Porosity: Porosity of a sample or a compact is the percentage of the total space not occupied by the particulate material.

Bulk Density: Bulk density is the mass of the particles per unit volume of sample or compact.

Apparent volume: Apparent volume is the volume of the sample occupied by unit true volume of the particles**.**

Packing Fraction: Packing fraction is the fraction of the total sample volume occupied by the particulate material.

In a stable particle structure all particles are in contact with each other and packed with certain packing density αt. In a real concrete mixture, the partial volume of all the particles in a unit volume, φmix , is lower. This is shown in Figure below, where the same amount of particles in a stable particle structure is packed closer (Fig. , middle) than in a real mixture (Fig. , left). In a real concrete mixture part of the water is used to fill the voids between the particles,while the rest of the water is regarded as excess water. This excess water provides the flowability of the mixture. Flowability increases with a higher excess of water in the mixture. In that case, the solid content of the mixture φmix decreases.

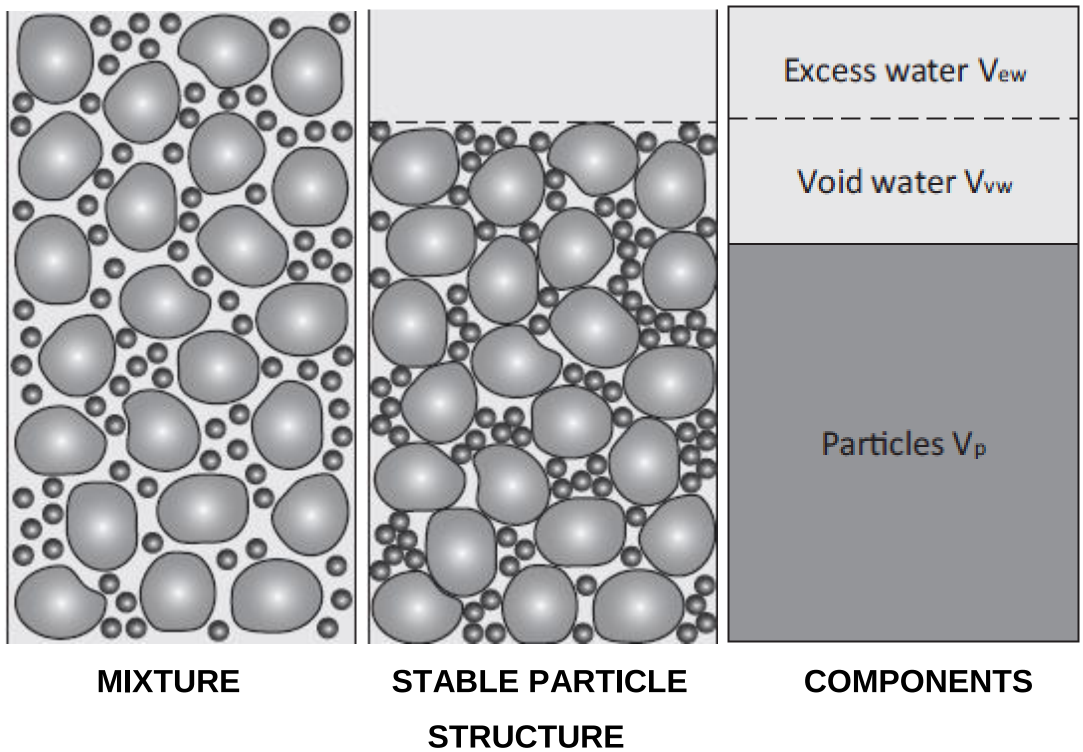

FIG0: The volume of a flowable mixture compared to volume occupied by a stable particle structure containing same particles.

If the particle composition of a concrete mixture is optimized in such a way that the maximum particle packing density increases, less void water is necessary. Because of this effect high packing density improves the workability of a mixture. When part of the water that first filled up the voids between the particles, becomes available as excess water, it will provide more flowability. Clearly, the resulting increase in flowability is very useful in the design of concrete mixtures.

2.3 Application of particle packing concept:

The annual production of Portland cement, estimated at 3.4 billion tons in 2011, is responsible for about 7% of the total worldwide CO2-emission. To reduce this environmental impact it is important to use innovative technologies for the design of concrete structures and mixtures.In this project, it is shown how particle packing technology can be used to reduce the amount of cement in concrete by concrete mixture optimization, resulting in more sustainable concrete.There are 3 different methods to determine the particle distribution of a mixture optimization curve , particle packing models , discrete element modeling but we generally used optimization curve in our whole project. The advantage of using analytical particle packing models is presented based on relations between packing density, water demand and strength. Experiments on ecological concrete demonstrate how effective particle packing technology can be used to reduce the cement content in concrete. By using particle packing technology in concrete mixture optimization, it is possible to design concrete in which the cement content is reduced by more than 50% and the CO2-emission of concrete is reduced by 25%.

2.4 Packing density: Theory and implication on HPC

Imagine a concrete mix composed of a single-sized aggregate and cement paste only. In order to fill up all the gaps between the aggregate particles so as to drive away the air voids in the concrete mix, the volume of cement paste must be larger than the volume of gaps within the aggregate skeleton, Figure 1(a). If, instead of a single-sized aggregate, a multi-sized aggregate is used, the smaller size aggregate particles would fill up the gaps between the larger size aggregate particles, leading to a smaller volume of gaps within the aggregate skeleton, Figure 1(b). This has two implications. Firstly, with a multi-sized aggregate used, the volume of cement paste needed to fill up the gaps within the aggregate skeleton would be reduced. Secondly, if the volume of cement paste is kept the same, the use of a multi-sized aggregate would increase the volume of the excess paste (the portion of paste in excess of that needed to fill up the gaps within the aggregate skeleton), which disperses the aggregate particles, provides a coating of paste for each aggregate particleand renders workability to the concrete mix, Figure 1(c). Hence, the size distribution, or grading, of the aggregate has an important bearing on the paste demand and the workability of a concrete mix.

That the grading of the aggregate can have a great influence on the performance of the concrete mix is actually well known long time ago (Powers 1968). It is only that many parameters (the various size fractions of the aggregate) are needed to describe the grading and the effects of the various parameters are often blurred by the interaction between the various parameters involved. Nevertheless, it is nowadays very clear that the single most important parameter influencing the performance of concrete is the packing density of the aggregate. The packing density of a given aggregate or a given lump of solid particles is the ratio of the volume of solids to the bulk volume of the solid particles. Since the bulk volume is equal to the volume of solids plus the volume of voids, a higher packing density means a smaller volume of voids to be filled and vice versa. Figure 2 illustrates how the concept of packing density can be applied to concrete mix design. In Figure 1(a), the single-sized aggregate can be packed together to occupy only limited space, i.e. can achieve only a relatively low packing density. In Figures 1(b) and 1(c), the multi-sized aggregate can be packed together much more effectively toachieve a much higher packing density. With the paste volume fixed, the increase inpacking density of the aggregate could be employed to increase the workability of theconcrete at the same water/cementitious ratio or increase the strength of the concrete byreducing the water/cementitious ratio while maintaining the same workability.

Apart from increasing the excess paste at a given paste volume to improve the workability and/or strength of the concrete, the increase in packing density of the aggregate could also be employed to improve the dimensional stability of the concrete. In a concrete mix, it is the cement paste that generates heat of hydration causing thermal expansion/contraction during the early age and shrinks when subjected to drying in the longer term. Hence, the larger the paste volume is, the larger would be the changes in dimension of the hardened concrete due to early thermal expansion/contraction and long term drying shrinkage. The heat of hydration and drying shrinkage of the concrete are dependent also on the water/cementitious ratio, both being larger at higher water/cementitious ratio. The reduction in paste demand due to a higher packing density of the aggregate would for the same workability allow the use of a smaller paste volume at a fixed water/cementitious ratio or a lower water/cementitious ratio at the same paste volume, either of which would significantly improve the dimensional stability of the concrete.

The concept of packing density can be extended to apply also to the cementitious materials, which may include cement and other supplementary cementitious materials, such as pulverized fuel ash (PFA), ground granulated blast-furnace slag (GGBS) and condensed silica fume (CSF) etc. Drawing analogy to the previous case of packing aggregate particles, the packing density of the cementitious materials should have similar effect on the water demand and the flowability of the cement paste. The different types of cementitious materials are generally of different sizes. By mixing appropriate proportions of different cementitious materials together, the medium size particles would fill up the gaps between the larger size particles and the smaller size particles would fill up the gaps between the medium size particles and so forth. Hence, blending cementitious materials of different sizes together could increase the packing density of the cementitious materials and reduce the water demand.

