A
Major Project
On

FACTORS AFFECTING CEMENT CONTENT IN CONCRETE

Submitted in Partial fulfillment of the requirement
for the award of the degree of

MASTER OF ENGINEERING
(Structural Engineering)

Submitted by
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CERTIFICATE

This is to declare that the major project on **" Factors Affecting Cement Content In Concrete"** is a bonafide record of work done by me for partial fulfilment of requirement of award of degree in M.E. Civil Engineering (Structural Engineering) at Delhi College of Engineering.

This project has been carried out under the supervision of Dr. Awadhesh Kumar, Assistant Professor, Delhi College of Engineering, Delhi.

I have not submitted the matter embodied in this report to any other University or Institution for the award of any Degree or Diploma.

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This is to certify that the above statement laid by the candidate is correct to the best of my knowledge.

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ABSTRACT

Role of cement in the formation of concrete is of vital importance as no concrete can be formed without using a binder. It is the most important ingredient because its presence is necessary to achieve the most desirable property i.e. strength of concrete and the minimum of cement content is even more important for the concrete to perform during its life time that is for durability. In this project work it has been shown that how cement affects the strength property and in combination with water how it affects the properties of green and hardened concrete, further more how it can be optimized to achieve desired properties. Use of 12.5mm and down size coarse aggregate, along with Superplasticizer to reduce water cement ratio have been adopted to optimize the strength of concrete. These factors improve the specific surface area of coarse aggregate and reduce water cement ratio to achieve higher strength. Fine aggregate to coarse aggregate ratio is varied to improve the grading of aggregates to achieve high strength by reducing the water cement ratio. The effect of size and shape of the coarse aggregate has also been shown on compressive strength and workability.

As per the provision enshrined in the current code of practice for plane and reinforced cement concrete (IS456:2000)[24], restriction is imposed on usage of maximum quantity of cement not to exceed 450kg/m^3 of concrete work. In many of the recent works carried out to gain high strength of concrete, the quantity of cement used per cubic meter of concrete is in excess[6,10,14] of the quantity prescribed in the Indian standard code, IS 456:2000. Although maximum permissible limit on usage of cement is prescribed in the code but in general it is also noticed that no significant work has been done by using the cement content at the threshold level specified in the code. Accordingly in this project work concrete mix design data is prepared taking into consideration strength and workability of concrete maintaining the constant quantity of cement at maximum prescribed level along with the different fine and coarse aggregates available in the market in terms of their fineness.

IS code namely , IS 456:2000 further permits use of fly ash and ground granulated blast furnace slag popularly known as mineral admixtures in combination with cement. Fly ash and slag are industrial waste products, if utilized productively will help in protection of environment and reduce burden on dwindling natural resources. These mineral admixtures called cement replacing materials generally replace cement partially, thus making the concrete economic. The present experimental work is based on using fly ash as cement replacing material as well as supplementary cementitious material with addition of mineral admixtures to the cement keeping cement content constant at the maximum limit prescribed in the code to get information on how much strength can be achieved by keeping the concrete workable at the required degree.

List of Tables

List of Figures

Contents

6. DISCUSSION AND RESULTS

CHAPTER 1

INRODUCTION

1.1 INTRODUCTION

The various civil engineering materials used in construction activities are:-

1.1.1 Stones:

Stones are naturally occurring products obtained from rocks by the process of quarrying. Good building stones should possess characteristics like high crushing strength (i.e. crushing strength > 100 N/ mm^2), high durability, sufficient hardness (co-efficient of hardness >14) , high resistance to wear, good fire resistance, crystalline structure , specific gravity > 2.7, high impact value (i.e. toughness index >13), low water absorption(< 5% after immersion in water for 24 hours), facility for carving & dressing , weather resistant and good looking. To name a few building stones are Granite, Basalt, Sand Stone, Lime Stone, Slate, Marble, Gneisses etc. They are used subject to availability and suitability for the work.

1.1.2 Bricks:

Bricks are sand and clay products (Silica and Alumina) involving process of moulding, drying and burning. Good building bricks should possess characteristics like sharp / well defined edges with uniform reddish colour, crushing strength (> 7.5 N /mm^2) , sufficient hardness, durability, resistance to weather , resistance to fire, water absorption (<10% after immersion in water for 24 hours). It should not contain harmful alkaline salts to cause damage by efflorescence.

1.1.3 Lime:

It is not available naturally in Free State but it is a product obtained by calcining (burning over 900^0C) of lime stone.

$CaCo_3$ -------> Co_2 + Cao

Lime stone on burning ------> Carbon dioxide + Lime

Prior to the invention of cement it was a major binder used for mortar and concrete making, being comparatively weaker in strength. However it is still used for plastering interior surfaces of walls, white washing of rooms and buildings, laying concrete for foundation and under floors. It is a cheaper material.

1.1.4 Cement:

Cement is a product obtained by burning of well proportioned mixture of siliceous, argillaceous and calcareous materials and crushing the same to fine powder form. Water when added to cement possess the properties of adhesion and cohesion by virtue of which it can bond well with aggregates to form strong hard mass like rock known as concrete. Cement is used for making mortar and concrete in all construction activities whether small or large like floor, roof, wall or column of a building, dams, weirs, water tanks, bridges, docks, light houses, septic tanks, swimming pools, manufacturing pre cast pipes, piles, fencing posts, garden seats etc.

1.1.5 Timber:

Timber is the wood useful for building and other engineering purposes which is obtainable from a freshly felled tree trunk after seasoning and conversion to required market form and / or structural timber. The timber for engineering purposes should be free from decay, dry rot, wet rot, insects/fungi without/with defects like knots, rind galls, shakes, upsets etC. (in pErmissible lhmits). ThE Timber availabLe should possess properpies like strength, toughnEsc, elastic)ty, rEsistance to sheAr, hardness, retention of shape, durabIlity and workability etc. Chief varities of Indian timber available are Babool (Kikkar), Sissoo (Shisham), Teak (Sagwan), Sal, Jaman (Jamun), Mango(Aam), Deodar (Diar), Sandal (Chandan), Chir, Kail etc. Selection of particular type of timber depends upon availability and presence of specific properties.

As a result of cutting of more and more trees, forests are depleting and timber is becoming a scarce material. Thus timber is needed to be replaced and is being replaced by other substitute materials like PVC, Plastic and metals etc.

1.1.6 Metals:

The materials obtained by processing of metallic ores (found in nature as surface / sub-surface deposits) are known as metals. Metals formed with iron as their principal constituent are ferrous metals which include cast iron, wrought iron, steel etc. The metals formed with principal constituent like carbon, sulphur, manganese, phosphorus (Except iron) etc. are called non ferrous metals like copper, lead, tin, zinc, aluminum etc. The most common ferrous metals used in construction activity are cast iron and steel (particularly mild steel). Cast iron is used for making pipes for water supply purposes. Steel is used for wide variety of purposes like reinforcement for R.C.C. work, mild steel rolled sections (bars, sheets, plates, angles, channels, joists etc. for light, medium and heavy usage as structural steel), manufacture of various fittings and fixtures etc. Steel is costly but used due to its high strength, elasticity, durability etc.

Out of non ferrous metals copper being good conductor is used to form wires/cables for electricity and sound transmission. Copper is used in electroplating to give a pleasing appearance in water supply and sanitary fittings.

1.1.7 Plastic:

Plastics are the natural, synthetic or semi synthetic organic substances which are prepared out of natural or synthetic resins with or without moulding compounds like fillers, plasticizers, solvents, pigments etc. As a building material plastic possess dimensional stability, strength, durability, chemical resistance, weather resistance, fire resistance (only phenol formaldehyde and urea formaldehyde varities), does not require finishing treatment etc. Plastic is being used in building industries for making doors for bathrooms and toilets, partition walls, HDPE water tanks, PVC Pipes, PVC wall tiles, washbasins, cisterns, valves, handles, towel rails, thermal insulation in buildings etc. Foamed plastic is being used in USA in structural load bearing members.

1.1.8 Glass and allied products:

Glass is a hard, brittle and transparent / translucent material obtained by fusing and super cooling of a mixture of a number of metallic silicates. Glass possess properties like hardness, fusibility, refractive power, weather resistance, good electric insulator, can be fabricated into desired shape and size etc. Glass is used in construction industry in glazing of doors / windows / partitions etc. Wired glass is used for skylight / north light for safety purposes. Glass wool / fiber glass is used for insulation of pipes, bends, valves etc.

1.1.9 Cement concrete:

It is a heterogeneous mixture of cement water paste, aggregates and admixtures (if required / added). The cement water paste has the role to bind the aggregates to form a strong hard mass after hardening as a result of chemical reaction between cement and water. Aggregates are classified as fine and coarse aggregates. Fine aggregate consists of sand whose particle size does not exceed 4.75 mm. Coarse aggregate consists of gravel, crushed stone etc. of particle size greater than 4.75 mm. In the hardened mass of concrete the voids of larger particles (coarse aggregate) are filled up by smaller particles (fine aggregate) and voids of smaller particles are filled up with cement.

The final properties of concrete depend upon the properties of its ingredients, mix proportion, method of mixing, method of compaction and curing etc. Concrete as a construction material has gained popularity as it can be made with the locally available constituent materials by properly designing the mix to satisfy the specific requirements of the structure.

Concrete as a building material is weak in tension but very strong in compression. So, when concrete has to encounter tensile stresses, it is strengthened by using steel bars thus forming a composite construction known as reinforced cement concrete (R.C.C.). An alternative method to encounter the tensile stresses is by introducing the compressive stresses in concrete so that this initial compression neutralizes the tensile stresses. This type of construction is known as pre- stressed cement concrete construction.

1.2 Advantages of Concrete:

As a construction material, concrete has following advantages:

a) Concrete is economical as compared to other building materials because all materials used except cement are locally available.

b) Concrete can be easily handled and moulded to desired shape when freshly mixed.

c) The formwork can be used repeatedly resulting into economy.

d) Concrete provide quickness and ease in monolithic construction.

e) Its monolithic character gives much rigidity to the structure.

f) Concrete has high compressive strength, it can be used in combination with steel reinforcement for almost every type of structure like buildings, bridges, water retaining structures, silos, dams, bunkers, shell roofs, roads, airfields, docks and harbours etc.

g) Concrete and steel have approximately equal coefficients of thermal expansion and good bond between them.

h) Concrete can be used as sound proofing material in the form of cellular concrete.

i) It is quite durable, fire resistant, corrosion free and not liable to rot or decay thus maintenance cost is very low.

j) Concrete can be pumped hence easy to be laid even in difficult locations.

k) Concrete can be sprayed on to fill the fine cracks for repairs by gunniting process.

1.3 Disadvantage of Concrete

a) Concrete possess low tensile strength and hence cracks easily thus requiring use of reinforcement bars or meshes.

b) Concrete is heavy in weight thus requiring strong centering and shuttering for casting of concrete.

c) Concrete is liable to shrink on drying and expand on wetting, thus provision of contraction joint has to be made to avoid shrinkage / expansion due to removal / ingress of moisture.

d) As a result of variation in temperature concrete expands/contracts thus making it mandatory to provide expansion joint in large structure.

e) Concrete develops creep under sustained loading and this factor requires to be taken care of while designing bridges and dams etc.

f) Due to the presence of sulphate and alkali concrete is likely to disintegrate.

g) Due to lack of ductility in concrete as a material it is disadvantageous with respect to seismic design.

CHAPTER 2

ROLE OF CEMENT IN CONCRETE

2.1 ROLE OF CEMENT

Cement plays a vital role of binding all the ingredients of concrete, when mixed with water. Cement fills up the voids left after the various ingredients have arranged themselves to provide a compact concrete.

2.2 TYPES OF CEMENT

Variety of cements are commercially available, possessing variety of chemical composition and thus resulting into use under different situations. IS 456:2000 stipulates type of cement selected should be appropriate for the intended use[24].

The various cements allowed to be used for formation of concrete are:

a) 33 grade ordinary Portland Cement conforming to IS 269:1989
b) 43 grade ordinary Portland Cement conforming to IS 8112:1989
c) 53 grade ordinary Portland Cement conforming to IS 12269:1989
d) Rapid hardening Portland Cement conforming to IS 8041:1990
e) Portland slag Cement conforming to IS 455:1989
f) Portland pozzolana Cement (fly ash based) conforming to IS 1489(Part I):1991
g) Portland pozzolana Cement (calcined clay based) conforming to IS 1489(Part 2):1991
h) Hydrophobic Cement conforming to IS 8043:1991
i) Low heat Portland Cement conforming to IS 12600:1989
j) Sulphate resisting Portland Cement confirming to IS 12330:1988
k) High alumina Cement conforming to IS 6452:1989

l) Super Sulphated Cement conforming to IS 6909:1990

2.2.1 Hydration of Cement

It is an exothermic chemical reaction taking place within cement, on addition of water by virtue of which it acts as a bonding medium. The nature of hydration reaction is depicted in figure 2.1 which measure the heat evolved during the exothermic reaction.

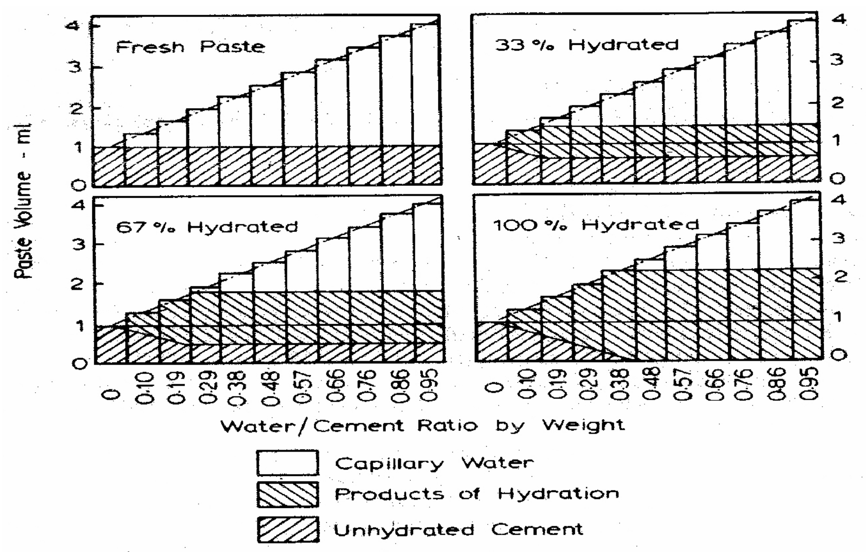

Fig 2.1 Composition of Cement paste at different stages of hydration

2.2.2 Setting and Hardening of Cement

Setting of cement refers to the change from the plastic state to the semi rigid state. As the setting commences the cement paste acquires some strength, this gain in strength of the cement paste is hardening. The setting time of cement depends upon temperature. At low temperature setting is retarded but above about 30^0 C the setting is accelerated thus reducing the setting time.

2.3 COMPRESSIVE STRENGTH

The compressive strength of hardened concrete is considered to be one of the vital properties of concrete which can be measured easily on standard sized cubes and is often taken as an index of the overall quality of concrete. Many other desirable properties of concrete e.g. tensile strength, shear strength, modulus of elasticity, bond, impact, abrasion resistance and durability etc. are also taken to be related to the compressive strength at least to a general extent.

2.4 WORKABILITY

From the stage of mixing till it is transported, placed in the form work, compacted and finished, fresh concrete should satisfy a number of requirements[22].

The mix should be stable, in that it should not segregate during transportation and placing. The tendency of bleeding should be minimized.

a) The mix should be cohesive and mobile enough to be placed in the form around the reinforcement and should be able to cast into the required shape.
b) The mix should be amenable to proper and thorough compaction as possible in the situation of placing and with the facilities of compaction.
c) It should be possible to obtain the required strength and satisfactory surface finish.

The diverse requirements of stability, mobility, compact ability, place ability and finish ability of fresh concrete are collectively referred to as workability.

As per IS:6461(Part VII) 1973, workability is defined as property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, compacted and finished. The optimum workability of fresh concrete varies from situation to situation.

2.4.1 Need for Sufficient Workability

Workability is a vital property as far as finished product is concerned because concrete must be workable such that compaction to maximum density is possible with a reasonable amount of work.

The need for compaction becomes apparent from study of the relation between the degree of compaction and the resulting strength[20]. It is convenient to express the former as density ratio i.e. a ratio of the actual density of the given concrete to the density of the same mix when fully compacted. Likewise the ratio of the strength of concrete actually (partially) compacted to the strength of the same mix when fully compacted can be called the strength ratio. The presence of voids in concrete greatly reduces its strength. The relation between strength ratio and density ratio is shown in figure 2.2

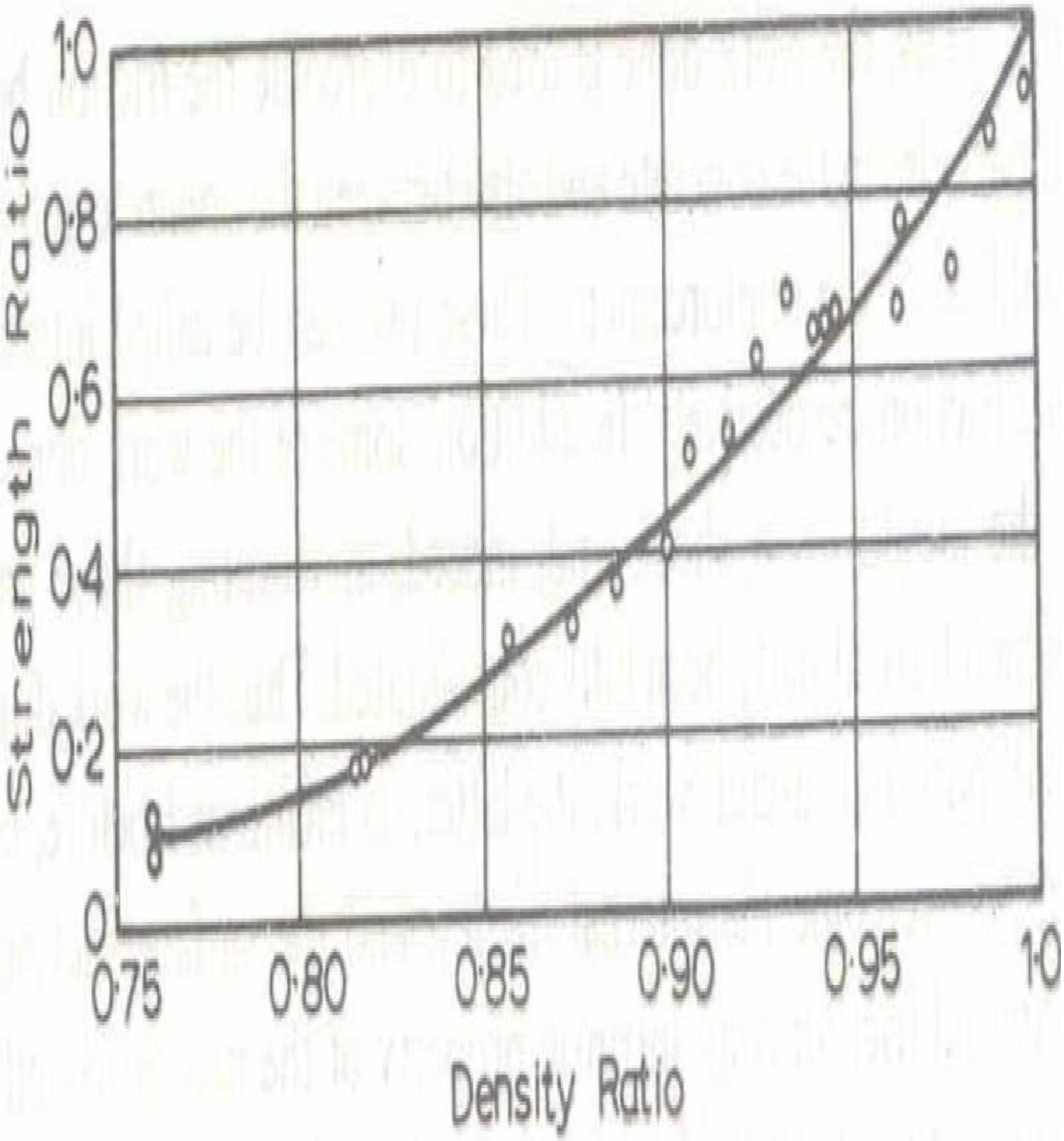

Fig. 2.2 Relation between strength ratio and density ratio

2.4.2 Slump Test

It is a most common method of measuring the consistency of concrete. It serves as a control test to give an indication about the uniformity of concrete from batch to batch. Repeated batches of the same mix, brought to the same slump will indicate to have the same water content and water cement ratio, provided the binder are uniform and grading of aggregates within acceptable limits. More information of workability and quality of concrete can be gathered by observing the slump pattern. Quality of concrete can also be assessed by observing the deformation on concrete by giving a few tapings with tamping rod on the base plate. This will reflect tendency of concrete to segregation.

The test mould consists of a frustum of a cone with 300mm height, top and bottom diameters 100mm and 200mm respectively. For tamping of concrete 16mm diameter, 600mm long rod with bullet end is used. The concrete is filled in the cone in 3 layers (each approximately $_{1/3}$ of the height of mould) after placing it on the non absorbent horizontal surface. Each layer is tamped 25 times by tamping rod evenly over the entire cross- section. After the top layer is rodded the concrete is struck off to level with trowel a tamping rod. The mould is removed vertically upwards continuously without disturbing the concrete. This allows the concrete to subside. The subsidence of concrete is referred as slump which is measured in mm.

2.4.3 Effect of Time and Temperature on Workability

Freshly mixed concrete stiffens as the time elapses and this is separate from the process of setting. In this (setting) process part of water is absorbed by the unsaturated aggregate and part of it is evaporated when concrete is exposed to sun or wind and a part is removed by the initial chemical reaction. Further the loss of workability is also depend upon initial workability, such that higher it is, greater the slump and loss in rich mixes. Rate of slump loss is also related to the properties of cement use: higher the loss rate when the alkali content is higher and the sulphate content is low[20]. Slump time relation of concrete with water cement ratio of 0.4 with amount of alkali content 0.58 is shown in fig.2.3.

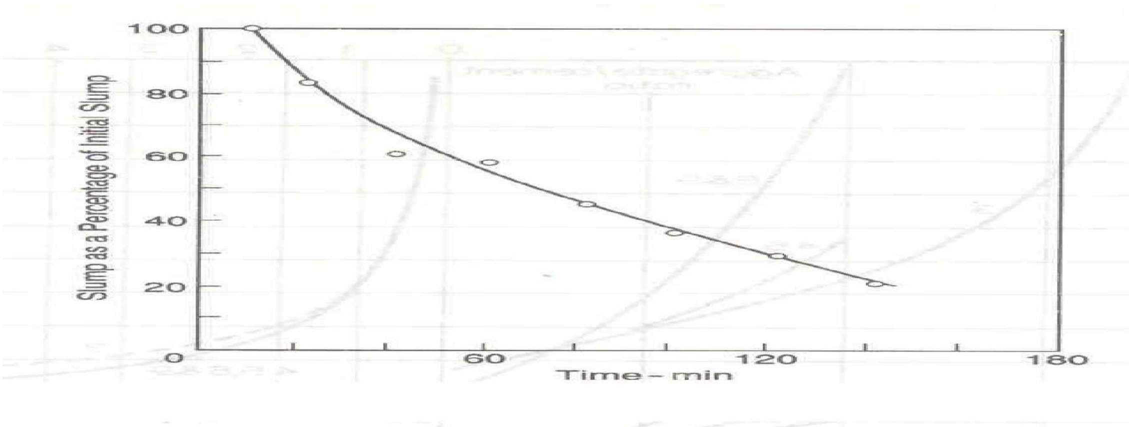

Fig. 2.3 Loss of slump with time since mixing

Workability of mix is also affected by temperature of the surrounding[20]. Fig. 2.4 shows the effect of temperature on slump of concrete.

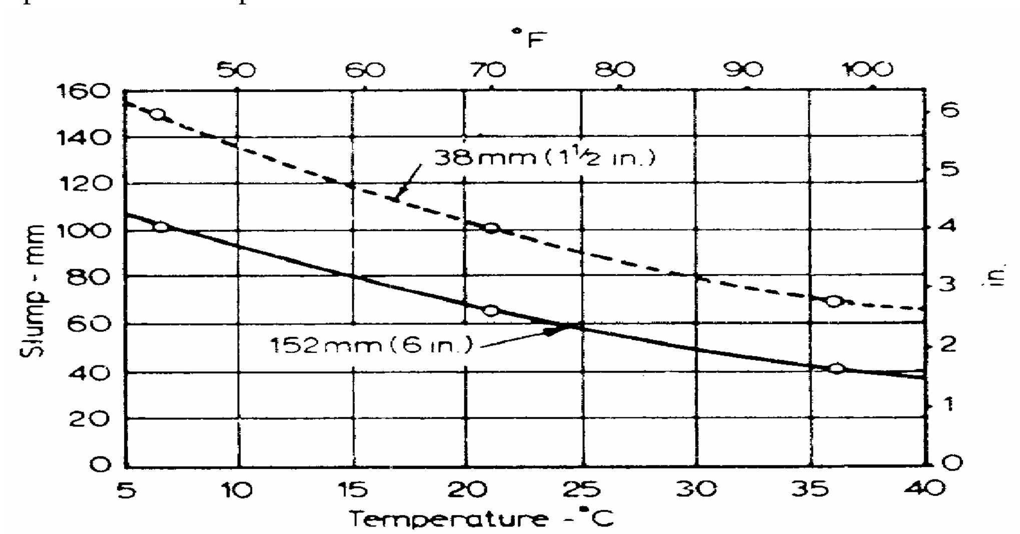

Fig. 2.4 Influence of temperature on slump of concrete with different

maximum aggregate size

It is quite clear that on a hot day the water content of the mix would have to be increased for maintaining constant early workability. In case of stiff mixes of concrete the loss of slump is less influenced by temperature because such mixes are less affected by a change in water content. Fig. 2.5 shows that the concrete temperature increases the percentage increase in water requirement per 25 mm[20]. Influence of temperature on loss of slump after 90 minutes for concrete with a cement content of 306kg/m^3.

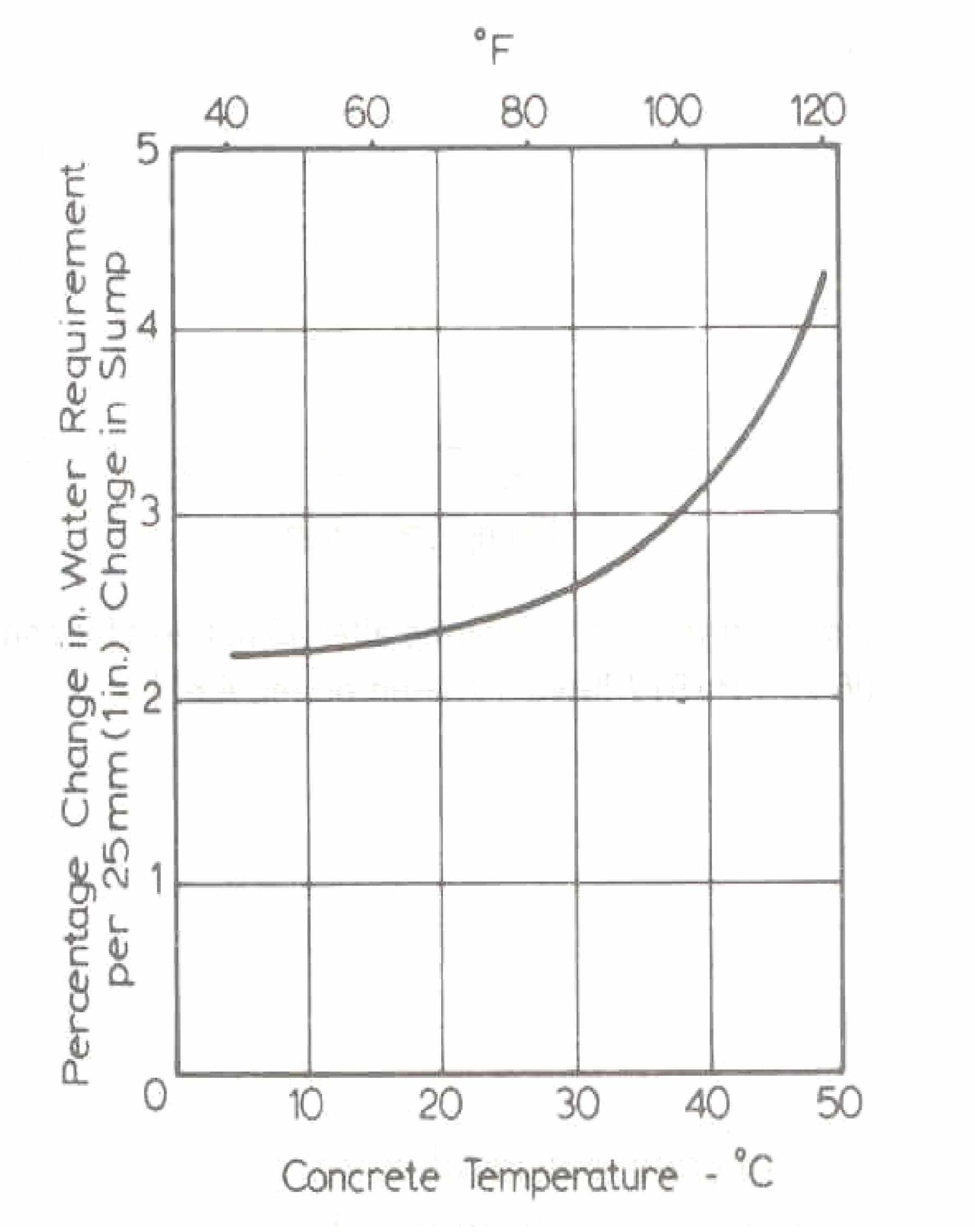

Fig. 2.5 Influence of temperature on the amount of water required to change slump

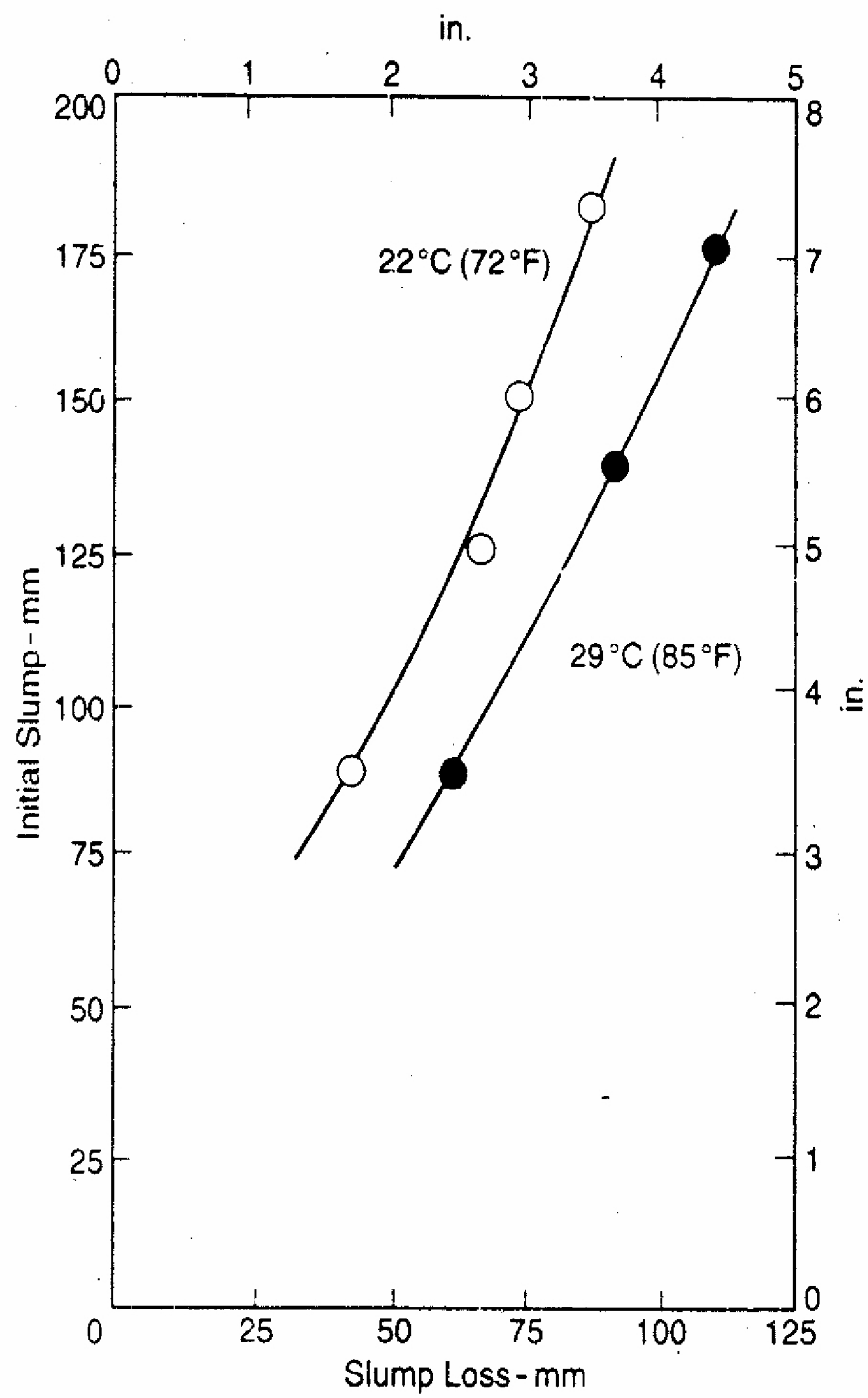

Fig. 2.6 Influence of temperature on loss of slump after 90 minutes for concrete with a cement content of 306 kg/m^3

2.5 MINIMUM AND MAXIMUM CEMENT CONTENT IN CONCRETE

The requirement of minimum cement content in concrete is governed by the environmental exposure conditions and the minimum grade of concrete required to be used in the work. This requirement is different for plain and reinforced concrete work. For reinforced

Cement concrete work minimum cement content using M20 grade of concrete with mild exposure conditions and M25 grade of concrete with moderate exposure conditions (Both using 20mm nominal maximum size of aggregate) is 300kg/m^3.For higher grades of concrete and with severe conditions of exposure the minimum cement content increases but the restriction imposed under the provisions of IS 456:2000 for maximum cement content to 450kg/m^3(Fly ash and ground granulated blast furnace slag not included).This limit is imposed to check the increased risk of cracking of concrete due to drying shrinkage in thin sections or early thermal cracking and to save guard against the increased risk of damage due to alkali silica reaction[24].

CHAPTER 3

FACTORS INFLUENCING ROLE OF CEMENT

3.1 FACTORS INFLUENCING ROLE OF CEMENT

Cement is by far the most important constituent of mortar / concrete, in that it forms the binding medium for the discrete ingredients. The cost of cement per unit is maximum among all the constituents, in case of ordinary concrete. In case of use of cement superior than ordinary quality cement it is still costlier. The use of a particular type of cement depends upon the circumstances in which such special cement is to be used. The cost of concrete mainly depends upon the quantity and quality of cement to be used. With the dwindling natural resources, the cement needs to be judiciously and optimally used in all concrete work, making it economical and suitable for the purpose for which it is intended.

Role of cement is measured in terms of various performance characteristics in the wet concrete and in the hardened concrete. The concrete should be workable while wet and it should possess the properties of desired strengths, durability, impermeability etc in the hardened stage. Compressive strength as one of the important properties of concrete is governed by a host of controllable factors namely size, shape and amount of coarse aggregate, fine aggregate, quantity of water, quantity and quality of cement etc. Some of the other factors which are uncontrollable, keeping in view the large quantum of work area for execution of projects but result in variation in strength, variation in shape and size of coarse segregate, fineness of fine aggregate, different quality of cement, environmental conditions of cement (temperature and humidity) etc.

In case of high performance concrete (HPC), it has to satisfy the special performance and uniformity requirements that cannot be always achieved by using conventional materials, normal mixing, placing and curing practices. Thus, HPC combines high strength with high durability[6].Lee, Kim and Lee et.al[10] have reported that HPC is to posses high workability, high strength, superior dimensional stability and high long term durability compared to conventional concrete[10].

3.2 WATER CEMENT RATIO

The compressive strength of concrete at a given age and under normal temperature, depends primarily on the water cement ratio; lower the water cement ratio, greater is the compressive strength and vice versa[20]. Duff Abrams first found the water cement and compressive strength relationship as:

$S=K_1 / K_2^{w/c}$

S à Compressive strength,

w/c à Water cement ratio of a fully compacted concrete mix,

K_1 & K_2 à Empirical constants .