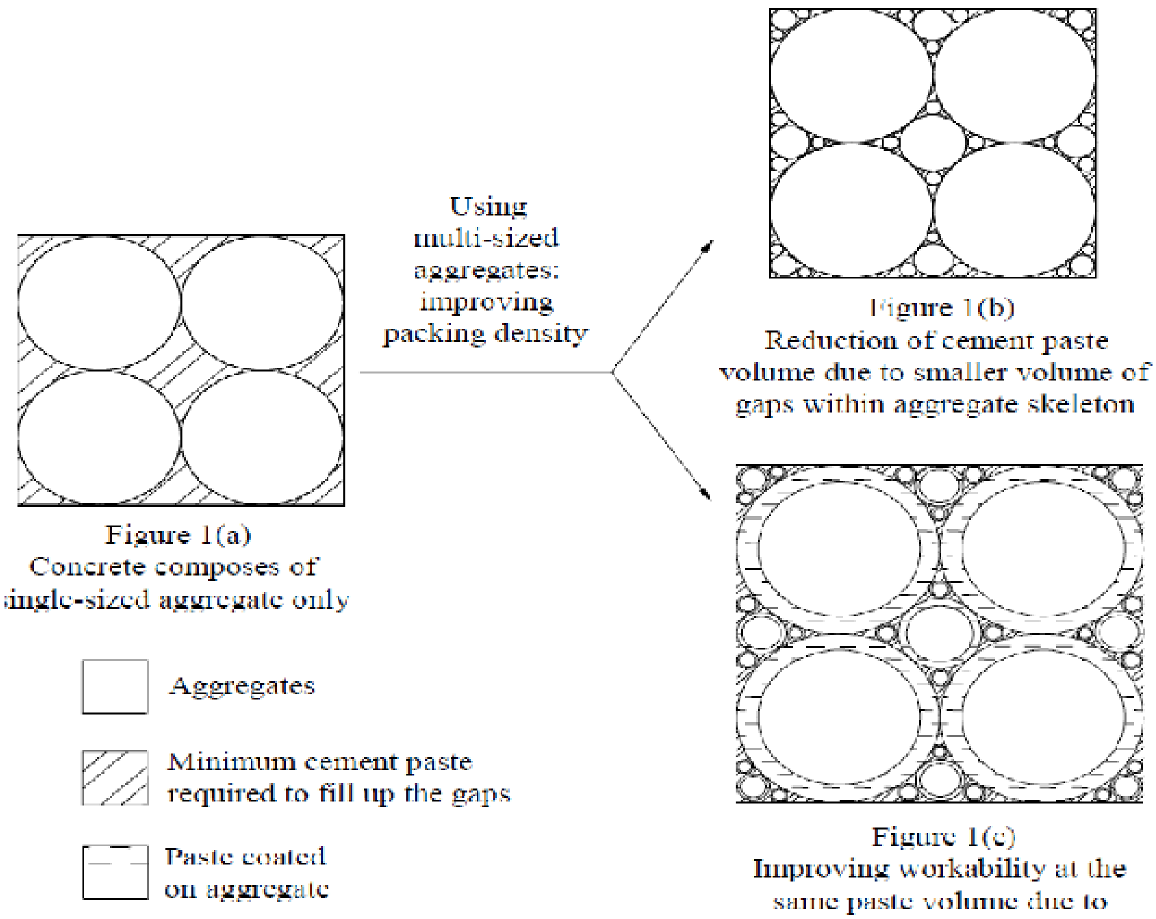

Figure 1(a)
Concrete composes of
single-sized aggregate only

Figure 1(b)
Reduction of cement paste
volume due to smaller volume of
gaps within aggregate skeleton

Figure 1(c)
Improving workability at the
same paste volume due to
formation of paste coating on
aggregate surfaces

The packing density of the cementitious materials has great impact on the strength of the concrete produced. First of all, the reduction in water demand due to a higher packing density would allow the use of a lower water/cementitious ratio for achieving higher strength. Secondly, better packing would reduce the permeability of the bulk of cementitious materials and thus bleeding of the fresh cement paste. Thirdly, better packing would reduce the porosity of the transition zone by filling up the voids formed as a result of the wall effect of the aggregate with very fine particles. Both the reduced substantially improve the quality of the transition zone, which, as the weakest link in bleeding of the cement paste and the reduced porosity of the transition zone would concrete, has dominant effect on the strength of concrete . This phenomenon is often manifested by having transgranular failure (failure with fracture planes cutting through the aggregate particles) instead of transition zone failure (debonding failure at the transition zone) in high strength concrete made withdensely packed cementitious materials containing CSF. Morerecently, Bui *et al.* have demonstrated that due to improved packing, blendingcement with a rice husk ash can lead to an increase in strength of the concrete and thatbecause of the more significant improvement in packing density, the increase in strengthis larger when the cement is gap-graded.

Apart from strength, an increase in packing density of the cementitious materialswould also improve the overall performance of the concrete. For instance, at the samewater/cementitious ratio, the flowability of the cement paste and the workability of theconcrete mix would be improved. Furthermore, with increased packing density, thecement paste would be more cohesive and the concrete mix would be less likely tosegregate during placing. With the water demand reduced, the water content of theconcrete mix might also be adjusted downwards to limit the drying shrinkage and improve the dimensional stability of the concrete.

Lastly, with better packing, the permeability of the bulk of cementitious materials, both in fresh state and in hardened state, would be dramatically reduced leading to a much higher durability of the concrete

.Summing up the above discussions, the authors are of the view that the packing density of the solid particles in the concrete mix is the key concept in the design of HPC mixes. Both the packing of the aggregate and the packing of the cementitious materials need to be considered. In fact, it is the grading or packing of the whole range of particles from the coarse aggregate to fine aggregate, to cement grains, and to fine and ultra-fine cementitious materials that determines the overall performance of a concrete mix.

2.5 Method Of Particle Packing Optimization

Particle packing optimization in concrete mixture design covers the selection of the right sizes and amounts of various particles. The particles should be selected to fill up the voidsbetween large particles with smaller particles and so on, in order to increase the particlepacking density αt. The definition of particle packing density αt is the solid volume ofparticles in a unit volume. In the history of concrete, the concept of packing of aggregatesalready received interest in the 19th century, but especially the last decades,particle size optimization has gained new interest with the introduction of new types ofconcrete, such as high performance concrete, self-compacting concrete, fiber reinforcedconcrete and ecological concrete. Particle optimization methods can be divided into threegroups:

• **Optimization curves**. Groups of particles, with a specific particle size distribution,are combined in such a way that the total particle size distribution of the mixtureis closest to an optimum curve.

• Particle packing models. These models are analytical models that calculate the overall packing density of a mixture based on the geometry of the combined particle groups.

• **Discrete element models.** With numerical models a 'virtual' particle structure from a given particle size distribution is generated.

2.5.1 Optimization curves

After Féret stated in 1892 that the choice of aggregates influences concrete strength many researchers tried to find the ideal grading curve. In this area the most wellknownresearcher is Fuller with his famous Fuller curve. Mixdesign calculations based on his curve are still used today. The Fuller curve is described byEquation 1 with q = 0.5. The curve shouldrepresented the grading with the greatest density, based on their conclusions that thegradation that gives the greatest density of the aggregates alone may not necessarily givethe greatest density when combined with water and cement because of the way the cementparticles fit into smaller pores.Some researchers tried to improve this curve. They proposed the use of an exponent *q* in the range of 0.33 – 0.50. This adjustment factor*q* had to be determined experimentally and therefore can differ depending on the characteristics of the particles. With angular coarse particles the ideal curve would be bestprescribed with a lower value for *q* , since more fine particles should be added to fill thevoids between the coarse particles.

Adjusting mixture composition to a fixed optimization curve is relatively easy since it requires only a limited amount of input parameters. When the *q* factor is fixed, only the particle size distributions of the available materials are necessary to optimize a concrete mixture. Commercial computer programs such as *EMMA* areavailable. However, particle characteristics like shape or packing density are not taken intoaccount. The output of the model is an optimized particle size distribution, which notinevitably leads to a mixture with the highest packing density. This is because optimization curves are limited with respect to taking into account differences in particle shape and particle packing of different size groups. Furthermore, Palm and Wolter [2009] andStroeven et al. [2003] show that the application of gap graded mixtures can lead to higherpacking densities.