The general form of strength versus water cement ratio curve is shown in fig. 3.1

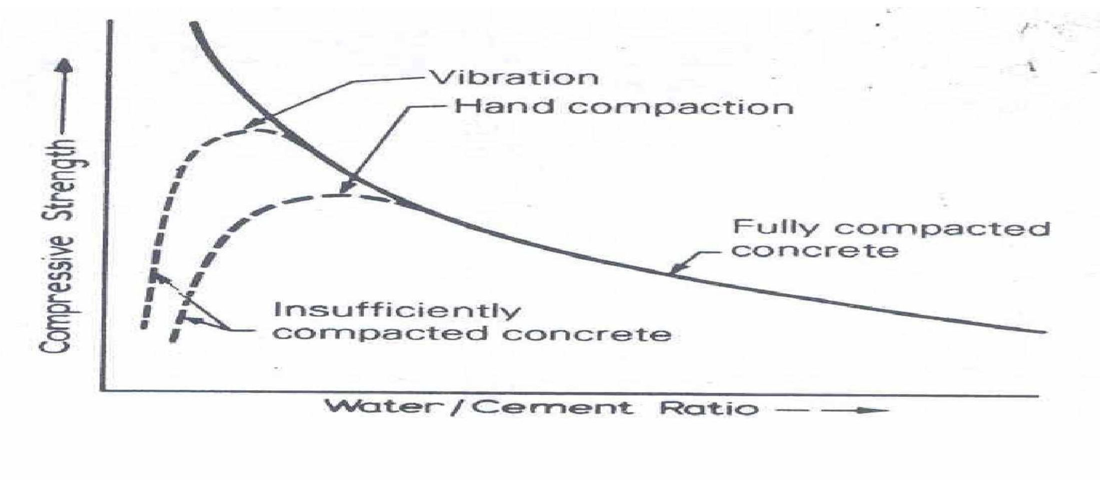

Fig. 3.1 The relation between strength and water cement ratio of concrete

Based on various researches the result showing relationship between free water cement ratio and compressive strength of concrete is shown in fig. 3.2[22].The water cement ratio has significant influence on permeability. The reduction in permeability with reducing water cement ratio has already been established as a fact by Glanville[9].

In modern day concrete air entraining agents are added to concrete to keep the workability constant or to reduce the water cement ratio, this leads to creation of tiny voids in the concrete resulting into reduction in its strength. The presence of entrained air is beneficial in reducing bleeding. The loss in strength of air entrained concrete is estimated at 5 percent per 1 percent increase in entrained air content. This is due to irregular bubble sizing and coalescence of bubbles in the mix[3].

Concrete mix using OPC cement of 45,55,65mpa with cement content @370kg/m^3, 450kg/m^3 and 500kg/m^3 with water cement ratio of 0.5,0.35 and 0.31/0.27 have gained 28 day compressive strengths of 31.1, 47.1 and 55.5/66.2N/mm^2.

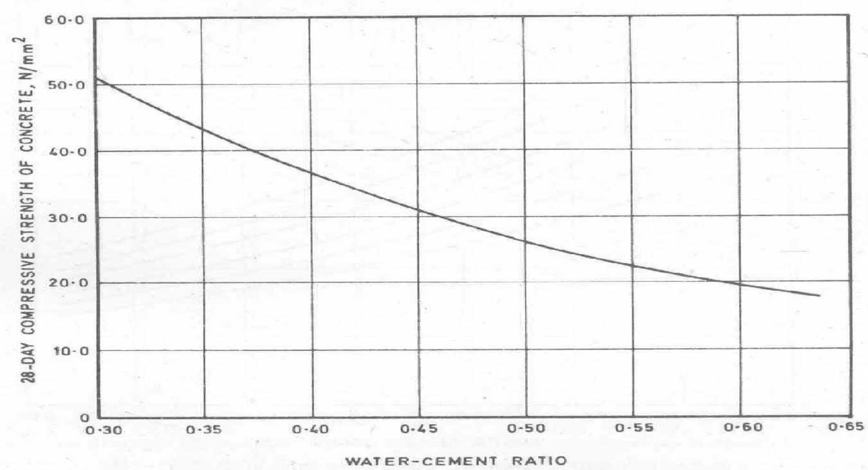

Fig. 3.2 Generalised relationship between free water cement ratio and compressive strength of concrete (adopted by BIS)

3.3 GEL / SPACE RATIO

The water cement ratio propounded by Duff Abrams has certain limitations like the strength at any water cement ratio depends upon the degree of hydration of cement and its physical / chemical properties, temperature at which hydration takes place, air content in case of air entrained concrete, change of effective water cement ratio and the formation of fissures and cracks due to bleeding or shrinkage. The strength of concrete can be more correctly related to the solid products of hydration of cement to the space available for formation of this product.

Gel space ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of the volumes of the hydrated cement and the capillary pores[19]. Experiments have shown that the strength of concrete bears a specific relationship with the gel / space ratio given by $240x^3$, where x is the gel / space ratio. Fig.3.3 shows the relationship between strength and gel / space ratio. This relationship is independent of age whereas water cement ratio holds good primarily for 28 days strength for fully compacted concrete.

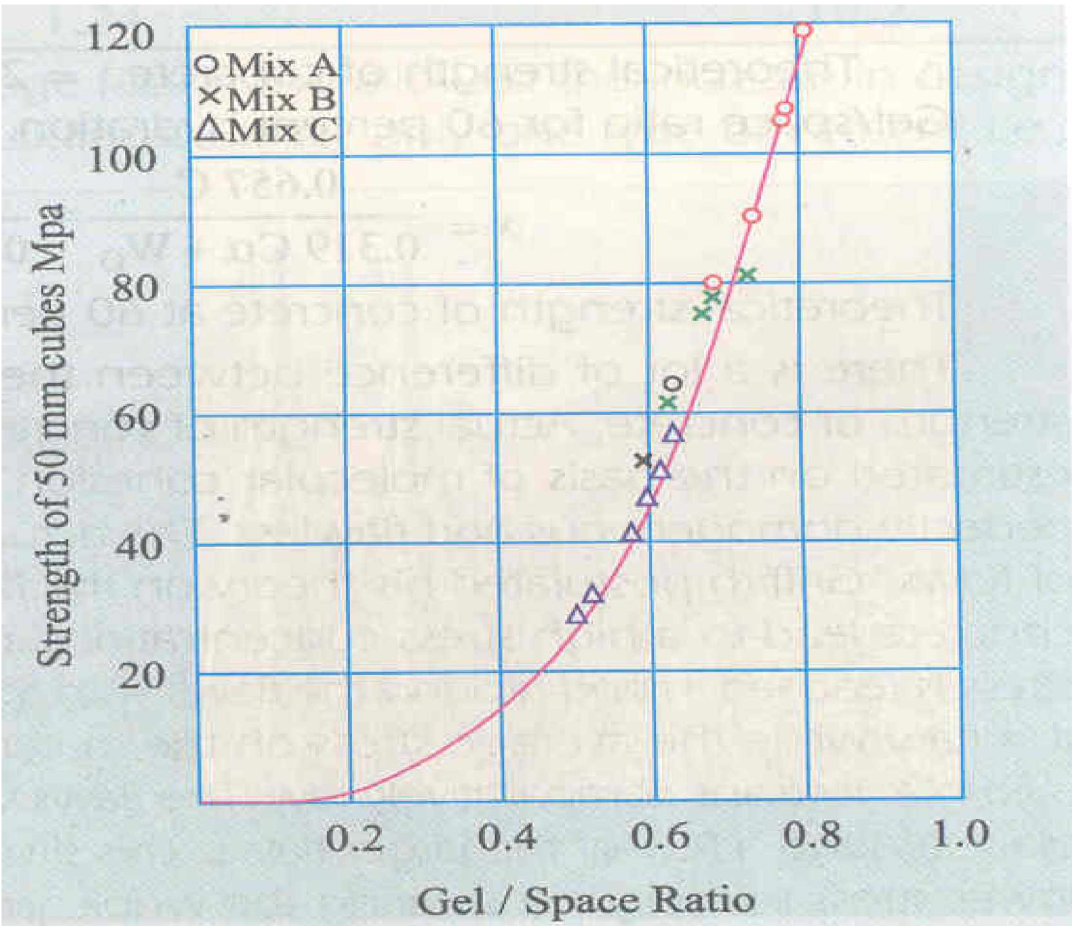

Fig. 3.3 Relationship between the compressive strength of mortar and gel/space ratio.

3.4 CEMENT CONTENT AND CHARACTERISTICS

The water cement ratio and the aggregate cement ratio together determine the cement content of the concrete mix. Generally the cement content itself would not have a direct role on the strength of concrete; if cement content is required to increase the workability of concrete mix for a water cement ratio, then the compressive strength may increase with the richness of the mix[22]. However, for a particular water cement ratio there would always be an optimum cement content resulting in 28 days compressive strength being the highest as shown in fig.3.4.

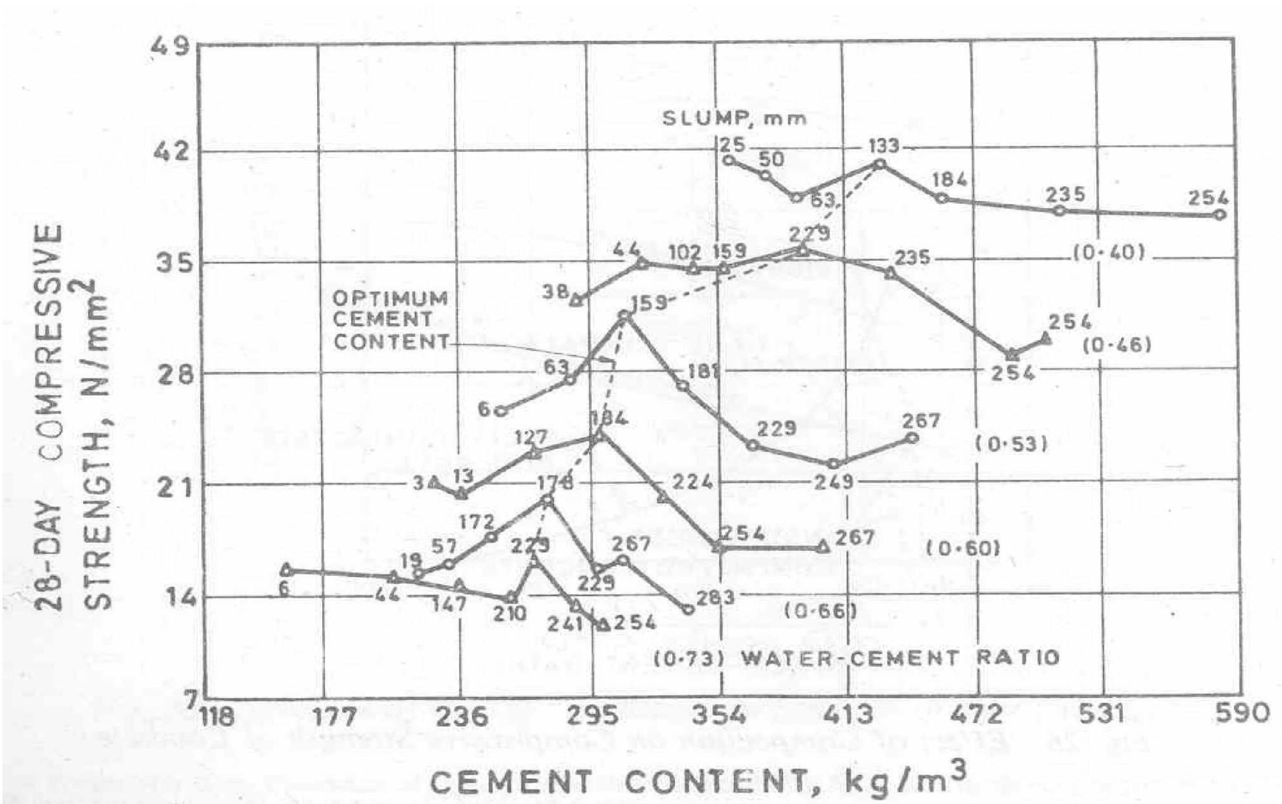

Fig. 3.4 Effect of cement content on the compressive strength of concrete

3.5 FINENESS OF CEMENT

Fineness of cement contributes to the kinetics of reaction and initial rate of gain of strength[19]. Generally greater the fineness, greater is the rate of development of strength during the initial period as shown in fig.3.5. The heat evolution is also larger. This is possible because greater fineness enables a large surface of cement to come in contact with water during the initial period although the long term effect may not be different. In addition, the particle size also influences the hydration and strength at various ages. Particles below 5 micron hydrate within 1 to 2 days and the hydration of 10-25 micron size may commence after 7 days[22].

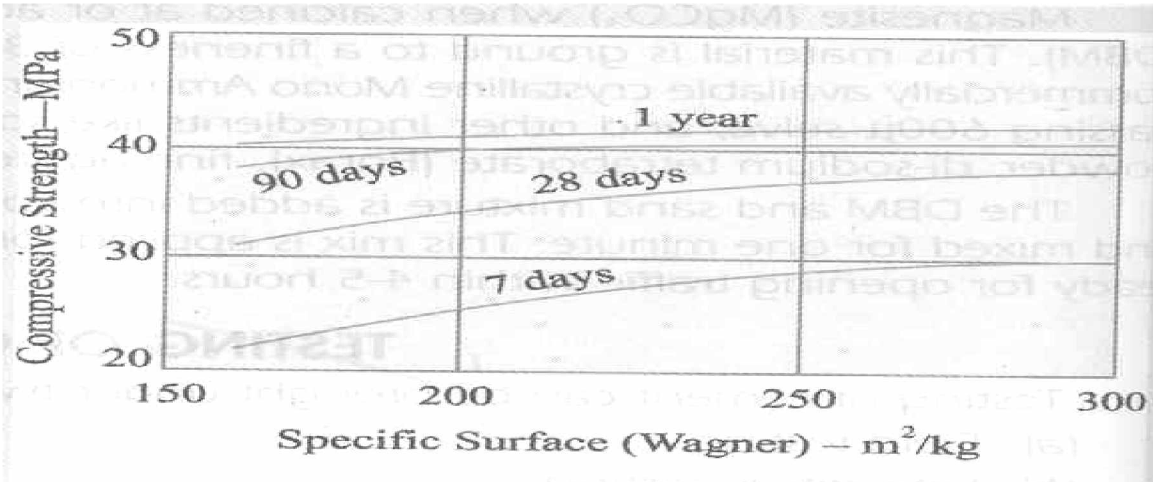

Fig. 3.5 Relationship between strength of concrete at different ages and fineness of cement

It is seen that whenever a higher rate of initial strength gain is required, this is achieved by grinding the cement to greater fineness and the cement composition perhaps being richer in C_3S and C_3A, but it may give rise to more heat of hydration. Contrary to this, the low heat cement would be required to be ground to a lower fineness and would have lower percentage of C_3A and greater percentage of C_2S[22]. Fig. 3.6 shows the calculated temperature rise of different cements at different ages under adiabatic condition[22].

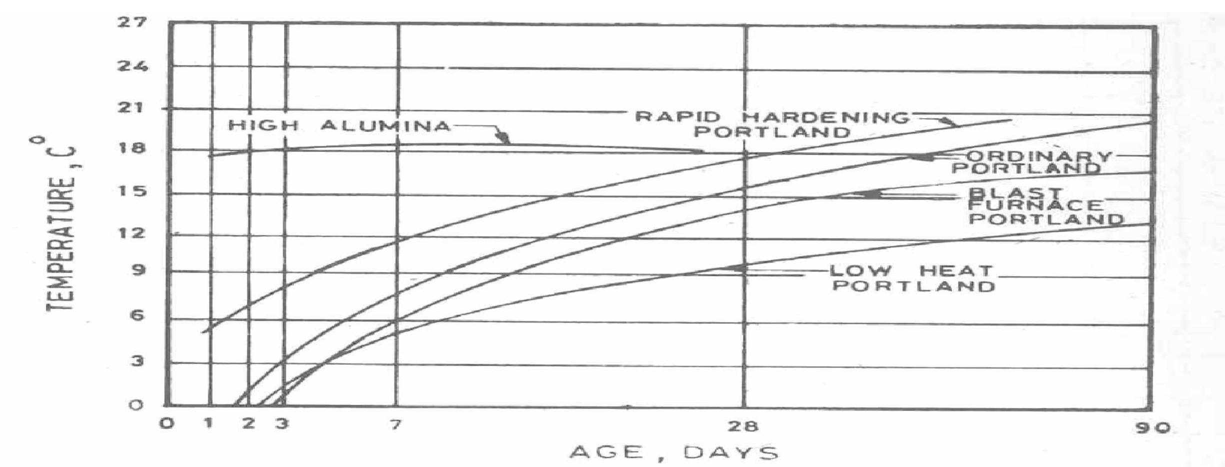

Fig. 3.6 Calculated temperature rise of different cements under adiabatic condition

3.6 CURING OF CONCRETE

Hydration of cement takes place only when the capillary pores remain saturated. Also additional water available from outside is needed to fill the gel pores, which will otherwise make the capillaries empty. This makes the function of curing as two fold; firstly to prevent the loss of water in the concrete from evaporation and secondly to supplement water consumed in hydration of cement.

In concrete mixes with higher water cement ratio, the hydration can proceed by self-desiccation and prevention of evaporation of water (by covering with wet gunny bags, membranes and curing compounds) may be sufficient. But for high strength concrete with lower water cement ratio, the mixing water may not be sufficient for hydration to proceed by self desiccation and mere prevention of evaporation of water will not be sufficient. In this situation continuous ponding of water is necessarily required[22] as compared to mixes with high water cement ratio as shown in fig. 3.7

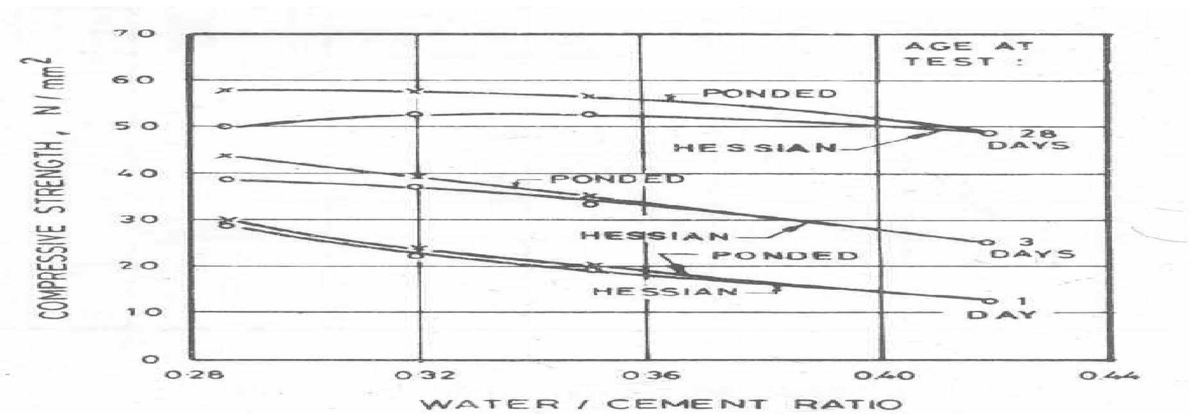

Fig. 3.7 Influence of curing condition on strength

Concrete will continue gaining strength with time provided sufficient moisture is available for hydration of cement which can be assured only by proper moist curing. Fig. 3.8 shows the effect of duration of moist curing on the compressive strength of concrete. On an average, the one year strength of continuously moist cured concrete is 50 percent higher than that of 28 day moist cured concrete, while no moist curing can lower the strength by about 30 percent. Moist curing for first 7-14 days may result in compressive strength being 85 to 92 percent of that of 28 day moist curing[22].