Optimization curves are continuous particle size distributions based on geometrical considerations. Andersen [1930] started with the assumption of a similaritycondition that has to be fulfilled as the particles and their environments increase in size. Inthis way, a change of the size scale should not affect the packing density of the system.

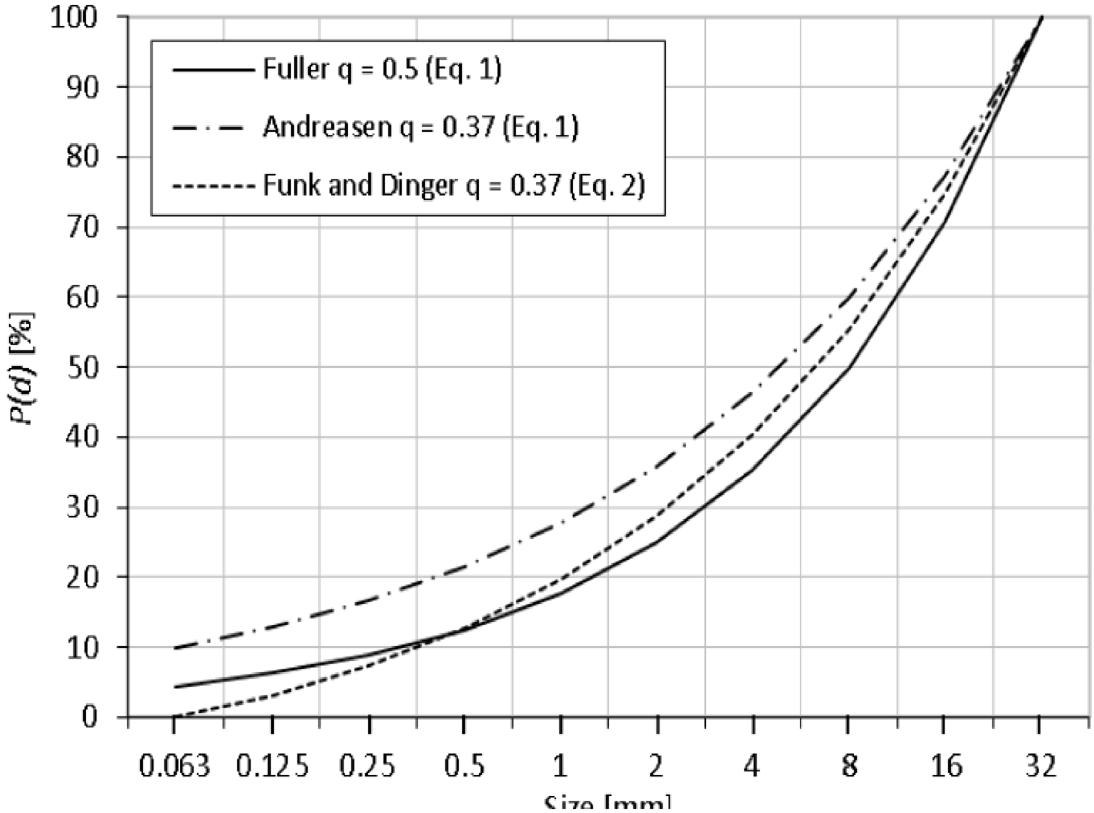

FIG2: Ideal packing curves according to Fuller,Andreasen and Funk and Dinger for a maximum particle diameter of 32 mm and minimum particle diameter of 63um

2.6 Packing Of Aggregate

The packing density of an aggregate can be determined directly by measuring the bulk density of the aggregate. The basic procedure is to mix the aggregate particles thoroughly, place them into a container of known volume, and then weigh the aggregate 6 particles in the container. With the solid density of the aggregate particles known, the packing density of the aggregate (the volumetric ratio of the solid in the bulk volume) may be determined simply as the ratio of the bulk density of the aggregate to the solid density of the aggregate particles. The packing density so measured represents how well the aggregate would be packed together. From this, the voids content, i.e. the volume of voids in the bulk volume of aggregate to be filled up with cement paste, may also be determined (the volume of voids as a ratio of the bulk volume is equal to 1.0 minus the packing density. Thepacking density of an aggregate may be measured under compacted or uncompactedcondition. As the packing density is dependent on the compaction applied, it should beexplicitly stated whether the packing density being referred to is the compacted oruncompacted one. Imagine that particles of decreasing sizes are mixed together such that the gaps between the particles are filled up successively by smaller size particles. If the filling up process is extended infinitely by incorporating particles of extremely fine size, all the voids can be filled up by solid particles, leading to a packing density very close to 1. However, in reality, this can never be achieved due to several reasons. Firstly, since thefinest size particles cannot be too fine and the largest size particles cannot be too large,there is a practical limit to the size range of the particles and therefore there is always some voids remaining unfilled. Secondly, the surface roughness of the aggregate particles would limit the effectiveness of the mixing and compaction processes. A high surface roughness of the aggregate particles would induce large inter-particle frictional forces during mixing and compaction, and thus reduce the packing density of the aggregate. Lastly, the fillingeffect of the fine particles is often hindered by two types of particle interactions: the 7 wall effect and the loosening effect. The wall effect occurs when the fine particles are butting into the surfaces of very large size particles. Because of such wall effect, the gaps between the fine particles and the surfaces of the very large size particles are prevented from being filled up. This phenomenon is called wall effect because such effect also occurs at the surfaces of the container walls. On the other hand, the loosening effect occurs when the fine particles cannot fitthemselves perfectly into the gaps of the larger size particles. As a result, the larger size particles are pushed apart causing the skeleton of the larger size particles to dilate and leading to increase in voids volume or decrease in packing density. Both the wall and loosening effects are depended on the size ratios of the particles interacting with each other and the volumetric proportions of the different size particles. This implies that the grading of the aggregate is a controlling factor of these two effects. From the above, it is evident that the major factors affecting the packing density of an aggregate include: size range, grading,particle shape, surface roughness, and effectiveness of the mixing and compaction processes.

2.7Packing Of Cementitious Material

The packing of the cementitious materials has greater effects than the packing of the aggregate on the performance of the concrete produced and therefore should be considered even more carefully in the mix design. In fact, HPC has nowadays developed to such stage that any further improvement in performance is very difficult to achieve. Nevertheless, the packing density maximization of the cementitious materials should provide room for the continuous advancement of HPC. For example, Kwan and Ng have, by blending different types of cementitious materials together to maximize the packing density of the cementitious materials, produced self-consolidating concreteof grade up to 100. However, recent progress in the prediction and maximization of thepacking density of cementitious materials has slowed down dramatically. There are twomain hurdles. Firstly, the packing behaviour of the cementitious materials and that ofthe aggregate are actually quite different and the usual practice of applying thetheoretical models and experimental methods originally developed for aggregateparticles to cementitious materials often yield erroneous results. Secondly, it is up tonow not yet possible to measure directly the packing density of cementitious materials.

It is a common belief that the packing density of cementitious materials can bedetermined using the method of measuring the dry bulk density of the particles, whichhas been successfully applied to aggregate for many years. It has been found, however,that when this method is applied to cementitious materials, the packing density resultsobtained are often unrealistically low and too sensitive to the type and level ofcompaction applied. The most probably cause was the presence of electrostatic and vander Waals forces at the particle surfaces, which caused flocculation and thus loosepacking of the fine particles . Hence, such dry packing method ofpacking dry particles together for direct measurement of packing density is not really applicable to cementitious materials.

Actually, in a concrete mix, the cementitious materials are always mixed withwater to form a cement paste and therefore should be wet. Hence, the packing density ofcementitious materials should be measured under wet instead of dry condition. In fact,because of the wetness, which lubricates the fine particles, and the capillary forces, which holds the fine particles together, the effectiveness of the compaction applied is higher under wet condition. The authors have measured the packingdensities of pure cement under both dry and wet conditions and found that the packingdensity of cement under wet condition is substantially higher than that under dry condition. It is therefore suggested that a wet packing method (measurement of packingdensity under wet condition) should be used instead of the conventional dry packing method. Apart from water, superplasticizer should also be added when measuring thepacking density of cementitious materials. Superplasticizer is an essential component ofHPC. It disperses the flocculated particles, improves the packing density and therebyreduces the water demand of the cementitious materials. With superplasticizer added,the packing density measured by the wet packing method would be higher.