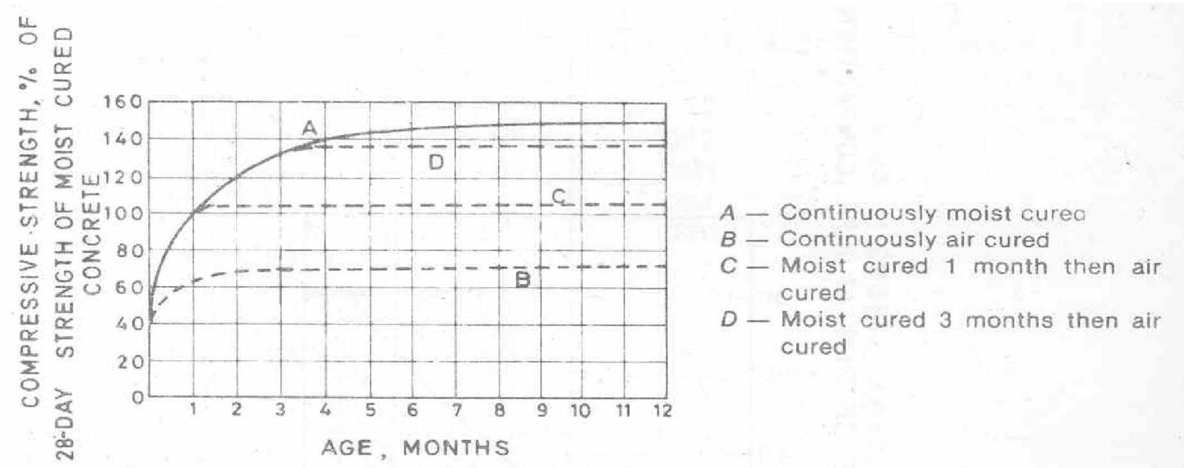

Fig. 3.8 Strength versus age relationship for different curing periods for Portland cement concrete

The use of more and more of the precast sections require higher rate of strength development of concrete which is achieved by removing the concrete products from the form work and handled as early as possible. For this the chemical reaction of hydration is thermally actuated and the increased rate of strength development of concrete is achieved by resorting to steam curing at atmospheric pressure/ autoclaving .

The influence of curing temperature on strength of concrete is shown in fig. 3.9, 3.10 & 3.11[19]. The gain in strength of concrete is more for the concrete which are cured at higher temperature as shown in fig.3.9. Fig. 3.10 shows that the one day strength increases with increase in curing temperature while the 28 day strength decreases with increase in curing temperature. Fig. 3.11 shows the effect of temperature during the first two hours after casting on development of strength. The concrete subjected to higher temperature at the early period of hydration is found to lose some of the strength gained at a later stage compared to concrete cured at relatively lower temperature. Such concrete is said to undergo “retrogression of strength”. Fig. 3.12 shows the effect of temperature on strength of concrete. The concrete subjected to higher temperature at early age attains higher strength at a shorter duration but suffers considerable retrogression of strength. On the contrary concrete cured at comparatively low temperature takes longer time to develop strength but the strength attained is not lost at later stage.

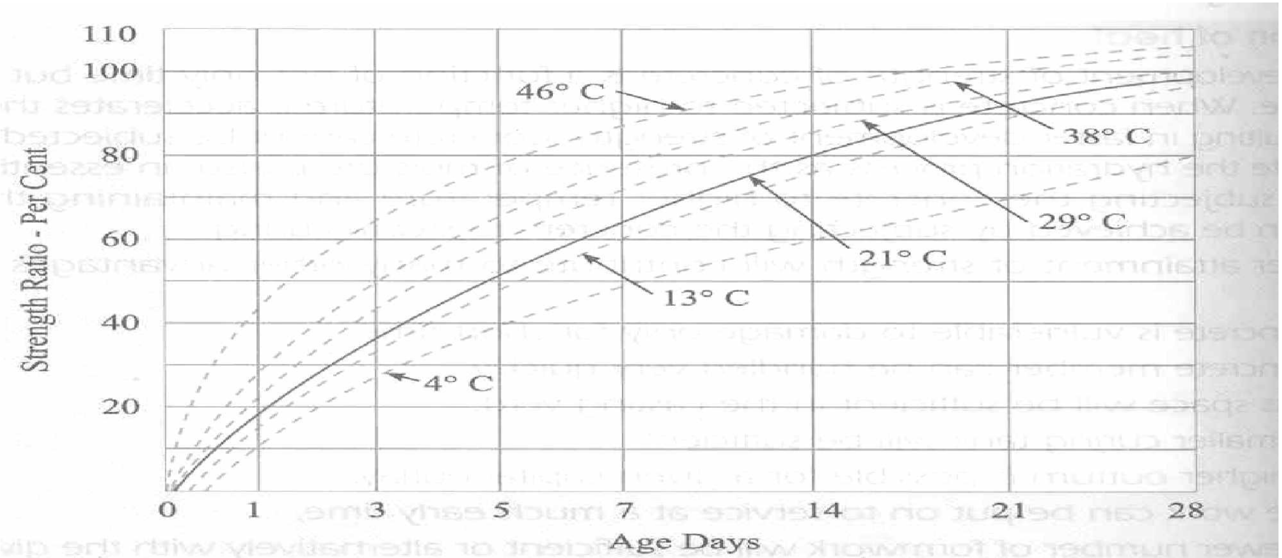

Fig. 3.9 Ratio of strength of concrete cured at different temperatures to the 28 day strength of concrete cured at 21^{0}C (w/c=0.5), samples cured at indicated temperature.

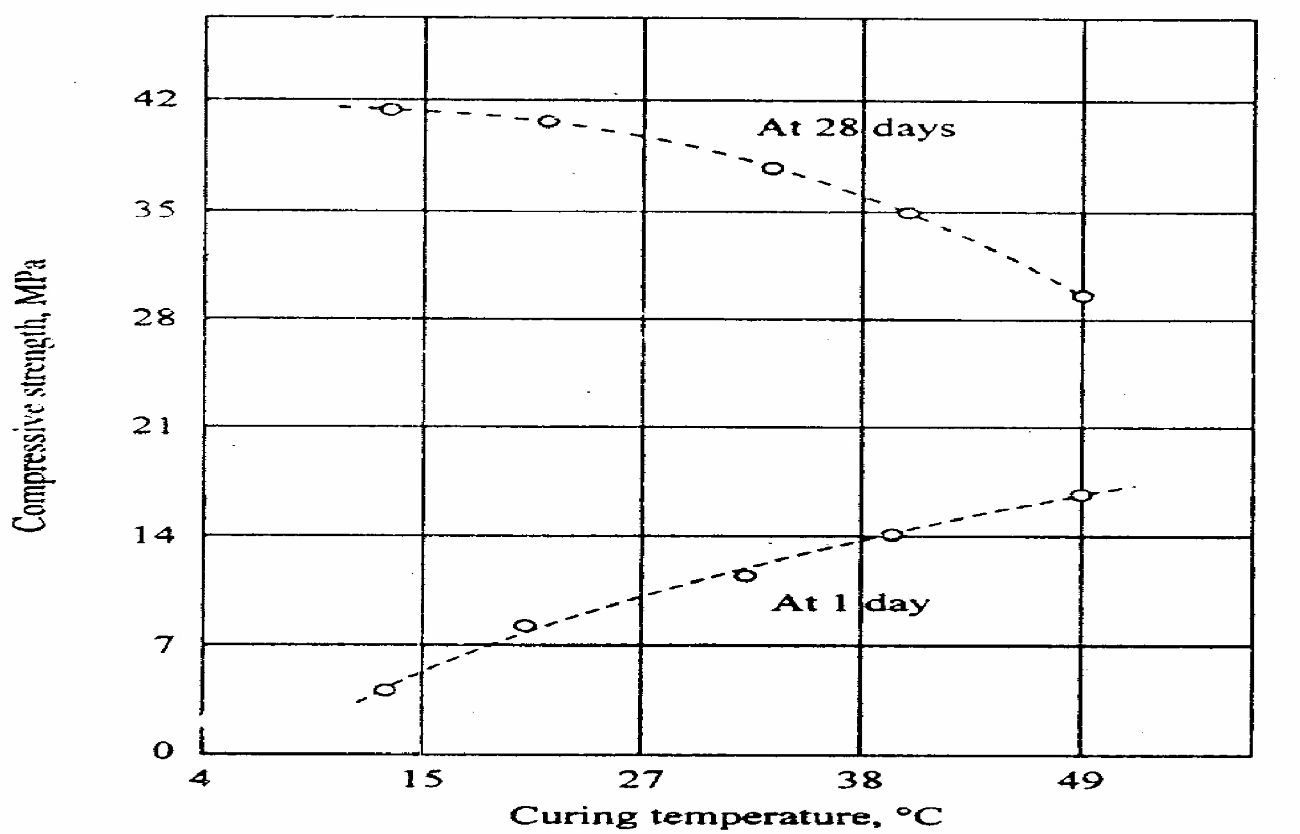

Fig. 3.10 One day strength increases with increase in curing temperature but 28 day strength decreases with increase in temperature.

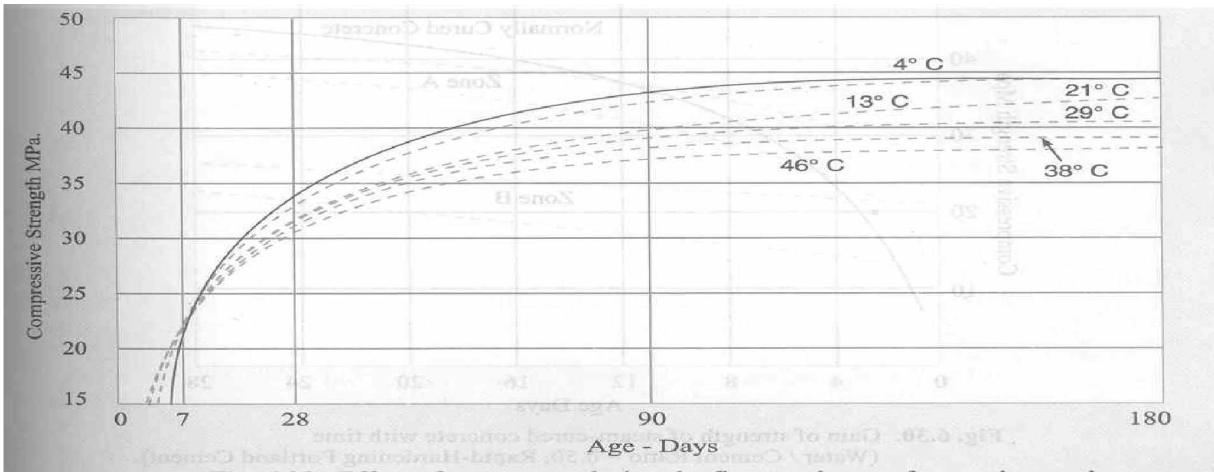

Fig. 3.11 Effect of temperature during the first two hours after curing on the development of strength (all specimens sealed and after two hours cured at 21^0C)

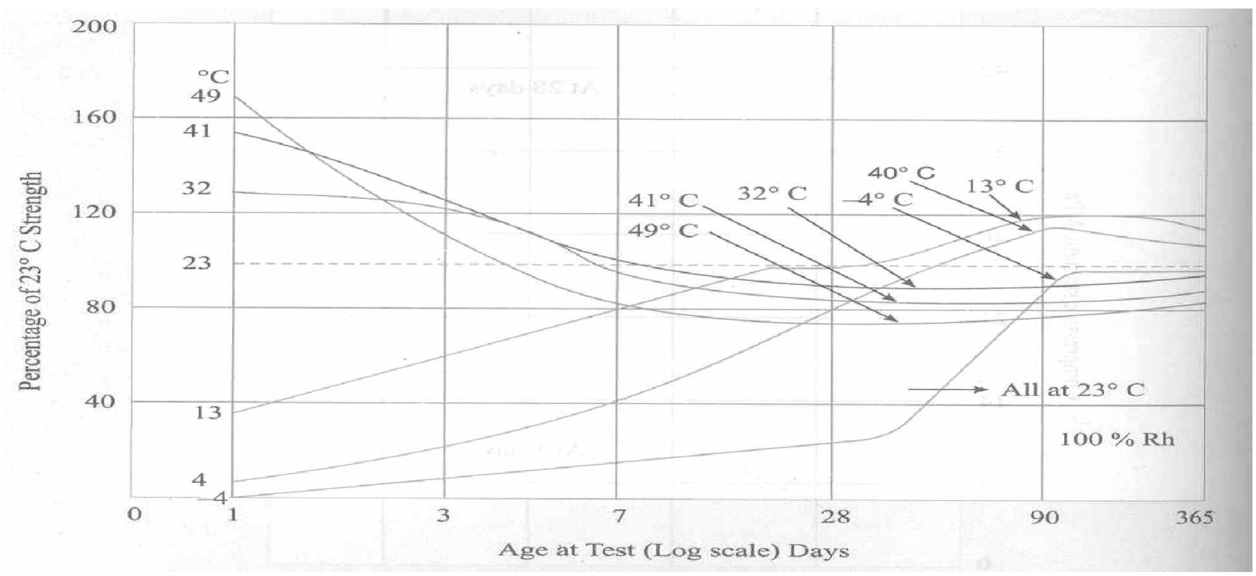

Fig.3.12 Effect of temperature during the first 28 days on the strength of concrete (w/c=0.41, air content = 4.5 percent, OPC)

A steam curing cycle is shown in fig.3.13. In the normal steam curing procedure, a pre-steaming period of 1 to 3 hours is usual. The rate of initial temperature rise after the pre-steaming period is of the order of 10 to 20^0C per hour and the maximum curing temperature is limited to 85 to 90^0C. Temperature higher than this will not produce any increase in the strength of concrete, a temperature of 70^0C may be sufficient. For a particular product, the maximum desired temperature raised at a moderate rate and then the steam is cut off, and the product is allowed to soak in the residual heat and moisture of the curing chamber. By adopting proper steam curing cycle, more than 70 percent of the 28 day compressive strength of concrete can be obtained in about 16 to 24 hours[22]. Bam forth et.al.[9] has reported, as the period of water curing increases the rate of change of permeability with respect to strength also increases and the same is reported to be in logarithmatic. It has further being reported by Bam Forth that coefficient of water permeability, a measure of durability of concrete cannot be inferred from the strength measurement alone without detail knowledge about its curing history.

Cement concrete consisting of cement content varying from 370-475kg/m^3 resulting in it 28 day compressive strength of the order of 60.6 to 100.3 N/mm^2.In case of cement concrete with total cementitious content of 400 and 500kg/m^3 with replacement of cement by fly ash at 30 percent level along with Superplasticizer has resulted into 28 day compressive strength of 42.3 and 55N/m^2 respectively[9].

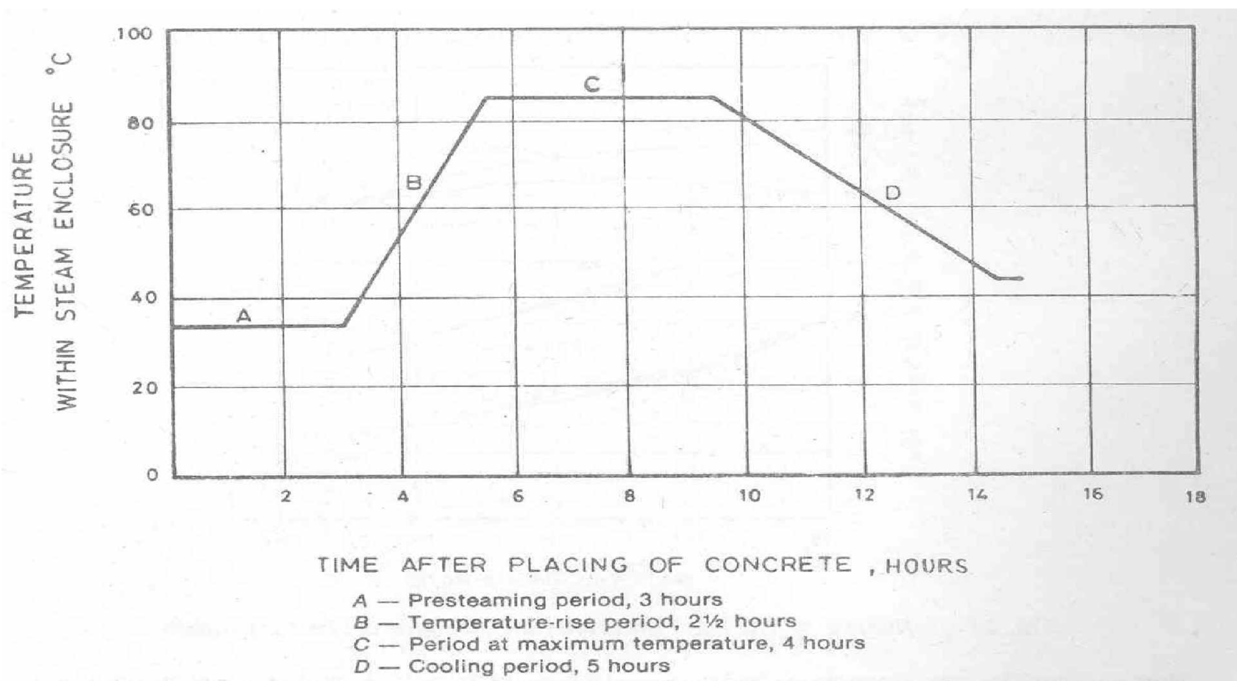

Fig. 3.13 Steam curing cycle[22].

3.7 TEMPERATURE OF CONCRETE

Concrete mixed, placed and cured at elevated temperatures normally develops higher early strengths than concretes produced and cured at normal temperatures but at 28 days or later strengths are generally lower. It is shown that for concretes placed and cured upto28 days at various temperatures ranging from 49^0C to -4^0C at 100 percent relative humidity, the initial strength (Up to an age of 7 day) was greater, at higher temperatures(in case of silica fume concrete)[16]. However, the difference in the strength at various temperature tended to be narrower as the age of concrete increased, and at an age of nearly one year the low temperature concrete developed higher strength than those at higher temperatures as shown in fig.3.14. For the influence of simultaneous reduction in the relative humidity, it is shown that specimens moulded and cured in air at 23^0C, 60 percent relative humidity and at 38^0 C, 25 percent relative humidity, produced strength of only 73 and 62 percent, respectively, in comparison with the specimens moist cured at 23^0 C for 28 days. It is also found that the larger the delay between casting and placing, greater is the strength reduction. High temperature results in greater evaporation loss and hence necessitates increase of mixing water consequently reducing strength.

Gardner, Sau and Cheung et.al[12] have reported that casting and curing of concrete at near freezing temperature does not necessarily slow its strength development. The rate of strength development of concrete cast and cured at 0^0 C relative to controlled concrete cast at 16^0 C and 22^0 C is dependent upon water cement ratio. Higher is the water cement ratio lower is the development of the strength of concrete when compared with a low water cement ratio concrete. It is further reported[12] that freezing and thawing resistance of concrete cast and cured at warm temperature is better than concrete cast and cured at 0^0 C.

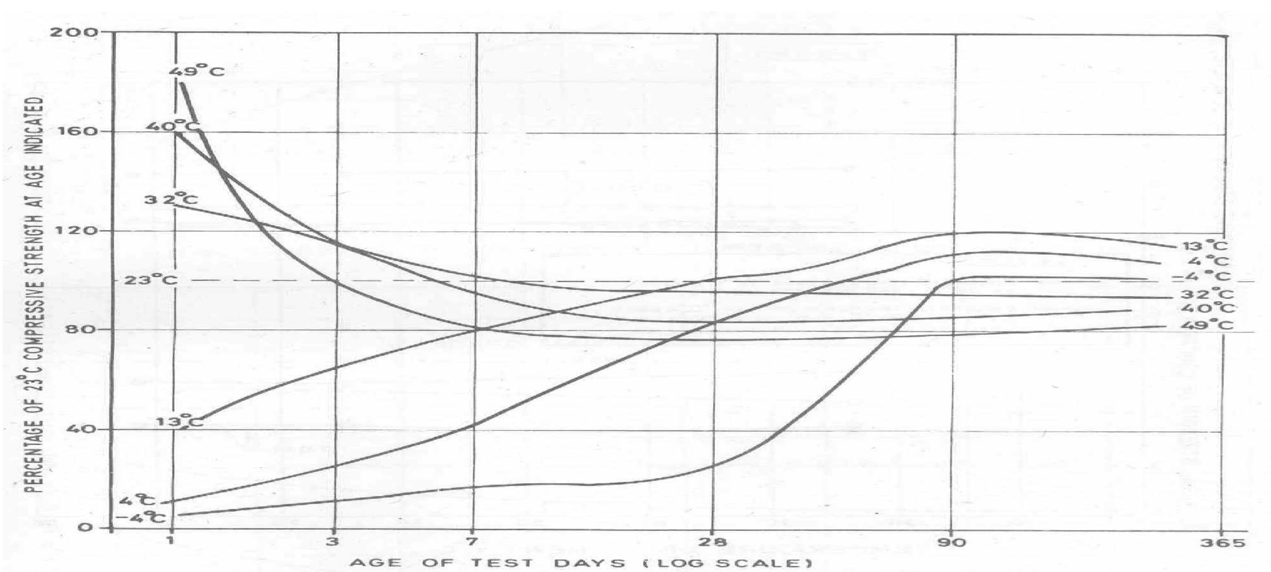

Fig. 3.14 Effect of temperature on compressive strength of concrete made with ordinary Portland cement

3.8 SIZE OF AGGREGATE

The maximum nominal size of the aggregate to be used in reinforced concrete is governed by the thickness of the section and spacing of the reinforcement. Within the limits specified by the relevant standards, the nominal maximum size of the coarse aggregates may be as large as possible. Generally it is found that larger the maximum size of aggregate, smaller is the cement requirement for a particular water cement ratio as shown in fig.3.15.

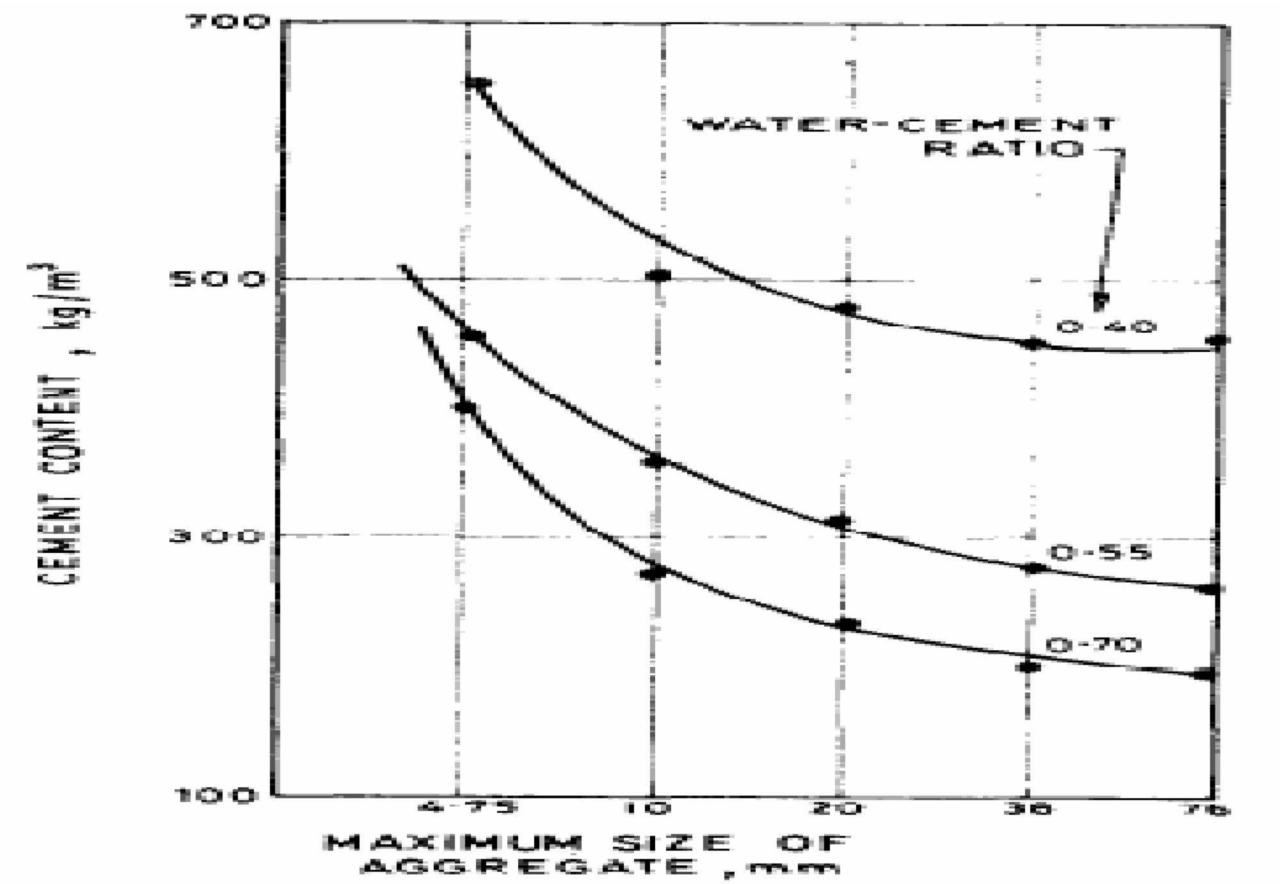

Fig. 3.15 Influence of maximum size of aggregate on cement requirement of concrete mix

This arises mainly from the fact that workability of concrete increases with increase in maximum size of aggregate. However, the maximum size of aggregates also influences the compressive strength of concrete in that, for a particular volume of aggregate, the compressive strength tends to increase with decrease in the size of coarse aggregate(High strength concrete). This is due to the fact that smaller size aggregates present a larger surface area for bonding with the mortar matrix; it also results from the fact that the stress concentration in the mortar- aggregate interfaces increases with increase in the maximum size of aggregate. There is an interaction of the maximum size of aggregate as well as the grade of concrete which determine the strength efficiency of the cement and, therefore, the requirement of cement for a particular compressive strength is to be specified[22] as shown in fig.3.16. From this figure, it is clear that for concrete with higher water-cement ratio, larger maximum size of aggregates may be beneficial whereas for high strength concretes 10 to 20mm size aggregate is preferable.

As far as fine aggregates are concerned proper grading of the same is of utmost importance for making good concrete. To help reduction in bleeding an adequate proportion of aggregate particles (<150 µm) is necessary. The use of angular crushed fine aggregate does not lead to more bleeding than rounded particles of river sand.

Use of crushed fine aggregate in concrete is reported to have improved effect in mechanical properties like higher compressive strength increase in split tensile and flexural strength due to stronger bond characteristics.

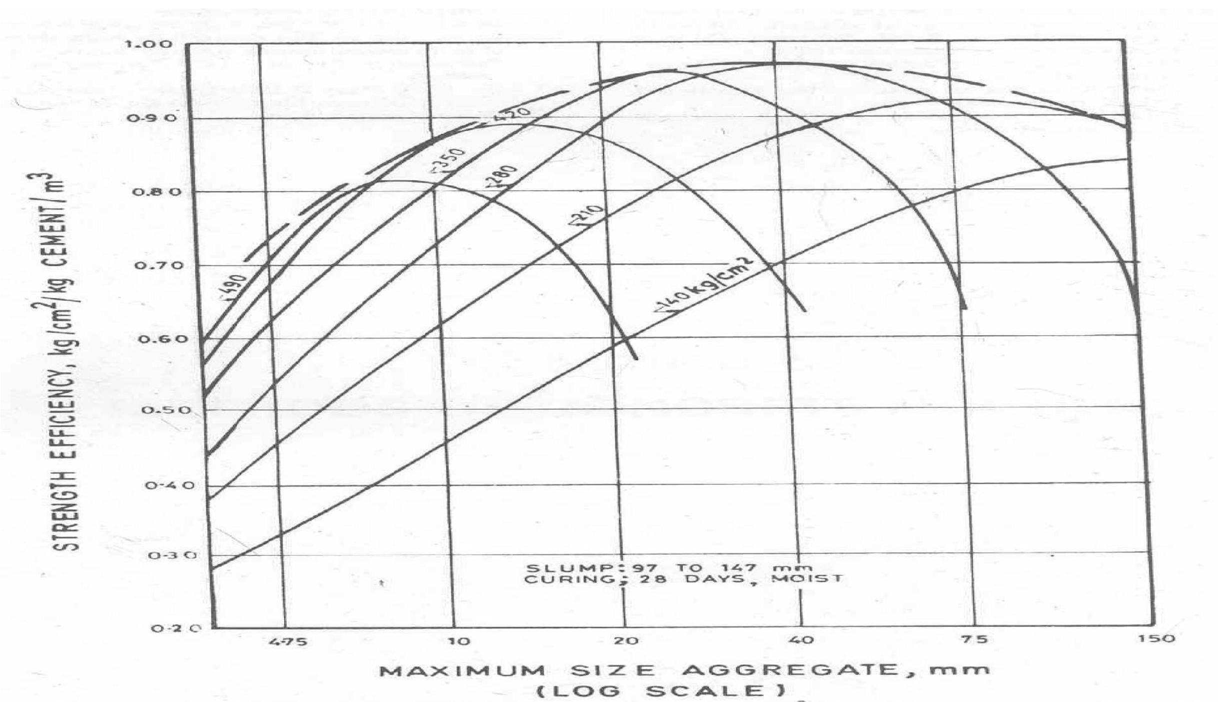

Fig. 3.16 Maximum size aggregate for strength efficiency envelope[22].

Natural sands are often particularly suitable for concrete to be pumped because of their rounded shape and also due to their true and more continuous grading as compared to crushed aggregate. The requirement of fine aggregate /mortar matrix (cement+ fine aggregate) is enhanced due to “wall effect”, where thin members having greater surface area of finishing require an increase in sand content nearly equal to 10 percent of the total mass of aggregate as compared with a mix used in infinitely large section. The wall effect at times causes problem in actual site execution even with a properly designed laboratory concrete mix.

Malhotra and Carette et.al.[2] have reported that up to 10 percent limestone dust as partial replacement and 5 percent limestone dust replacing fine aggregate in concrete with water cement ratio 0.7 and 0.53 respectively do not significantly affect the concrete property at green stage(slump, unit weight and air content) and at hardened stage (drying shrinkage, compressive strength)[2]. Shrinkage increases by up to 20 percent which is of little practical significance. Significant increase in strength is reported[2] in case of lean concrete with increasing amount of limestone dust but the same is not applicable to rich cement mixes.

The strength of concrete containing cement varying from 217-379kg/$m^3$of concrete having water cement ratio 0.7 to 0.4 have produced 28 day compressive strength of the order of 19.9N/$mm^2$to 40.1N/mm^2 on standard cylinders[2].

With partial replacement of sand by limestone dust, 28 day compressive strength of concrete is reported as 28.1 N/mm^2 to 32.8N/mm^2 by Rao and Kumar et.al.[11]using cement content of the order of 360 kg/$m^3$of concrete with water cement ratio of 0.53/0.54 without chemical admixture with slump ranging from 25-28mm.

CHAPTER 4

SUPPLIMENTRY CEMENTITIOUS MATERIAL

4.1 CEMENTITIOUS MATERIALS

The cementitious materials are those materials which may or may not be cementitious in themselves, have latent cementitious properties and which contribute to strength of concrete primarily through their physical behaviour. All these cementitious materials have one property in common that they are atleast as fine as particles of Portland cement and sometimes much finer. The supplementary cementitious materials are also known as pozzolanic materials**.**

4.2 POZZOLANIC MATERIALS

These materials are siliceous or siliceous and aluminous materials, which themselves possess little or no cementitious value but when ground in very fine from then in the presence of water chemically react with calcium hydroxide which is liberated on hydration of cement, at ordinary temperature to form compounds, possessing cementitious properties. Best pozzolans in optimum proportion when mixed with Portland cement help in improving the qualities of concrete like:

- Lower the rate of hydration and thermal shrinkage.
- Increase water tightness.
- Reduce alkali aggregate reaction.
- Improve resistance to attack by sulphate soils and sea water.
- Improve workability.
- Lowers cost.

Pozzolan + Calcium hydroxide + water ---- à C-S-H(Gel)

(At ambient temperature)

The above reaction is termed as pozzolanic reaction, which is slow in the beginning result in slow hydration and slow strength development.

Pozzolanic materials can be divided into two groups:

Natural pozzolans:

- Clay and shales.
- Diatomaceous earth.
- Opaline cherts.
- Volcanic tuffs and pumicites.

  These Pozzolanas need further grinding and sometimes need calcining to activate them to show pozzolanic activities.

Artificial Pozzolans :

- Fly ash.
- Silica fume.
- Rice husk ash.
- Metakaolin.
- Ground granulated blast furnace slag.

4.3 FLY ASH (PULVERIZED FUEL ASH)

Fly ash is the ash precipitated electro statically or cyclonically from the exhaust gases of the coal fired power stations. The fly ash particles are spherical with the particle size/diameter of fly ash particles varying between 1 micron and 100 microns. There are two ways in which fly ash can be used:

One way is to inter grind certain percentage of fly ash with cement clinker at the factory to produce Portland pozzolana cement (PPC) and the second way is to use fly ash as an admixture at the time of making concrete at the site of work.

ASTM classifies fly ash into two classes:

Class C

Normally produced by burning lignite or sub bituminous coal. Class C fly ash may have CaO content in excess of 10 percent. In addition to pozzolanic properties, class C fly ash also possesses cementitious properties.

Class F

Normally produced by burning anthracite or bituminous coal which have CaO content less than 5 percent. This has only pozzolanic properties.

The use of right quality of fly ash in concrete results in reduced water demand for desired slump thereby reducing bleeding and drying shrinkage. The initial strength of fly ash concrete tends to be lower than that of concrete without fly ash. Due to continued pozzolanic reactivity concrete develops greater strength at later age[4, 14, 15], which may exceed that of concrete without fly ash. Pozzolanic reaction contributes in making the texture of concrete dense resulting into decrease in water[4,13] and gas permeability. The optimum fly ash content to produce concrete with best surface absorption properties varies with the type of cement and the age of concrete, but more importantly with the curing environment[17].Dhir and Byars et.al.[13] reported that the absorption and permeability properties decrease with fly ash replacement up to 30 percent for concrete cured in water and air both. Rapid hardening Portland cement/fly ash blends produce better concrete than OPC concrete alone but the best quality is obtained when fly ash is blended with OPC[17].This effect also improves with age. The pozzolanic reaction can only proceed in the presence of water, enough moisture should be available for long time and therefore, fly ash concrete should be cured for longer period[14, 17].

High volume fly ash (HVFA) concrete with replacement level of 50 to 55 percent are economical[5], durable[4,5], high strength[4,5] and high performance[4] concrete. Ashraf, Sharma and Mokal et.al.[5.]have reported that HVFA concrete does not require special effort for mixing, placing, transporting and these operations can be done by conventional means[5].

HVFA concrete is cohesive and can be used in under water situations. It is also good for mass concrete where control on rise of temperature is desirable. The total binder content of 450kg/m^3 and 400kg/m^3 have been used with replacement level of 50 percent and 55 percent. The minimum and the maximum 28 day compressive strength of concrete used in the studies are (40 and 26.4 N/mm^2) and (43.2 and 32.9N/mm^2) respectively for the two mixes, both using OPC 53 grade cement.

Lee, Kim and Lee et.al[10] have reported that partial replacement of cement by fly ash effectively reduces autogeneous shrinkage stress of high performance concrete. It cannot completely eliminate early age cracking[10].

In the concrete mix using total cementitious content of 500kg/m^3 and 550kg/m^3 with water cement ratio of 0.31 and 0.27 at 10 percent replacement level with fly ash has reported[10] a 28 day compressive strength of 53.4N/mm^2 and 63.9Nm^2.At 20 percent replacement level with fly ash in the concrete mix using total cementitious material of 370kg/m^3, 450kg/m^3, 500kg/m^3 and 550kg/m^3 with water cement ratio of 0.5,0.35,0.31 and 0.27 have given 28 day compressive strength of 29.3N/mm^2, 45.9N/mm^2,52.6N/mm^{2}and 62.4N/mm^2 respectively. At 30 percent replacement level of cement the fly ash using total cementitious material of 500 kg/m^3 and 550 kg/m^3 with water cement ratio 0.31 and 0.27 has reported strengths of 49.3N/mm^2 and 55.83N/mm^2 respectively[10].