After many unsuccessful trials with the dry packing method, the authors haverecently turned to the possibility of measuring the packing density of cementitiousmaterials by wet packing. Based on wet packing, the authors have developed a newmethod for the measurement of the packing density of cementitious materials. The mainfeatures of this new method are: (1) the cementitious materials are first added and mixedwith water to form a paste before packing density measurement (2) the packing density is measured repeatedly at differentwater/cementitious ratios and the maximum packing density obtained is taken as thepacking density of the cementitious materials. This newly developed wet packingmethod has been successfully applied to measure the packing densities of different mixproportions of cement, PFA and CSF.

Chapter -3

3.1- Problem statement:-

1-To study the effect of Particle Size Distribution on performance of concrete by varying the proportion of different materials available with us.

2-We have ordinary Portland cement (43 grade) , flyash and ultra fine slag as cementitious materials with us , we have to find a proportion of these materials on which packing density is maximum.

3-Determination of water content and packing density by using formula.

3.2- Methodology used:-

-Puntke Method(Water Demand Method)

The particle packing models and optimization techniques nowadays used in the design of concrete have resulted in new mixture compositions with very high compressive strengths. These new methods and theories can also be used to investigate the effects of cement replacing materials and fine fillers. This way the particle packing theories would not serve an increase of strength, but a reduction of the cement content, thus creating a more ecological concrete. However, the existing particle packing models do not yet include the particle packing of fine particles (< 100 micrometer) in a sound way. One of the reasons for this might be caused by the difficulty measuring the maximum packing density of fine powders.

The method is based on the idea that a fine, low-cohesion particle packing without a load, then and only then can be compacted to a powder specific value, when the water content is sufficient to fill all the voids in that packing. With humid but not yet saturated particle packing of fine powders, the surface tension (capillary forces) will block the water from surrounding the particles. At the saturation point the capillary forces will disappear and the particles can easily be packed to the characteristic highest packing density. Not the compaction energy is important, but the compactability. The transition from 'not yet compactable’ to ‘compactable’ can occur by adding just 0.1 grams of water to a sample containing 100 gram of powder. An excess amount of water will also lead to possible compaction, but it will result in a lower packing density or possible bleeding. For this reason it is very important to approach the saturation point by carefully adding water according to the next procedure: Place 50 grams of powder in a plastic or metal container with a flat bottom. Water is added slowly by making use of a siphon/pipette while the humid powder is mixed with a steel blade or rod. The saturation point is reached when after repeatedly tapping against the container the powder surface levels off and starts to shine. The test should be repeated at least two times with a slightly lower amount of water. The final water demand is calculated according to formula 1 from the smallest amount of water of three tests.

A **disadvantage** of the test is that the method can only confidently be used when the the existence of air voids in the ‘saturated paste’ can be ruled out.

Chapter -4

Experimental Work

4.1 Raw Materials Used

The material used in this project consist of ordinary Portland cement , ultra fine slag , fly ash , aggregates.The mortar mix is prepared with OPC 43 grade cement with fineness of 225square-m/kg with specific gravity of 3.15.The fly ash used has a finness of 320 square-m/kg.Sand having specific gravity 2.69 and finness modulus of 2.55 is used as a fine aggregates.

4.2 Instrument Used

- X-ray Laser Diffractometer

It is being used for particle size distribution analysis of fine particles less than 0.2 micron.

4.3 Formula Used

Packing Density= [1-(Volume of water/volume of water + volume of paste)] = 1-e

e= void ratio

Procedure employed:-

1-First we calculate the packing density of cement only by varying the amount of water which fill voids in it.

2-Next starting with a mix of cement and flyash calculate packing density for mix ,by varying the amount of flyash which replaces cement find out the optimum packing density and proportion of mix corresponding to that density.

3-Next starting with a mix of cement and ultra fine slag calculate packing density for mix, by varying the amount of ultra fine slag which replaces cement fin out optimum packing density and proportion of mix corresponding to that density.

4-Now keeping the amount of flyash constant given by step 1, we will alter the amount of ultra fine slag which will replace cement.This is a ternary blend , uses Ordinary Portland cement, fly ash and ultra fine slag.This will give a proportion of mix corresponding to which packing density is maximum.

5-All test will follow the instructions given by Puntke method for calculating packing density.

6-Next we will compare this proportion with the optimum proportion given by EMMA (Elkem material mix analyser) and try to match our proportion with this ideal proportion given by software.

Chapter -5

Results of Experimental Work :

5.1-CEMENT:

1st trial:

TABLE -1

Cement(gm)	Cumulative Water(ml)	Packing density
100	25	0.8
100	30	0.76
100	35	0.74
100	40	0.71
100	45	0.68

Optimum Packing density=0.68

2nd trial:

TABLE -2

Cement (gm)	Cumulative Water(ml)	Packing density
100	20	0.83
100	30	0.76
100	40	0.71
100	43	0.69
100	45	0.68

Optimum packing density=0.69

3rd trial:

TABLE -3

Cement (gm)	Cumulative Water(ml)	Packing density
100	20	0.83
100	30	0.76
100	40	0.71
100	42	0.70
100	43	0.69

Optimum packing density=0.70

Optimum packing density from 3 above calculated packing density =0.70

5.2:CEMENT + FLY ASH:

1st trial:(90% cement + 10% fly ash)

TABLE -4

Cement(gm)	Flyash(gm)	Cumulative Water(ml)	Packing density
90	10	10	0.90
90	10	20	0.83
90	10	30	0.76
90	10	40	0.71
90	10	45	0.68
90	10	50	0.66

2nd trial:(80%cement + 20% fly ash)

TABLE -5

Cement(gm)	Flyash(gm)	Cumulative Water(ml)	Packing density
80	20	10	0.90
80	20	20	0.83
80	20	30	0.76
80	20	40	0.71
80	20	48	0.67

3rd trial:(70% cement + 30% fly ash)

TABLE -6

Cement(gm)	Fly ash(gm)	Cumulative Water(ml)	Packing density
70	30	10	0.90
70	30	20	0.83
70	30	30	0.76
70	30	40	0.71
70	30	45	0.68

4th trial:(60% cement + 40% Fly ash)

TABLE -7

Cement(gm)	Fly ash(gm)	Cumulative Water(ml)	Packing density
60	40	10	0.90
60	40	20	0.83
60	40	30	0.76
60	40	35	0.74
60	40	40	0.71

5th trial:(50% cement + 50% Fly ash)

TABLE -8

Cement(gm)	Fly ash(gm)	Cumulative Water(ml)	Packing density
50	50	10	0.90
50	50	20	0.83
50	50	30	0.76
50	50	40	0.71
50	50	47	0.68

Optimum packing density fromabove 5 trials = 0.71

5.3: CEMENT + ULTRA FINE SLAG:

1st trial(90%cement + 10 % ultra fine slag)

TABLE -9

Cement (gm)	Ultra fine slag(gm)	Cumulative Water(ml)	Packing density
90	10	15	0.86
90	10	25	0.80
90	10	35	0.74
90	10	45	0.68

2nd trial: (80%cement+20%slag)

TABLE -10

Cement(gm)	Slag(gm)	Cumulative Water(ml)	Packing density
80	20	15	0.86
80	20	25	0.80
80	20	35	0.74
80	20	41	0.70

3rd trial : (70%cement + 30%slag)

TABLE -11

Cement(gm)	**Slag(gm)**	**Cumulative Water(gm)**	**Packing density**
70	30	10	0.90
70	30	20	0.83
70	30	30	0.76
70	30	38	0.72

4th trial : (60%cement + 40%slag)

TABLE -12

Cement(gm)	**Slag(gm)**	**Cumulative Water(ml)**	**Packing density**
60	40	10	0.90
60	40	20	0.83
60	40	30	0.76
60	40	40	0.71

Optimum packing density from above 4 tables= 0.72

5.4:Cement + flyash + ultra fine slag:

1st trial : (50%cement+40%Fly ash+10%slag)

TABLE -13

Cement(gm)	Fly Ash(gm)	Slag(gm)	Cumulative Water(ml)	Packing density
50	40	10	10	0.90
50	40	10	25	0.80
50	40	10	35	0.74
50	40	10	45	0.68
50	40	10	55	0.64

2nd trial : (40%cement+40%Fly ash+20%slag)

TABLE -14

Cement(gm)	Fly Ash(gm)	Slag(gm)	Cumulative Water(ml)	Packing density
40	40	20	15	0.869
40	40	20	30	0.769
40	40	20	40	0.714
40	40	20	50	0.66
40	40	20	53	0.65

3rd trial : (30%cement+40%Fly ash+30%slag)

TABLE -15

Cement(gm)	Fly Ash(gm)	Slag (gm)	Cumulative Water(ml)	Packing density
30	40	30	15	0.869
30	40	30	30	0.769
30	40	30	40	0.714
30	40	30	50	0.66

4th trial : (20%cement+40%Fly ash+40%slag)

TABLE -16

Cement(gm)	Fly ash(gm)	Slag(gm)	Cumulative Water(ml)	Packing density
20	40	40	15	0.869
20	40	40	30	0.769
20	40	40	40	0.714
20	40	40	45	0.689

5th trial : (15%cement+40%Fly ash+45%Slag)

TABLE -17

Cement(gm)	Fly Ash(gm)	Slag(gm)	Cumulative Water(ml)	Packing density
15	40	45	15	0.869
15	40	45	30	0.769
15	40	45	40	0.714

6th trial : (10%cement+40%FlyAsh+50%slag)

TABLE -18

Cement(gm)	Fly Ash(gm)	Slag(gm)	Cumulative Water(ml)	Packing density
10	40	50	15	0.869
10	40	50	30	0.769
10	40	50	40	0.714
10	40	50	43	0.69

Optimum packing density =0.714 and final proportion corresponding to it = 3:8:9

Chapter 6

Optimization of granular mix using EMMA:

6.1-Raw Materials Used in software:

1-Ordinary Portland Cement-OPC 53 grade cement is used having particle density=3.15

2-Quartz Sand-Quartz sand is used as a replacement of fine aggregate having specific gravity=2.53

3-Silica Fumes-It is used as a filler material which is 10 times finer than cement and having specific gravity=2.25

4-Fly Ash-This materials is used as a replacement of cement and quartz sand and fill the pores between them to optimize the packing density.Fly ash having specific gravity=2.25

5-Ultra Fine Slag-This material is also used as a replacement of cement and quartz sand and fill the pores between them to optimize the packing density.Ultra fine slag having specific gravity=3.75

7.2- How to fit curve using EMMA

Step-1. Creating material library- Add all the above mentioned materials in the material library inside EMMA which requires some details regarding materials like its particle density and particle size distribution of each material added individually.

Step-2.**Creating recipe-** A recipe is been made within EMMA by using materials added in the material library.

Step-3.**Create a curve using basic mixture-** A basic mixture has been made within the recipe by just entering amount of materials used for 1m3 of concrete in specific proportion.

Step-4.**Trial curves-** Generate the number of trial curves by altering the amount of quantity of materials according to basic mixture to get the best fit curve with the curve according to modified andersean model curve.

Step-5. **Interpretation of the curve-** The best fit curve we get after doing lot of trials represent the optimum dosage of materials to prepare ultra high performance concrete(Reactive Powder Concrete) having strength greater than 150 Mpa and meet other durability aspects.

6.3 Particle Size Distribution Data Using X-ray Laser Diffractometer:

TABLE-19

Size(micron)	Silica fume	Ultra fine slag	Fly ash	Quartz sand	Cement(53 grade)
Particle density	2.25	3.75	2.25	2.53	3.12
32000	100	100	100	100	100
22400	100	100	100	100	100
16000	100	100	100	100	100
11200	100	100	100	100	100
8000	100	100	100	100	100
5600	100	100	100	100	100
4000	100	100	100	95.16	99.98
2000	100	99.88	95.90	90.23	93.89
1000	100	99.82	67.95	58.95	63.88
500	99.94	98.14	43.78	38.82	40.81
250	99.44	85.53	24.81	16.81	20.14
125	96.21	56.70	13.01	4.59	8.53
63	80.37	27.44	7.33	1.53	4.89
0	0	0	0	0	0

6.4 Curve preparation for base mixture

For 1m3 of concrete equivalent to 2328kg

Cement used=900kg(36.2%)

Quartz sand=1005kg(40.5%)

Water=63kg(6.5%)

Silica fume=220kg(8.9%)