4.4 SILICA FUME

Silica fume is a byproduct resulting from reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidized vapour. It cools, condenses and is collected in cloth bags. The shape of silica fume particle is spherical with particle size less than 1 micron. It has an average diameter of about 0.1 micron. Silica fume has specific surface area of about 20,000 m^2/kg.

Silica fume by itself do not contribute to the strength dramatically although it does contribute to the strength property by its being very fine pozzolanic material and also creating dense packing and pore filler of cement paste. Due to very small particle size the rate of reaction of silica fume is considerably high and thus silica fume starts to contribute to strength development as early as one day after mixing of concrete[15].Addition of silica fume to high slag cement concrete had no effect on compressive strength till the age of 91 days but the same increased significantly at the age of 1 year[15]. The use of silica fume in conjunction with super plasticizer is the back bone of the modern High Performance Concrete.

Micro silica is much more reactive then fly ash or any other natural pozzolana. The reactivity of pozzolana can be quantified by measuring the amount of $Ca(OH)_2$, in the cement paste at different times.

Water demand increases by about 1 percent for every 1 percent of cement substituted by micro silica. With the 20mm maximum size aggregate concrete containing 10 percent micro silica will have an increased water content of about 20 litre/m^3. By adjusting the aggregate grading and using super plasticizers this increase can be avoided[15]. The addition of micro silica will lead to lower slump but more cohesive mix and this is in agreement with the findings of Khatri and Sirivivatnanon[15]. The addition of micro silica, helps in reduction of bleeding and concrete could be handled without segregation. Concrete containing micro silica is vulnerable to plastic shrinkage cracking and therefore sheet or mat curing should be considered.

Concrete containing silica fume show good strength development of the order of 60-80 Mpa relatively easily at all ages[15]. Early curing by way of membrane curing is essential to keep off plastic shrinkage due to rate of evaporation at the surface being faster than the rate of migration of water from the interior to the surface.

The compressive strength of silica fume concrete at 8 percent replacement level having total cementitious material content of 500 kg/m^3 has shown that the compressive strength of silica fume concrete was consistently higher than OPC concrete when cured in same standard condition at the end of 28 days. For the same silica fume concrete compressive strength at the end of 1 year was approximately 10 percent more than OPC concrete[16].

4.5 RICE HUSK ASH

Rice husk ash is obtained by burning rice husk in a controlled manner without causing environmental pollution. When burnt properly it contains high SiO_2 content (about 90 percent) and can be used as a concrete admixture. It exhibits high pozzolanic characteristics and contributes to high strength and high impermeability of concrete. The particle size is large as compared to silica fume and have complex shapes and also have high water demand unless inter ground with clinker so as to break down the porous structure. To achieve adequate workability use of super plasticizer may be necessary.

4.6 METAKAOLIN

Natural pozzolans namely kaolinite clay and thermally activated ordinary clay are often called metakaolin. They posses certain amount of pozzolanic properties and are not highly reactive. By removing unreactive impurities from these pozzolans by water processing they are made highly reactive pozzolan termed High Reactive Metakaolin (HRM). High reactive metakaolin shows high pozzolanic reactivity and reduction in $Ca(OH)_2$ even as early as at one day. The cement paste undergoes densification and as a result the strength increases and the permeability decreases[1].Basu and Kulkarni et.al.[1] reported that Indian kaolin used as High reactive meta kaolin (HRM) concrete has low penetrability which further decreases with increase in richness of the mix. The high reactive metakaolin is having the potential to compete with silica fume. Mavin kurve, Basu etc[1] reported that HRM dosage of 10 percent by weight of cement yields high 28 day compressive strength up to 82.75 mpa with reasonably high (100mm) slump using water cement ratio of 0.3.

4.7 GROUND GRANULATED BLAST FURNACE SLAG

The slag is a waste product obtained in the manufacturing of pig iron and consists of mixture of lime, silica and alumina. The Portland blast furnace slag cement can be produced either by inter grinding Portland cement clinker and dry granulated blast furnace slag (together with gypsum) or by dry blending of Portland cement powder and granulated blast furnace slag. Clinker and blast furnace slag are separately ground to give a smoother texture and thus benefiting the workability. Slag with various components like lime (40-50 percent), silica (30 -40 percent), alumina (8-18 percent) and magnesia (0-8 percent) are satisfactory for cement.

The replacement of cement with ground granulated blast furnace slag reduces the water content necessary to obtain the same slump. It reduces heat of hydration, results into refinement of pore structure, reduced permeability to the effect of external agencies and increased resistance to chemical attack.

Bala Subramanian, Krishna moorthy et.al[8]. have reported that compressive strength of concrete mixes are not affected by cement replacement materials(CRM) like ground granulated blast furnace slag(GGBS) up to a level of 40percent in respect of their 28 day strength. Beyond 40 percent replacement level of GGBFS, there is a reduction in compressive strength. But at the age of 56 days the compressive strength of concrete mix without CRM and with slag based CRM at 40 percent and 70 percent were almost same. It was further reported that durability properties like water absorption and chloride diffusion were very much improved with the addition of GGBFS.

The general particle size of slag being 10-20µm, it takes more than three days for hydration of slag and strength contribution property of cement[15].

Bharat Kumar, Narayanan et.al[14] have reported that slag mixes with up to 50 percent replacement level show better performance in terms of mechanical properties and durability characteristics as compared with fly ash mixes.

In general the early age strength of cement replacement material mixes show lower value for the same water binder ratio due to slower pozzolanic reaction. Generally in CRM mixes there is an increase in total binder content as the effective water binder ratio decreases. However, as the CRM content increases, the cement required per unit strength reduces, thus it is possible to effectively utilize the cement by adopting the lower effective water binder ratio with higher CRM content[14].

Long term strength of concrete containing ordinary cement and silica fume was similar to those concretes containing ordinary cement, silica fume at 10 percent replacement level and 15 or 25 percent of the cementitious material as fly ash[15] with total cementitious content of 425kg/m^3.

CHAPTER 5

EXPERIMENTAL PROGRAMME

5.0 GENERAL

Strength of concrete is of paramount importance because it is one of the major properties, while all other properties like flexural strength, modulus of elasticity etc. are generally considered to be related to it in one or the other way. The strength of concrete helps it to resist various types of stresses and environmental exposures etc. Strength of concrete is not known immediately on its preparation but takes time for setting and hardening. If concrete is not found suitable at the time when its strength can be ascertained, no alternative exists except to strengthen it, if possible by incurring huge expenses or to demolish the structure. Only the strong concretes are said to be durable. Although, a number of factors are responsible for strength and durability of concrete but cement content and water cement ratio are the two main factors which are mainly responsible for imparting strength and durability to concrete. From the point of view of field execution of concrete it should be workable to the desired level. The unworkable concrete despite of the presence of sufficient cement content results in honey combing, segregation, bleeding, non-durable concrete etc. Number of provisions laid down in the relevant codes prescribing rules for making concrete workable, strong, durable etc. Thus technically speaking a concrete is said to be good which possesses properties of desired level of workability, strength and adequate durability.

5.1 OBJECT OF THE PROJECT WORK

The objective of project work on concrete is to study the effects of variation in ingredients of concrete, to name a few are, grade of cement, fine aggregate-fineness modulus and grading in particular, coarse aggregate -flakiness, elongation, shape, size and others like water cement ratio etc. The study of these effects is to be done within the frame work of parameters specified in the relevant IS codes. For a successful study efforts are made to make the concrete of required strength which possesses desired level of workability. Every efforts was made to achieve the objective by using cements of different grade, coarse and fine aggregates were procured from different sources to achieve variation in shape, size, grading etc. The work involved study on wide range of concrete which included normal strength concrete to high strength concrete with variation in workability from no slump/low slump to high workability. The addition of mineral admixtures was also incorporated to study their effect on normal strength as well on high strength concrete.

5.2 EXPERIMENTAL WORK

The following activities were under taken in sequence to accomplish completion of project work

1) After the procurement of materials, various tests on all materials were performed to ascertain their suitability for use in project work of normal strength concrete and high strength concrete.

2) In the next stage number of trail mixes were prepared and tested using accelerated curing method to find out strength that can be achieved by using available cement, fine aggregate, coarse aggregate etc. Achieving workability in the trial mixes was not much of concern at this stage.

3) Further studies were carried out on concrete having workability measured in terms of slump of concrete as 50± 25mm using minimum cement content along with other fine aggregates and course aggregates. Apart from plain concrete mixes fly ash mixes were also prepared by using fly ash as cement replacing material at 20 percent replacement level with workability in terms of slump as 50± 25mm.

4)Next stage studies included concrete having the same workability in terms of slump(50±25mm) with different fine aggregate and coarse aggregate combinations but with maximum allowable cement content of 450kg/m^3.Apart from these plain concrete mixes fly ash mixes were also prepared by using fly ash as supplementary cementitious material as 20 percent of cement with the workability defined in terms of slump of concrete 50±25mm.This fly ash was used in addition to 450kg/m^3 of cement content to exploit full potential of IS 456 :2000

5) In the first stage high strength concrete was prepared with 53 grade cement by using maximum allowable cement content of 450kg/m^3 along with Superplasticizer to maintain low

water cement ratio. In this mix 20mm down size coarse aggregate has been used in addition fly ash is used as supplementary cementitious material at 20 percent and 30 percent level.

6) In the final stage of preparation of high strength concrete all the materials except coarse aggregate of size 20mm down, have been retained the same and coarse aggregate is replaced by aggregate of size 12mm down.fly ash concrete were also prepared as above.

5.3 METHOD OF MIX DESIGN

1. American Concrete Institute method (A.C.I. method)

2. Department of Environment method (D.O.E. method)

5.3.1 ACI Method

This method of mix design is equally applicable for rounded /angular aggregates, normal/light weight aggregates and air entrained/non air entrained concrete with more or less identical procedure. This method makes use of relation that optimum dry rodded volume of coarse aggregate per unit volume of concrete depends upon maximum size and fineness modulus of the fine aggregate irrespective of shape of particles. The method also uses the fact that over a considerable range of practical proportions, fresh concrete of given slump and containing reasonably well graded aggregate of given maximum size will have practically constant total water content regardless of variation in water cement ratio and cement content, which are necessarily interrelated. It also assumes that even after complete compaction by the suitable method adopted, a definite percentage of air remains in the mix which is inversely proportional to the maximum size of the aggregate. The procedure for mix design is

A) Data is first collected in respect of materials to be used as under:

Cement-Specific gravity

Fine aggregate - Specific gravity (Surface saturated dry condition), absorption characteristics and fineness modulus.

Coarse aggregate - Specific gravity (Surface saturated dry condition), absorption characteristics and dry unit weight.

B) From the minimum specified strength, estimate the average design strength by the use of standard deviation.

C) Find the water cement ratio required from the strength point of view and also find it from durability point of view. Adopt lower of the two values.

D) Decide maximum size of coarse aggregate to be used. Decide workability in terms of slump keeping in view the type of job involved.

E) Based on the slump requirement and selected maximum size of aggregate total water in Kg /m^3 of concrete is read from tables.

F) Cement content is computed based on total water content and water cement ratio.

G) By the use of standard tables available, the bulk volume of dry rodded coarse aggregate is selected for the maximum size of aggregate and fineness modulus of the fine aggregate in per unit volume.

H) When the coarse segregate per m^3 is calculated by multiplying bulk volume selected with bulk density.

I) Using specific gravity of coarse aggregate, solid volume of coarse aggregate is calculated per cubic meter of concrete. Similarly solid volume of cement, water, and volume of air is calculated per cubic meter of concrete.

J) The solid volume of sand is computed by subtracting solid volume of cement, coarse segregate, water and entrapped air from total volume of 1 cubic meter.

K) Weight of fine aggregate is calculated as a product of solid volume of fine aggregate and specific gravity of fine aggregate.

5.3.2 DOE Method

This method of mix design is applicable for normal concrete for most purposes including roads for 28 day compressive strength up to 75 Mpa for non air entrained concrete. This method can be used for concrete containing fly ash and ground granulated blast furnace slag. Relationship between water cement ratio and compressive strength of concrete depending upon type of cement and type of aggregate in use is used in this method. The water content is calculated to give the desired level of workability from the relevant table for the type of aggregate either crushed or uncrushed. The procedure for mix design is:

A) Target mean compressive strength is calculated from the stipulated characteristic strength.

B) Calculation of water cement ratio is done in two phases .firstly based on type of cement and type of coarse aggregate, value of compressive cement is read from the table which provides values at fixed water cement ratio of 0.5(approximate compressive strength of concrete make with free water cement ratio of 0.5) . Secondly from this value of compressive strength, value of water cement ratio is read from the relationship between compressive strength and free water cement ratio applicable in this method.

C) From the table of approximate free water content to give various levels of workability a value of water content in read from this table based on maximum size and type of coarse segregate for the degree of workability required in terms of slump or Vee-Bee time. In case fly ash is used in the mix reduction in free water content is made by using value read from the table of reduction in free water content when using fly ash.

D) Cement content is calculated based on the value of water cement ratio and water content finalized above in (b) and (c) respectively. This cement content is compared with the minimum requirement for durability and the higher of the two is adopted but in no case this value should exceed the prescribed maximum cement content limit.

E) An estimate of wet density of fully compacted concrete is made for the approximate water content and specific gravity of aggregate. The aggregate content is obtained by subtracting the weight of cement and water content from the weight of fresh concrete.

F) Based on maximum size of coarse aggregate ,proportion of fine aggregate is determined in the total aggregate from the graphs showing relationship between water cement ratio and proportion of fine aggregate –percent using different slump/Vee- Bee time values and percentage of fines passing 600μm sieve. Weight of fine aggregate is calculated by multiplying weight of total aggregate with the percentage of fine aggregate obtained. Then the weight of coarse aggregate can also be found out. The proportions above worked out are tried in a trial mix for validation of its suitability.

5.4 SUPERPLASTICIZER

Superplasticizers are organic polymeric compounds in solution, their action on cement particles hold for a limited period only. The operations of transporting, placing, compacting and finishing on plastic concrete should be completed well within this time period, during which the concrete is still workable. The Superplasticizer may be used within the prescribed dosage limits and in the manner prescribed to suit the requirements of type of use, initial slump, slump loss with time lapsed and for other actual field conditions. Superplasticizer should conform to requirements of IS: 9103-1999.The desired properties of Superplasticized concrete are

a) To improve workability of concrete for a sufficiently long period of time[7].

b) To retain the slump to the specified level, without any need of further addition of water till the end of process[7] of desired level of finishing of concrete.

The following types of Superplasticizer are common in use.

1) Modified lingo sulphonates

2) Sulphonated naphthalene formal dehyde (SNF) condensates

3) Sulphonated melamine formal dehyde (SMF) condensates

4) Carbo xylated acrylic ester (CAE)co polymer

5.4.1 Compatibility Test

The high performance concrete requires reduction in water cement ratio to achieve high strength, high durability and low permeability. The reduction in water cement ratio is achieved by the use of Superplasticizer The dosage of Superplasticizer influences the viscosity of cement paste and hence the workability of concrete. With the increase in dosage of Superplasticizer for same water cement ratio, the viscosity decreases, however this does not continue beyond a particular dosage. This point is called saturation point. before using any particular Superplasticizer and cement combination the compatibility between cement- Superplasticizer combination is an important factor and needs to be ascertained[2], especially in case of high performance concrete. For a selected brand of cement, Superplasticizer and pre–determined water cement ratio optimum dosage can be decided by any of the following methods:

a) Marsh cone test

b) Mini slump test

c) Flow table test

Marsh cone test is simple, which gives better results. In this test cement slurry is allowed to pass through the marsh cone. Marsh cone in the form of a cone with an aperture of 4.75mm at one end connected with a pipe of same nominal bore of length 50mm connected to it. The top internal diameter of cone is 100mm and the overall height including the 50mm long pipe is 350mm.

In the performance test cement slurry is made by keeping the quantity of cement, water cement ratio constant and varying the dosage of Superplasticizer. The ability of this cement paste to flow through the marsh cone is found out. A graph is plotted between the dosage of superplasticizer (weight percent of cement) and the time required by it to pass through the cone. This time is known as marsh flow time. The dosage at which marsh flow time is lowest is called the saturation point. At this point the dosage is the optimum dose for the selected cement and plasticizer for that water cement ratio.

The two types of super plasticizers manufactured by m/s Asian Laboratories, Okhla Industrial estate phase II, New Delhi have been used in the experimental programme.

5.4.1.1 CEMWET SP-3000(SR)

The Superplasticizer is a product of sulphonated polymer formed by modifying naphthalene formaldehyde condensate having high molecular weight. The Superplasticizer is chloride free. It produces self compacting concrete by dispersing cement particles and maintaining high slump retention without affecting early development of strength. The plasticizer conforms to IS: 9103-1999.

The results of marsh cone test with CEMWET SP-3000(SR) Superplasticizer, 53 grade cement (ULTRA TECH make manufactured by M/S BIRLA Cement) and water cement ratio 0.38 are plotted as shown below in figure 5.1.

It can be concluded from figure 5.1 that the Superplasticizer is compatible at dosage level of 2 percent of the weight of cement.

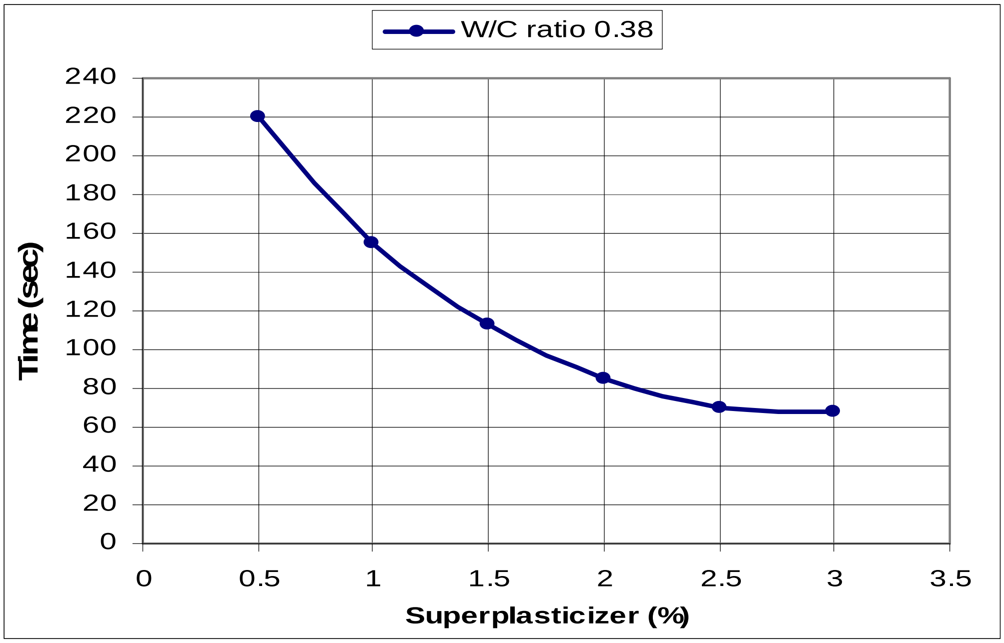

Fig.5.1   Marsh cone test results for CEMWET SP-3000(SR)

5.4.1.2   CEMWET   SP-3000 (PCE)

The Superplasticizer is a product of poly-carbo-ether based product having high molecular weight which allows improvement in flow characteristics of the concrete. This Superplasticizer is chloride free. It allows mixing water to be reduced considerably maintaining slump of concrete for longer period of time as compared to normal naphthalene polymer condensates. It is compatible with all types of cements e.g. OPC, PPC, Slag cement and high alumina cement. It is suitable for high volume fly ash concrete hence used in the experimental programme involving fly ash. T he plasticizer conforms to IS: 9103-1999.