Plasticizer=40kg

Water/binder ratio=0.145

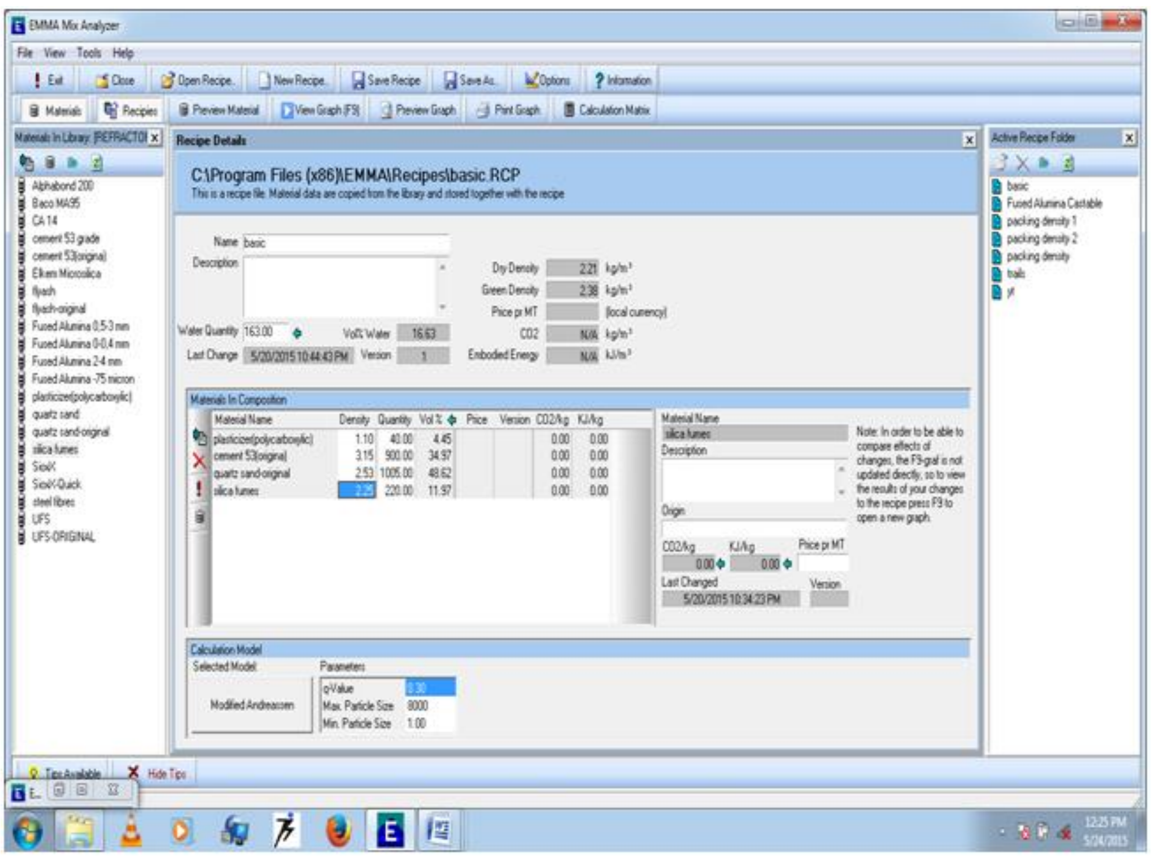

FIGURE 3-Reciepe making for Base mixture

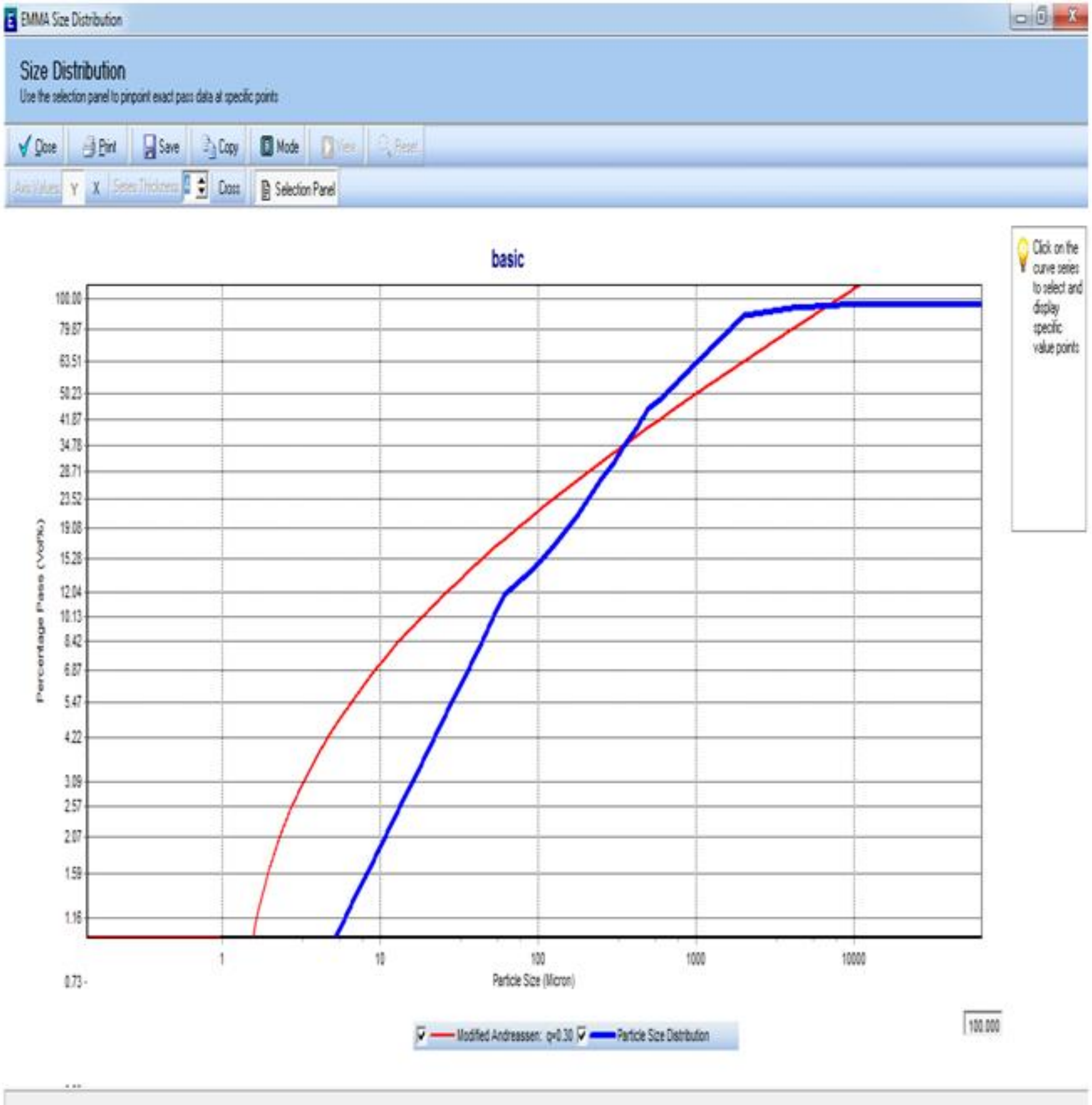

FIGURE 4-Percentage passing vs particle size(micron) curve for base mixture

6.5-Preparation Of Trial Mixture

Trial-1.

Quantity of materials used-

Cement-900kg

sand-1005kg

water-162kg

silica fume-132kg

flyash-44kg

ultra fine slag-44kg

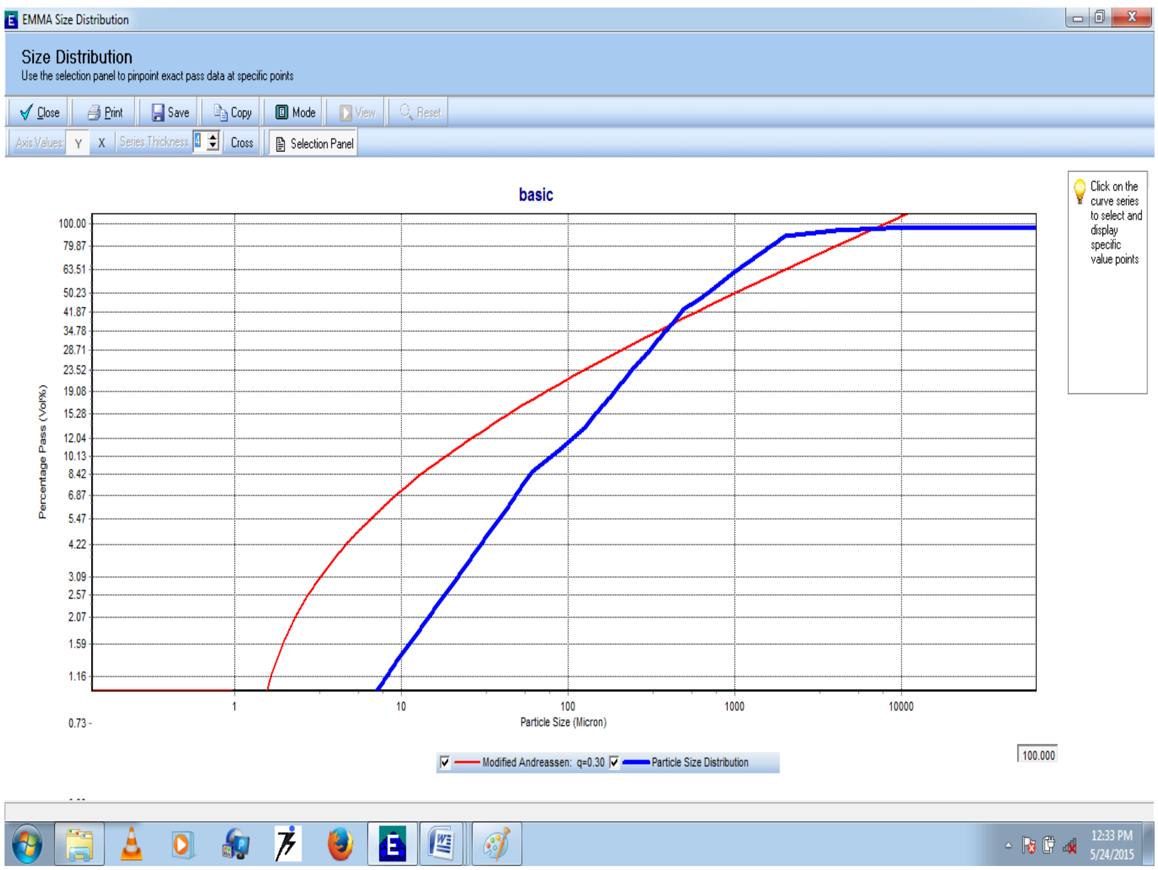

FIGURE 5-Percentage pass vs particle size(micron) curve for Trial1st mix using Elkem Material Mix Analyser.