The results of marsh cone test with CEMWET SP-3000(PCE) Superplasticizer, 53 grade cement (**ULTRA TECH** make manufactured by M/S BIRLA Cement) and water cement ratio 0.38 are plotted as shown below (figure 5.2).

It can be concluded from figure 5.2   that the Superplasticizer is compatible at dosage level of 1.5

percent of the weight of cement.

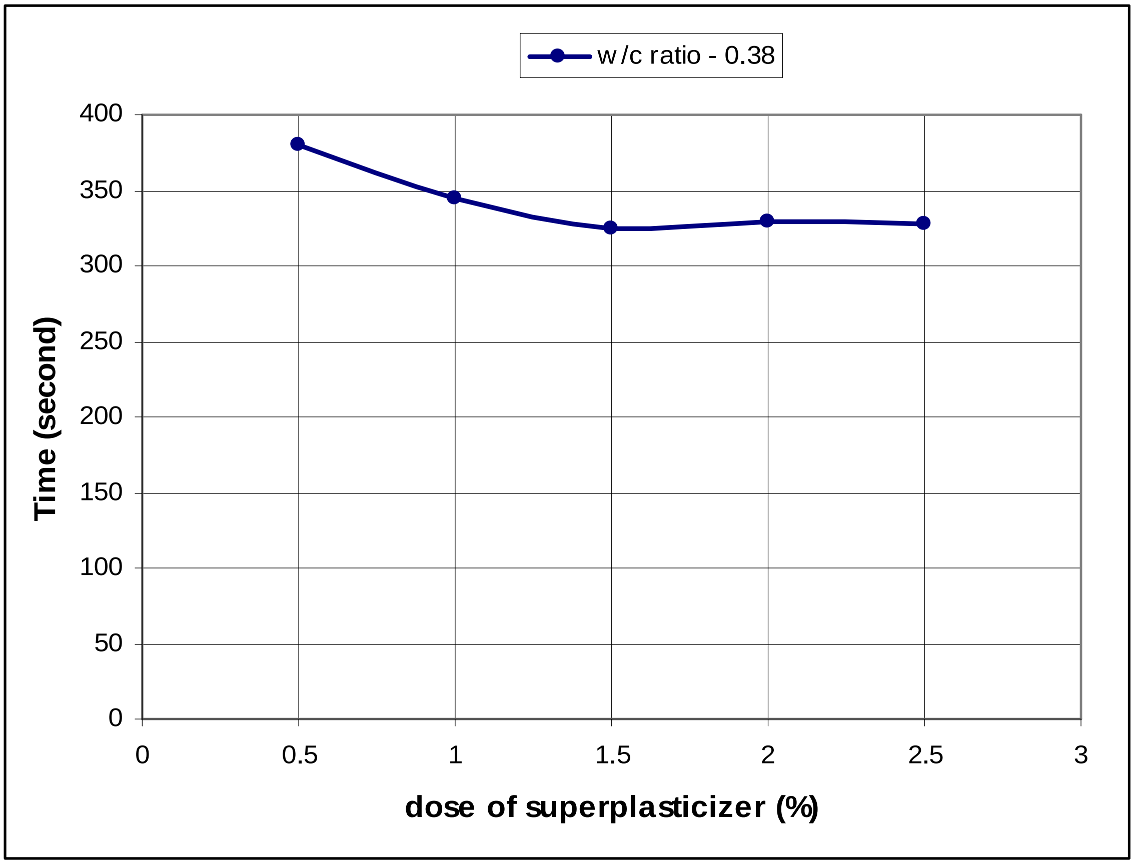

Fig.5. 2 Marsh cone test results for CEMWET SP-3000(PCE)

5. 5 MATERIALS USED AND THEIR PROPERTIES

5.5.1 Cement

Two types of cements are used:

43 Grade ordinary Portland cement conforming to IS 8112:1989[34](brand name-Binani,

Manufactured by m/s Binani Industries limited). Consistency of the cement is 31 percent. Initial setting time is 225 minutes. Specific gravity of the cement is 3.13.

53 Grade ordinary Portland cement confirming to IS 12269:1987[37](brand name –Ultra tech manufactured by m/s Ultra Tech Limited). Consistency of the cement is 33 percent. Initial setting time is 80 minutes. Specific gravity of the cement is 3.15.

5.5.2 Water

Potable tap water available in the laboratory is used for mixing as well as curing of concrete.

5.5.3 Fine Aggregates

Three types of fine aggregates collected from different sources are used. All the three fine aggregates are Badarpur sand.

1) Fine aggregate type 1 having fineness modulus 2.92 is named F1.

2) Fine aggregate type 2 having fineness modulus 2.1 is named F2.

3) Fine aggregate type 3 having fineness modulus 3.19 is named F3.

The above three types of Badarpur sand has been used as they were procured from market without any changes / adjustments. The following two types of Badarpur sand have been obtained by mixing the selected proportions of sand retained on various sieves from 4.75mm to 150µm size.

4) Fine aggregate tailored type 1 having fineness modulus 3.21 is named FT1.

5) Fine aggregate tailored type 2 having fineness modulus 3.38 is named FT2.

The results of sieve analysis and other properties of 5 types of fine aggregates (i.e.F1, F2, F3, FT1 and FT2) are tabulated in table 5.1. Particle size distribution of 5 types of fine aggregates is plotted in figure 5.3 to show a comparison between their particle sizes.

Table 5.1 Results of particle size distribution and other properties of fine aggregates (i.e.F1, F2, F3, FT1 andFT2)

Sieve size	**Percentage passing**				
	F1	**F2**	**F3**	**FT1**	**FT2**
4.75mm	**98.5**	**97.5**	**93.4**	**98.5**	**95**
2.36mm	**81.1**	**94.4**	**75.9**	**83.5**	**80**
1.18mm	**56.2**	**87.1**	**51.9**	**53.5**	**50**
600µm	**44.3**	**72.6**	**35.9**	**26.5**	**25**
300µ	**24.5**	**30.8**	**18.7**	**13.5**	**10**
150µ	**3.5**	**9.3**	**5.2**	**4**	**2**
Fineness modulus	2.92	2.1	3.19	3.21	3.38
Moisture Content (%)	0.2	0.2	0.2	0.2	0.22
Specific gravity	2.7	2.58	2.7	2.65	2.65
Water absorption (%)	1.5	4.5	1.5	1	1

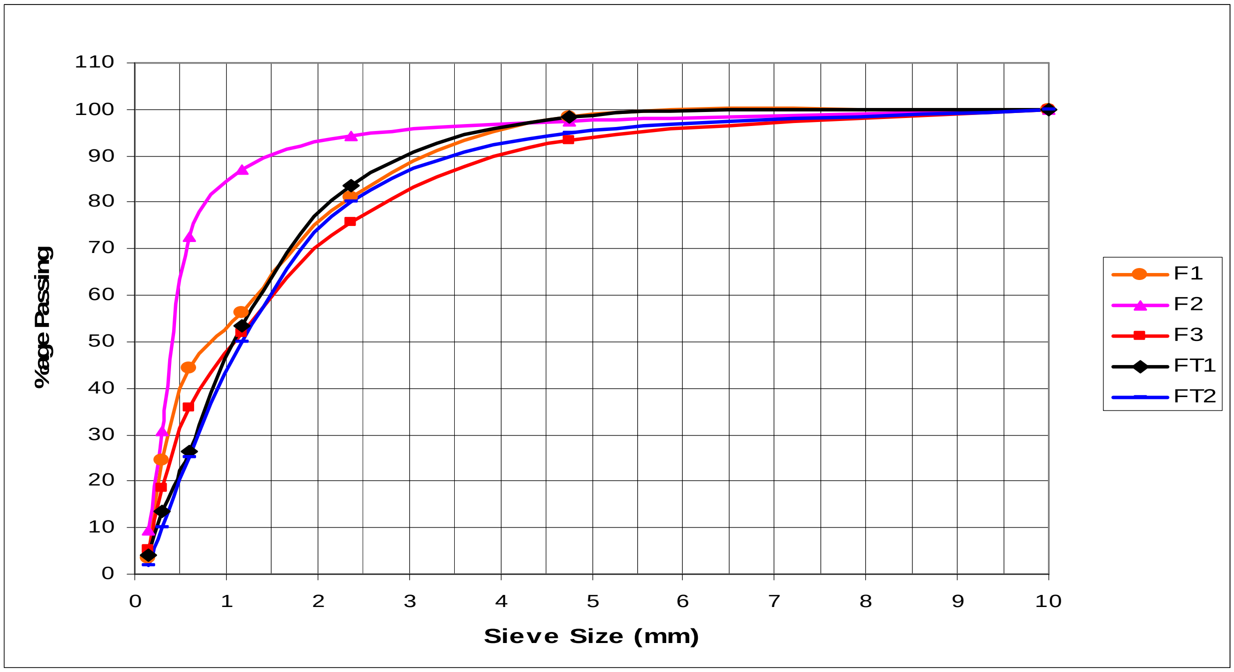

Fig5.3 Comparison of fine aggregates

5.5.4 Coarse aggregates

All the three types of coarse aggregates used are of crushed angular type

1) Coarse aggregate type 1 having maximum size 20mm, fineness modulus 7 and flakiness index 29.33% is named C1.

2) Coarse aggregate type 2 having maximum size 20mm, fineness modulus 7 and flakiness index 16.33% is named C2.

3) Coarse aggregate having maximum size 12.5mm, fineness modulus 5.95 and is named C3.

The above three types of coarse aggregates have been used as they were procured from market without any changes /adjustments.

The following three types of coarse aggregates have been obtained by mixing the selected proportions of stone aggregates retained on 20mm to 4.75mm size sieves.

4) Coarse tailored aggregate having maximum size 20mm and fineness modulus 6.9 is named CT1.

5) Coarse tailored aggregate having maximum size 20mm and fineness modulus 6.8 is named CT2.

6) Coarse tailored aggregate having maximum size 20mm and fineness modulus 6.7 is named CT3.

The following tailored coarse aggregate has been obtained by mixing the selected proportions of stone aggregate retained on 12.5mm to 4.75mm size sieves.

7) Tailored coarse aggregate having maximum size 12.5mm and fineness modulus 6.6 is named CT4.

The difference between coarse aggregates i.e. C1 and C2 is in their flakiness index. C1 was having relatively more flaky particles as compared to C2. Elongation index of coarse aggregate C2 is higher than elongation index ofC1.

The particle size distribution and other properties of above 7 types of coarse aggregates are given below:

5.5.4.1 Coarse aggregates 20 mm maximum size

20 mm maximum size coarse aggregate (C1, C2, CT1, CT2 and CT3) are tabulated in table 5.2. Results of sieve analysis and other properties of

Table 5.2 Results of particle size distribution and other properties of 20 mm maximum size coarse aggregates (i.e.C1, C2, CT1, CT2 andCT3).

SIEVE SIZE	Percentage passing				
	C1	C2	CT1	CT2	CT3
40mm	100	100	100	100	100
20mm	90.17	91.87	90	100	100
10mm	3.5	3.53	20	20	30
4.75mm	1.6	0.53	-	-	-
2.36mm	1.6	0.53	-	-	-
1.18mm	1.6	0.33	-	-	-
600µm	1.4	0.23	-	-	-
300µm	0.4	0.17	-	-	-
150µm	0.33	0.07	-	-	-
Elongation index (%)	25.7	28.2	24.75	26.3	25.95
Flakiness index (%)	29.33	16.33	21.15	20.4	20.65
Fineness modulus	7	7	6.9	6.8	6.7
Moisture content (%)	0.2	0.2	0.2	0.2	0.2
Specific gravity	2.67	2.67	2.67	2.67	2.67
Water absorption (%)	0.5	0.5	0.5	0.5	0.5

5.5.4.2 Coarse aggregates 12.5 mm maximum size

Results of sieve analysis and other properties of 12.5 mm maximum size coarse aggregate (C3 and CT4) are tabulated in table 5.3.

Table 5.3 Results of particle size distribution and other properties of 12.5 mm maximum size coarse aggregates (i.e. C3, andCT4).

SIEVE SIZE	**Percentage passing**	
	C3	**CT4**
20mm	**100**	**100**
12.5mm	**95.83**	**100**
10mm	**73.1**	**40**
4.75mm	**34.43**	**-**
2.36mm	**1.17**	**-**
1.18mm	**0.23**	**-**
600µm	**0.17**	**-**
300µm	**0.12**	**-**
150µm	**0.05**	**-**
Elongation index (%)	-	25.2
Flakiness index (%)	-	29.7
Fineness modulus	5.95	6.6
Moisture content (%)	0.2	0.2
Specific gravity	2.69	2.68
Water absorption (%)	0.5	0.5

5.5.5 Fly Ash

Fly ash collected from fourth chamber (second last chamber) of Indraprastha thermal power station is used. The specific gravity of fly ash is 2.14.Results of sieve analysis performed on fly ash is tabulated below and a graph is plotted between sieve size and percentage passing through them.

Table 5.4 Particle size distribution of fly ash

Sieve size (µm)	150	90	75	63	45
Percentage passing	97.75	95.5	91.75	84.25	42.25

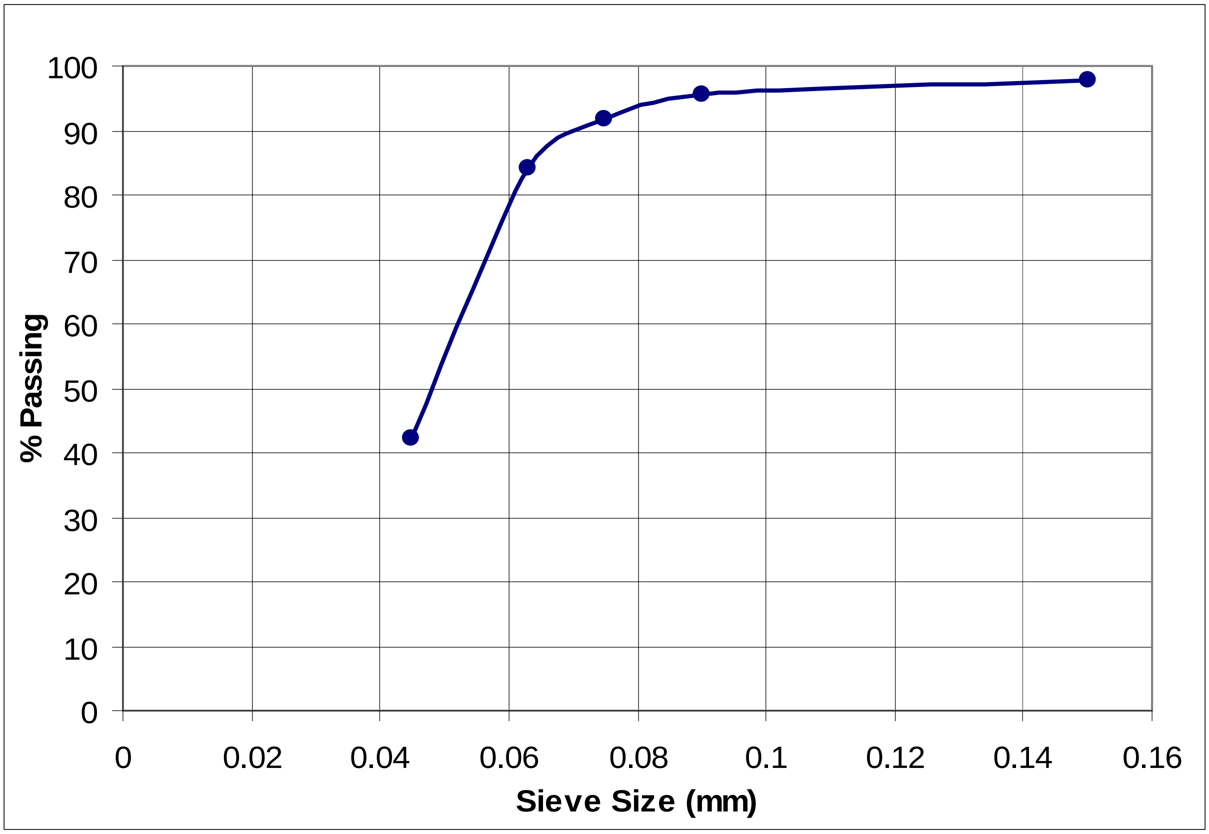

Fig .5.4 Particle size distribution curve for fly ash

5.6 TRIAL MIX

Initially some trial mixes were prepared and cured by warm water method and tested in crushing strength testing machine. Details of the mixes are given in table number 5.15.