TRIAL-2

Quantity of materials used-

Cement-900kg

Quartz Sand-900kg

Water-162kg

Silica fume-165kg

Ultra fine slag-50kg

Fly ash-110kg

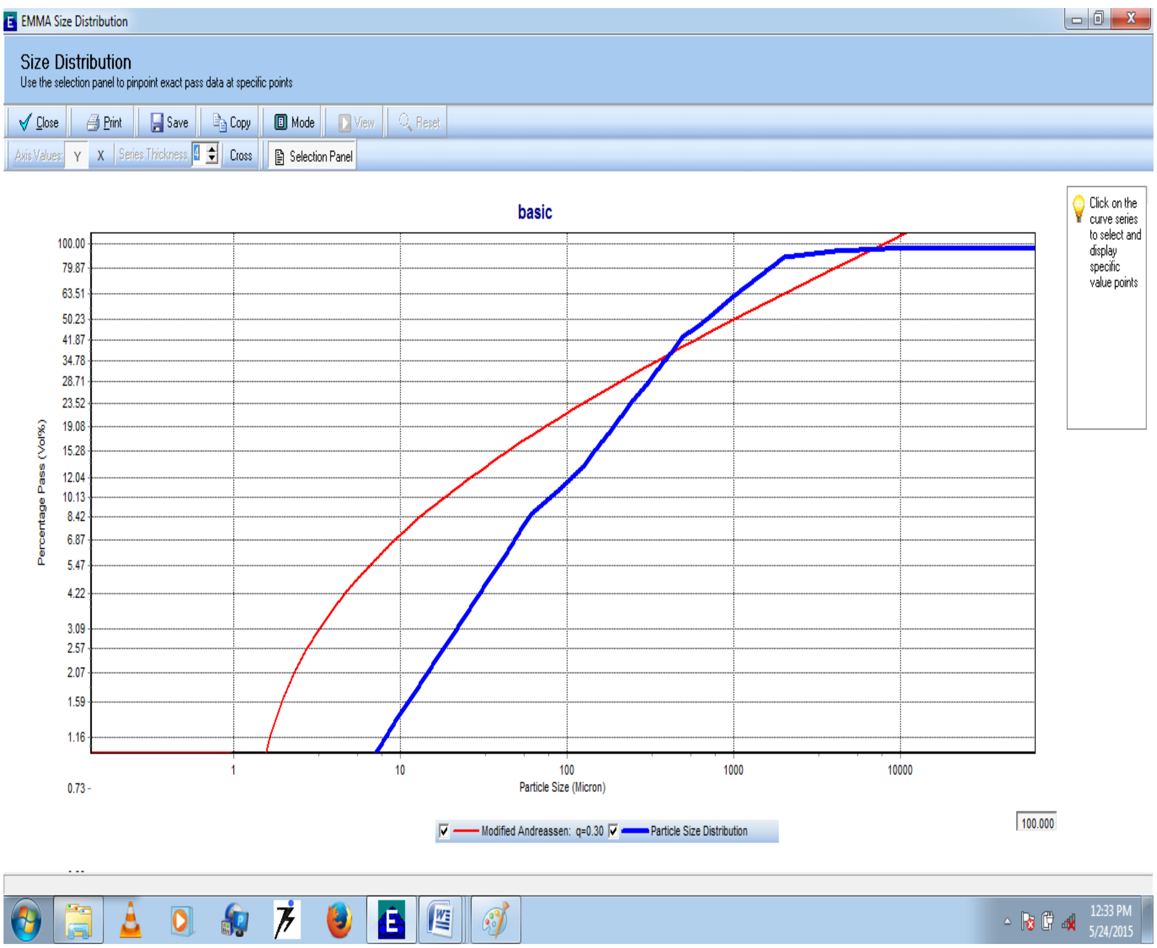

FIGURE6-Percentage pass vs particle size(micron) curve for Trial 2 using Elkem Material Mix Analyser.

TRIAL-3

Quantity of material used-

Cement-900kg

Flyash-310kg

Quartz sand-320kg

Silica fume-250kg

Ultra fine slag-80kg

Water-162kg

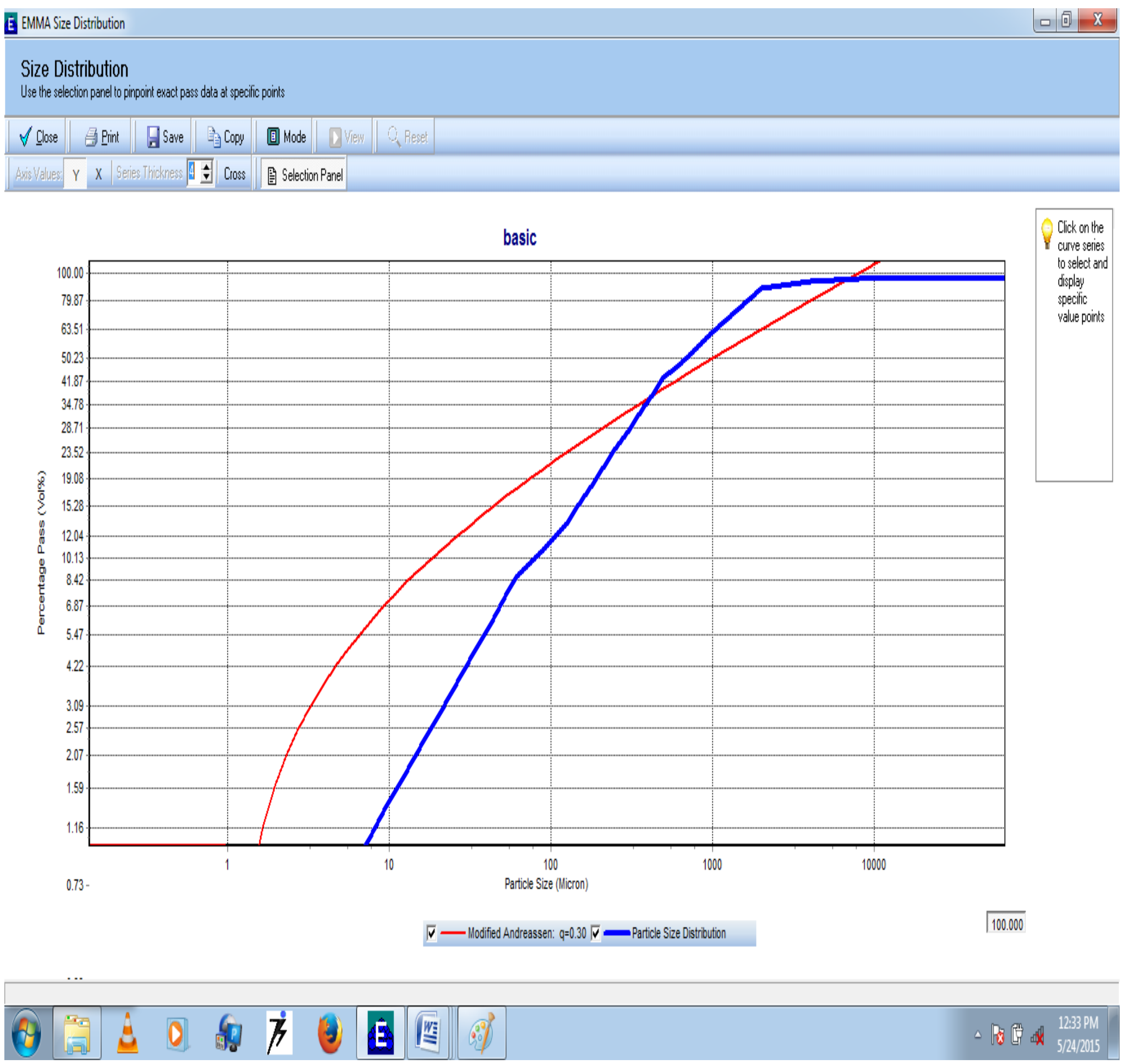

FIGURE 7-Percentage passing vsparticle size(micron) for Trial 3 using Elkem Material Mix Analyser

TRIAL-4

Quantity of materials used-

Cement-900kg

Flyash-348kg

Quartz sand-360kg

Silica fume-250kg

Ultra fine slag-100kg

Water-162kg

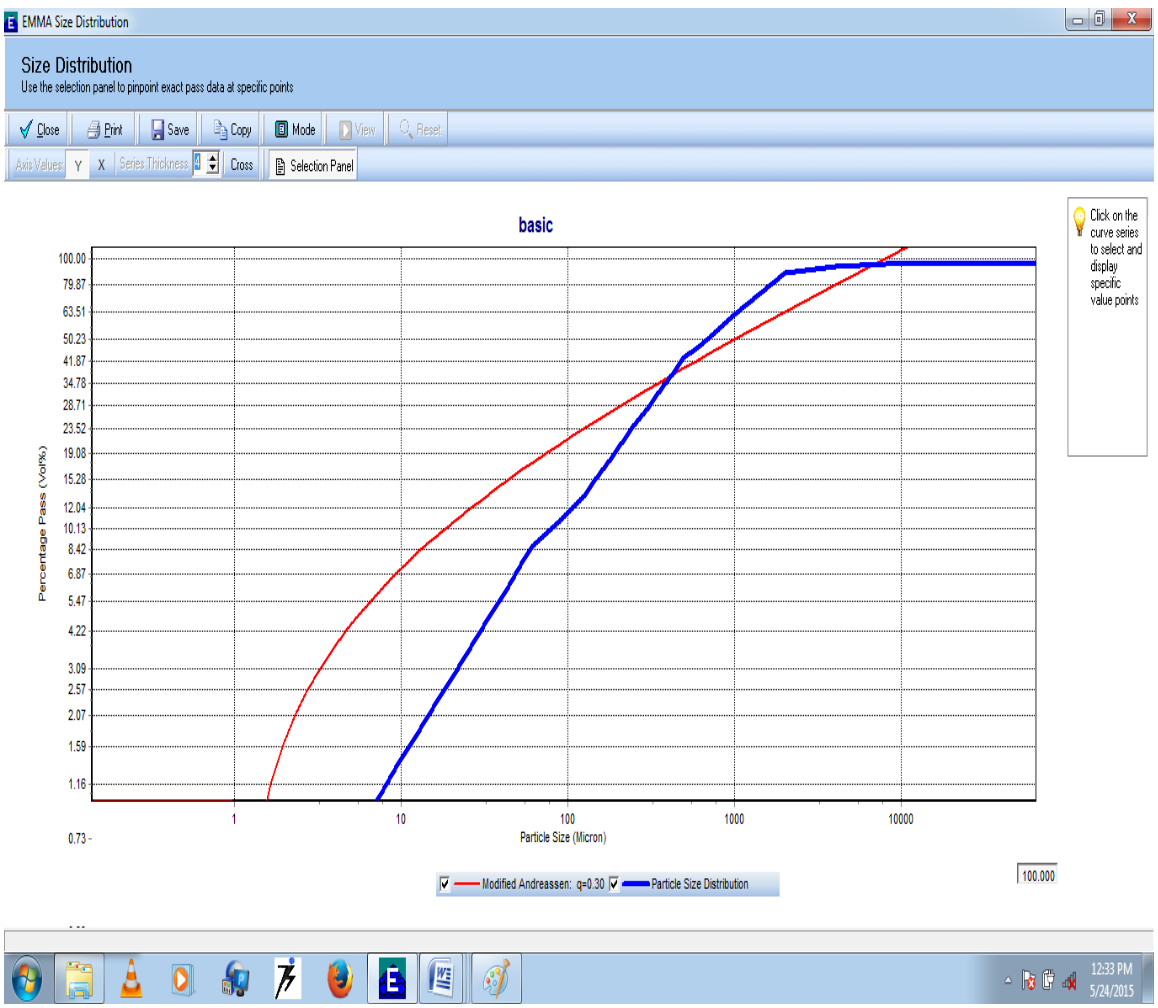

FIGURE 8-Percentage passing vs particle size(micron) for Trial 4 usinfElkem Material Mix Analyser.

TRIAL-5.

Quantity of materials used-

Cement-900kg

Flyash-400kg

Quartz sand-360kg

Silica fume-350kg

Ultra fine slag-70kg

Water-162kg

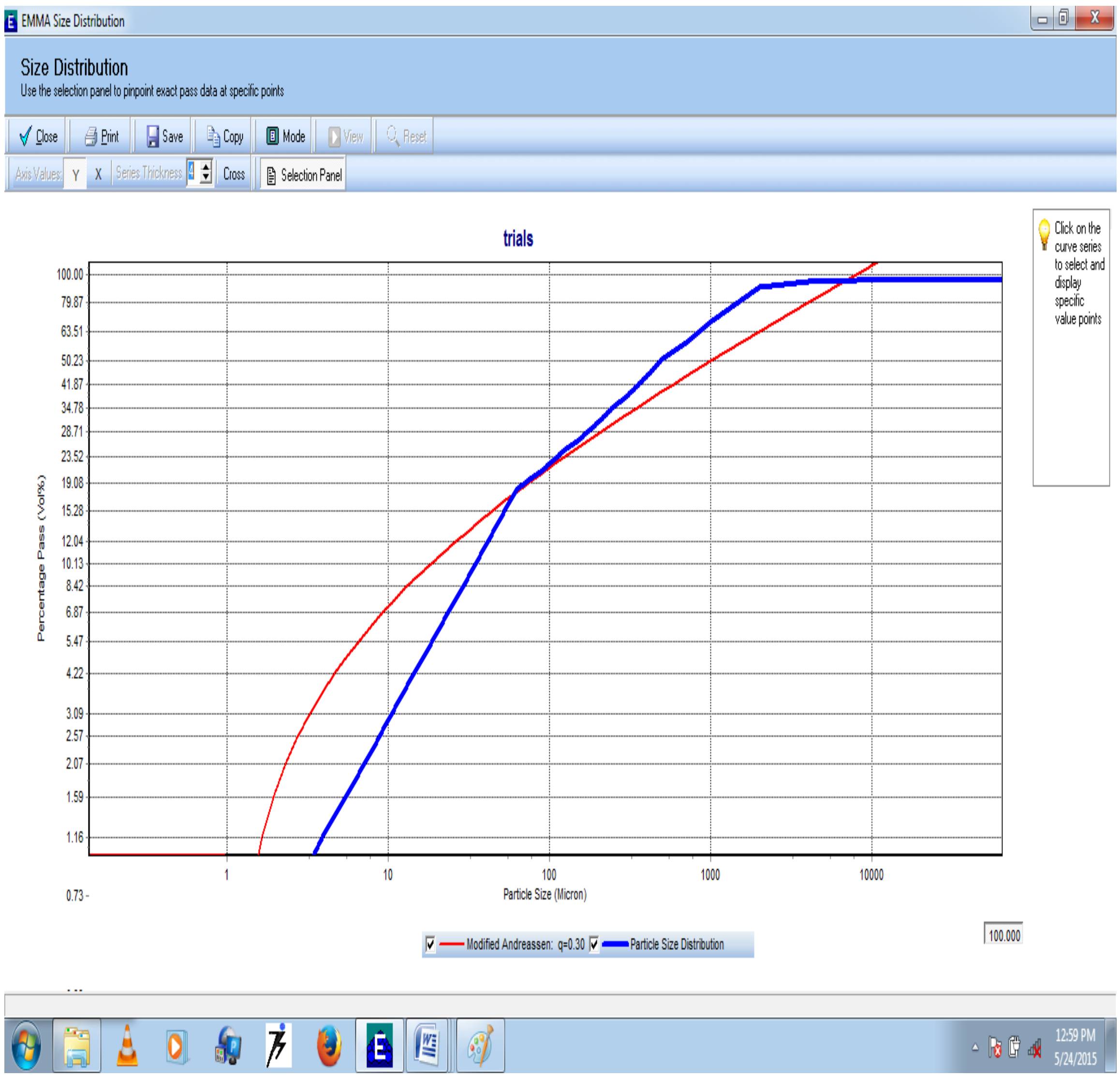

FIGURE 9-Percentage passing vsparcticlesize(micron) for Trial 5 using Elkem Material Mix Analyser.

6.6- Final results and discussion:

According to experimental work we have found that optimum dosage of cement ,ultra fine slag and flyash in ratio is 3:8:9 respectively.

According to analyses done by Elkem Material Mix Analyser to optimize the dose of materials by hit and trial method in order to fir the curve with modified andersean curve, we have replaced quantities of quartz sand with flyash , UFS and silica fumes and found that for ;

Cement-900kg

Flyash-400kg

Quartz sand-360kg

Silica fume-350kg

Ultra fine slag-70kg

Water-162kg

We got the best fit for our curve and packing density.This curve can further be optimized more and we can obtain a better fit for our curve which will utilize the finer materials to fill the pores of the coarser particles and can get a even better packing density.

Chapter -7

Conclusion:

In this project, the concept of packing density has been introduced. It is believedthat maximization of the packing density of the cementitious materials and the packingdensity of the aggregate particles could improve the overall performance of the resulting
concrete mix and thus should be the general guideline for mix optimization. On theother hand, despite the increasing popularity of UHPC, a systematic mix design methodfor UHPC is still lacking . At each stage, packing density maximization is carried out.Research studies by the authors on the packing of cementitious materials have alreadyproduced some promising results but further studies are needed before all the details ofthe mix design method could be worked out.

Punkte test was found to an ideal method for determining the exact proportions of paste and mortar phase for yielding maximum performance. Packing density was found to be dependent on the binary blends of ultra fine slag and cement; however, the maximum ultra fine slag has to be restricted based on the reactivity index which revealed that the ideal combination of cement to GGBS was 70:30.

Optimum water according to experimental work was found to be 40ml per 100gm of powder and optimum dosage corresponding to maximum packing density was 3:8:9.

According to analyses done by Elkem Material Mix Analyser to optimize the dosage of materials to maximize the packing density as well as prepare ultra high performance concrete we have found that by using **cement=900kg , quartz sand=360kg , flyash=400kg,silica fumes=350kg , ultra fine slag=70kg** the curve gives best fit to the modified andersean curve or we can say that flyash=400kg , silica fumes=350kg , UFS=70kg is used to replaced the cement and quartz sand which is the aim of our project to incorporate the cheap available material in mix design to design a ultra high performance concrete with strength more than 150Mpa.

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