Table 5.5 Trial Mixes carried out using Warm Water Curing Method

Mix No.	Mix proportion	Cement (kg/m³)	W/C ratio	SP (%)	Slump (mm)	Comp. factor	28 days predicted compressive strength (Mpa)	Materials used
1	1:1.24:3.01	405	0.43	-	0	0.62	37.13	Cement - 43 grade (O.P.C.) Fine Aggregate - F1 Coarse Aggregate - C1
2	1:1.24:3.01	405	0.48	-	-	0.72	32.41	Cement - 43 grade (O.P.C.) Fine Aggregate - F1 Coarse Aggregate - C1
3	1:1.01:3.03	420	0.32	2	11	0.64	-*	Cement - 43 grade (O.P.C.) Fine Aggregate - F1 Coarse Aggregate - C1(66.66%) Coarse Aggregate - C3 (33.33%)
4	1:1.01:3.03	420	0.38	1	7	0.68	42.07	Cement - 43 grade (O.P.C.) Fine Aggregate - F1 Coarse Aggregate - C1(66.66%) Coarse Aggregate - C3 (33.33%)

5	1:1.203:2.67	450	0.346	1.2	0	0.64	47	Cement - 43 grade (O.P.C.) Fine Aggregate - FT1 Coarse Aggregate - CT3
6	1:1.139:2.76	450	0.323	1.5	-	0.62	72	Cement - 53 grade (O.P.C.) Fine Aggregate - FT1 Coarse Aggregate - CT3
7	1:1.148:2.78	450	0.29	2	-	0.58	65.1**	Cement - 53 grade (O.P.C.) Fine Aggregate - FT1 Coarse Aggregate - CT3

* A different Superplasticizer used in this mix and due to over dosage of Superplasticizer the concrete did not set thus strength could not be determined

** Due to very low w/c ratio, it was very difficult to compact the concrete so there is a reduction in strength as compared to mix 6

The above trial mixes are only a fraction of the entire trials carried out and only those results found to be of value are shown above.

5.7 REAL CONCRETE MIXES

All the concrete mixes used in the project work have been divided into five different groups. Each mix is assigned a distinct two digit mix number the digit in left and right indicated group number and mix number respectively under that particular group. Where ever the mix number is followed by an alphabet it indicates use of mineral admixture either as cement replacing material or as supplementary cementitious material. Various mix proportions which we have studied are detailed in table 5.16 and their proportions are given in table 5.17.

5.7.1 Mix series 1

In view of minimum grade of concrete M20 with minimum cement content of 300 kg/m^3 five different concrete mixes have been studied using different combinations of ingredients. The workability is at about 10mm slump. The mix numbers under this series are mix number 11 to 15.

5.7.2 Mix series 2

cement are studied further using fine aggregates having lowest and highest fineness modulus along with tailored fine aggregate without using fly ash and with fly ash as cement replacing material at 20 percent level, their workability was targeted at 50 ± 25mm slump. The mix numbers under this series without using In this series M20 grade concrete with minimum cement content of 300 kg/m^3 using 43 grade fly ash and using fly ash are 21 to 23 and 21F to 23F respectively.

5.7.3 Mix series 3

In this series of mixes all the material have been retained the same as above in series 2 except the cement content which in this series is considered at maximum permissible limit prescribed by code at 450kg/m^3.Thus in this series mixes without fly ash and mixes with fly ash as supplementary cementitious material are studied. The mix numbers under this series without using fly ash and using fly ash are 31 to 33 and 31F to 33F respectively.

5.7.4 Mix series 4

In this series of mixes 53 grade of cement with 20mm maximum size of aggregate have been studied without / with fly ash as supplementary cementitious material at 20 percent and 30 percent levels along with Superplasticizer dose of 1.5 percent. The mix numbers under this series are 41, 42F and 43F.

5.7.5 Mix series 5

In this series of mixes all the materials including fly ash and Superplasticizer dose have been retained the same as in case of series 4 except the coarse aggregate which is 12.5mm and down size to achieve still higher level of compressive strength. The mix numbers under this series are 51, 52F and 53F.

5.8 MIX PREPARATION AND USE OF PLASTICIZER

The ingredients of concrete are thoroughly mixed in dry stage, substantial water (85-90 percent of calculated water, based on water –cement/water-binder ratio) added and mixed manually till the uniform consistency / colour was achieved. The total quantity of superplasticizer required was mixed with 10-15 percent of the total water required. This solution sprinkled over the entire wet mix spread over a larger area is now again turned over thoroughly and mixed to get uniform consistency/ colour.

5.9 PREPARATION OF TEST SPECIMEN[25]

All the test specimen i.e. cubes of size 15×15×15cm were cast using steel moulds and care was taken to see that the moulds were filled in with concrete in two layers and each layer was well compacted using a table vibrator. The specimen were demoulded after 24 hours and cured in water.

5.10 TESTING OF SPECIMEN

The hardened concrete specimens were to be loaded until crushing failure in a crushing strength testing machine of capacity 3000KN in accordance with IS 516:1959[25]. Test results of all these mixes are reported in the next chapter.

TABLE 5.6 DETAILS OF MATERIALS USED IN DIFFERENT MIXES

Mix Series	Mix no.	cement	Fine Aggregate	Coarse Aggregate	Mineral Admixtures	Superplasticizer
Series 1	11	43Grade	F1	C1		
	12	43Grade	F1	C2	-	-
	13	43Grade	F2	C1	-	-
	14	43Grade	F2	C2	-	-
	15	43Grade	FT2	CT1	-	-
Series2	21	43Grade	F2	C1	-	-
	22	43Grade	F3	C1	-	-
	23	43Grade	FT2	CT1	-	-
	21F	43Grade	F2	C1	F	-
	22F	43Grade	F3	C1	F	-
	23F	43Grade	FT2	CT1	F	-
Series3	31	43Grade	F2	C1	-	-
	32	43Grade	F3	C1	-	-
	33	43Grade	FT2	CT1	-	-
	31F	43Grade	F2	C1	F	-
	32F	43Grade	F3	C1	F	-
	33F	43Grade	FT2	CT1	F	-
Series4	41	53Grade	FT1	CT3	-	SP3000(SR)
	42F	53Grade	FT1	CT3	F	SP3000(PCE)
	43F	53Grade	FT1	CT3	F	SP3000(PCE)
Series5	51	53Grade	FT1	CT4	-	SP3000(SR)
	52F	53Grade	FT1	CT4	F	SP3000(PCE)
	53F	53 Grade	FT1	CT4	F	SP3000(PCE)

TABLE 5.7 DETAILS OF PROPORTION S AND QUANTITY IN VARIOUS MIXES

Mix Series	Mix no.	Proportion of cement	Proportion of fine aggregate	Proportion of coarse aggregate	Cement (kg/m^3)	W/C ratio	Mineral Admixture (%)	Super-Plasticizer (%)
Series1	11	1	2.2	2.67	372.7	0.55	-	-
	12	1	2.2	2.67	372.7	0.55	-	-
	13	1	1.64	3.14	372.7	0.55	-	-
	14	1	1.64	3.14	372.7	0.55	-	-
	15	1	1.605	3.852	336.5	0.52	-	-
Series2	21	1	1.38	2.53	408.3	0.6	-	-
	22	1	1.809	2.223	405	0.6	-	-
	23	1	1.343	2.55	411.7	0.6	-	-
	21F	1	1.41	3.01	344	0.6	20F	-
	22F	1	1.63	2.49	361.3	0.6	20F	-
	23F	1	1.218	2.924	358.7	0.6	20F	-
Series3	31	1	1.167	2.299	450	0.55	-	-
	32	1	1.417	2.135	450	0.55	-	-
	33	1	1.029	2.471	450	0.55	-	-
	31F	1	0.73	2.3	450	0.49	20F	-
	32F	1	1.05	2.0	450	0.49	20F	-
	33F	1	0.90	2.16	450	0.48	20F	-
Series4	41	1	1.13	2.712	450	0.38	-	1.5
	42F	1	1.07	2.56	450	0.35	20F	1.5
	43F	1	1.01	2.41	450	0.33	30F	1.5
Series5	51	1	1.127	2.704	450	0.39	-	1.5
	52F	1	1.04	2.51	450	0.36	20F	1.5
	53F	1	0.98	2.36	450	0.34	30F	1.5

CHAPTER 6

DISCUSSION AND RESULTS

6.0 GENERAL

Results of workability (slump / compaction factor) on wet concrete and compressive strength test at the age of 28 day/56 day are tabulated against each mix in table no 6.1

Table 6.1 Results of tests on concrete mixes in wet and hardened stage.

Mix series	Mix no.	Slump (mm)	Compaction factor	28 Day compressive strength(mpa)	56 Day compressive strength(mpa)
Series 1	11	8	-	27.17	-
	12	9	-	28.78	-
	13	8	-	22.09	-
	14	9	-	24.99	-
	15	10	-	30.66	-
Series 2	21	44	-	24.78	(27.26)
	22	48	-	25.58	(28.13)
	23	58	-	28.56	(31.41)
	24F	58	-	23.83	28.77
	25F	55	-	24.56	30.95
	26F	46	-	25.36	31.83
Series3	31	32	-	28.48	-
	32	58	-	29.36	-
	33	42	-	31.97	-
	34F	37	-	29.8	36.04
	35F	38	-	31.83	37.28
	36F	44	-	33.72	39.02
Series4	41	-	0.8	55.08	-
	42F	-	0.79	59.15	62.13
	43F	-	0.78	60.17	63.66
Series5	51	-	0.8	60.31	-
	52F	-	0.78	62.06	65.62
	53F	-	0.77	63.37	67.36

(*) values indicated in the parenthesis are 90 days compressive strength arrived at by multiplying 28 day compressive strength by age factor as per provision 5.2.1 contained in IS : 456-1978

6.1 DISCUSSION OF TEST RESULTS

Comparison of 28 day compressive strength test results of mix number 11 with mix number 12 and mix number 13 with mix number 14 reveals slight increase in strength in mix number 12 and 14. The percentage increase in strength in mix number 12 over mix number 11 is about 6 percent while in mix number 14 when compared with 13 the increase is about 13 percent. This may be due to reduction in flakiness index of coarse aggregate (C2) in mix number 12 and 14 over its corresponding mix number 11 and 13 where “C1” is used as coarse aggregate

Slump test result of mix number 11, 12 when compared with results of mix number 13, 14, both groups having the equal quantities of same types of materials indicate same workability in terms of equal slumps.

Comparing the 28 day compressive strength test results of mix number 11 with mix number 13, where coarse aggregate (C1) is used in both the mixes, but the fineness modulus of mix number 13 (FM=2.1) is much lower than the fineness modulus of mix number 11(FM=2.92), It is apparent from the table of results (table 6.1) that mix number 13 is having lower 28 days compressive strength. The decrease in 28 day compressive strength is approximately 19 percent This lower strength is attributable to the lower fineness modulus of fine aggregate in mix number 13,despite the fact quantity of fine aggregate is reduced by about 25 percent and quantity of coarse aggregate is increased by about 17 percent. Similarly on comparing 28 days compressive strength test results of mix number 12 and mix number 14 we find lower value in case of mix number 14.The decrease in 28 day compressive strength is approximately 13 percent, again despite the fact that quantity of fine aggregate has reduced by about 25 percent and quantity of coarse aggregate increased by about 17 percent. This again is attributable to reduction in fineness modulus of fine aggregate from 2.92 to 2.10.

A comparison of mix number 15 with mix numbers 11 to 14 reveal that with adjustment in grading of fine aggregate (increase in fineness modulus) and better grading of coarse aggregate by adjustment in percentage retained on various sieves (both tailored aggregates) increase in 28 day compressive strength has been achieved in mix number 15 along with slight increase in its workability. The percentage increase in strength of mix number 15 when compared with mix number 11 and 12 are 13 percent and 6.5 percent respectively. It is found that the increase in strength is also due to increase in quantity of coarse aggregate and reduction in quantity of fine aggregate.

In mix number 15 when compared with mix number 11 and 12 the percentage increase in coarse aggregate content is about 30 percent and the reduction in fine aggregate content is about 34 percent along with in increase in overall aggregate content by about 1 percent.

The percentage increase in strength in mix number 15 when compared with mix number 13 and 14 are about 39 percent and 23 percent respectively. It is again found that the increase in strength is also due to increase in quantity of coarse aggregate and reduction in quantity of fine aggregate. In this comparison the percentage increase in coarse aggregate content is about 11 percent, reduction in fine aggregate is 12 percent along with an increase in overall aggregate content of about 3 percent.

It is further seen that in mix number 15,the percentage increase in 28 day strength when compared to other mix of the group is in the range of 6.5 to 39 percent(average 22 percent, which has been achieved even after reducing the quantity of the cement by about 10 percent. This clearly shows how important is the selection (tailored coarse aggregate and fine aggregate) of proper ingredients in the concrete mix, where wide variety exists in their quality.

Comparison of 28 day compressive strength test result of mix number 21 with 22 and mix number 21F with 22F reveals marginal increase in strength of mix number 22 over 21 and 22F over 21F.This is attributable to increase in fineness modulus of fine aggregate used in mix number 22 over 21 and 22F over 21F.Cement content was replaced 20 percent by fly ash which resulted in lower strength at 28 days than their corresponding plain mix.

Comparison of slump test results between mix number 21 and 22 indicate slight increase in slump values of mix number 22 over mix number 21.This is due to increase in fineness modulus of sand used in mix 22 over mix 21, but slump test result of mix number 22F when compared with mix number 21F show slight decrease in slump value.

Comparison of mix number 23 with mix number 21, 22 and mix number 23F with mix number 21F, 22F reveal that with adjustment in grading of fine aggregate (increase in fineness modulus) and better grading of coarse aggregate by adjustment in percentage retained on various sieves (both tailored aggregates).Increase in compressive strength has been achieved in mix number 23 and 23F.

Same type of fine aggregate and coarse aggregate are used in mix number 21 and 13 but, there is an increase in water cement ratio and cement content per cubic meter in mix number 21.The increase in cement content, water cement ratio and reduction of total fine and coarse aggregate content in mix number 21 may have resulted in substantial increase in slump of the concrete mix.

Same type of fine aggregate and coarse aggregate are used in mix number 23 and 15. Higher water cement ratio in mix number 23, increase in total quantity of fine aggregate and decrease in total quantity of coarse aggregate per cubic meter of mix have resulted to decrease of strength and increase in workability despite of increase in cement content.

Workability of mix number 23 has improved over mix number 22 because of increased fineness modulus value and decrease in fine aggregate content per cubic meter of mix.

Mix number 21F, 22F and 23F have shown continues increase in strength despite of constant water cement ratio, which is attributable to increase in fineness modulus of fine aggregate and better grading of the coarse aggregate.

Comparison of 28 day compressive strength test results of mix number 21F, 22F, 23F (with fly ash) with corresponding mix number 21,22,23(without fly ash)indicate that there is a decrease in 28 day compressive cement test results of all the fly ash mixes. This is due to the addition of fly ash in the mixes at 20 percent replacement level of cement which results into slower pozzolanic reaction during this period.

A comparison of 56 day predicted compressive strength test result of mix number 21F to 23F (fly ash mixes) with the 90 days compressive strength test results over their corresponding mix number 21 to 23(non fly ash mixes) reveals that the 56 day compressive strength of fly ash mixes is higher than 90 day compressive strength test results of corresponding plain mixes. This is due to delayed continues pozzolanic reaction spread over longer period of time (value of 90 days compressive strength test results are arrived at by multiplying the 28 day compressive strength results with age factor of 1.10 as per provision contained in 5.2.1 of IS: 456-1978).Thus, the addition of fly ash results into utilization of an industrial waste product and simultaneous gain of strength at a later age. Fly ash addition results into reduction in cost of concrete, conservation of dwindling natural resources used for forming cement and also helps in reducing the impact on environment by consuming the material generally considered as a waste product with very few applications.

The percentage decrease in 28 day compressive strength using 20 percent fly ash as cement replacing material is 4 percent to 11 percent (4 percent with aggregates available in the market and 11 percent with tailored aggregates).The 56 day compressive strength test results when compared with 90 day (anticipated probable increase after 90 days as per IS 456:1978) strength reveal increase in marginal strength in case of tailored aggregate and 5 to 10 percent increase in case of generally available aggregates. This shows that average increase in strength at 56 days when compared with 28 day by using fly ash at 20 percent cement replacing material level is of the order of 12 percent.

All the concrete mixes are workable (number 31 to 33 and 31F to 33F) mix number 31, 32, 33 and 31F, 32F, 33F have shown continuous increase in 28 day compressive strengths (in each of the two groups) over the immediate previous mix of the same group, inspite of constant water cement ratio which is attributable to the increase in fineness modulus of fine aggregate and better grading of coarse aggregate.

Comparison of series 3 mixes(31 to 33, 31F to 33F)with series 2 mixes (21 to 23, 21F to23F) reveals that same types of material have been used but with increased cement content in series 3 mixes at 450kg/m^3 and reduction in water cement ratio in case of series 3 mixes. It is further revealed that all the 28 day compressive strength test results of series 3 mixes are more than its corresponding results of series 2 mixes. This is due to higher cement content and reduced water cement ratio.

Comparison of 28 days compressive strength test result of mix number 31F to 33F (with fly ash) to mix number 31 to 33(without fly ash) reveals that there is increase in strength in each mix using fly ash as supplementary cementing material as compared to its corresponding non fly ash mix. The increase in strength at 28 day using 43 grade OPC cement content at 450 kg/m^3 and 20 percent fly ash as supplementary cementitious material is of the order of 4.5 percent to 8.5 percent over corresponding non fly ash mixes. The increase in strength in fly ash mixes using supplementary cement material over the corresponding plain mixes is due to reduction in water cement ratio from 0.55(without fly ash) to 0.49/0.48(with fly ash mixes) and is also due to fly ash used as supplementary cement material. There is further increase in 56 day compressive strength test result of fly ash mixes which is due to slower pozzolanic reaction in the beginning up to 28 days after mixing of concrete and the same gets accelerated afterwards. The increase in strength during 28 day to 56 days in the fly ash mixes is of the order of 16 to 21 percent (average increase 18 percent) at 20 percent supplementary cementitious material with cement 43 grade OPC at 450 kg/m. By adopting appropriate factor of safety to the arrived values percent increase we can realistically gain the increase in strength of the order of 10 percent. Thus, by designing the structure considering strength gained at the age of 56 days(in general the building are subjected to full design loads at a period of more than 56 days) further economy to the extent of 10 percent can be achieved using cement content 450kg/m^3 supplemented by20 percent fly ash.

53 Grade ordinary Portland cement with constant maximum cement content of 450kg/m^3 has been used in all the three mixes (mix number 42F, 43F). All the three mixes are in workable range. Comparison of 28 day compressive strength test results of mix number 41, 42F and 43F indicate continuous increase in 28 day compressive strength over its immediate previous plain mix (i.e. 41),without significant change in water/binder ratio is due to the addition of fly ash at 20 percent and 30 percent level of supplementary cementitious material in mix number 42F and 43F respectively .The water/ cementitious material ratio in mixes of series 4 are much lower than the normal mixes which has been achieved by the use of superplasticizer at 1.5 percent to make the mix workable.

Continuous increase in 28 day compressive strength in mix number 51, 52F, 53F is indicated in the table of results which have same cement content and without significant change in water binder ratio. The increase in 28 day compressive strength of the subsequent mixes i.e. 52F and 53F over its immediate plain mix is due to the addition of fly ash at 20 percent and 30 percent level in mix number 52F and 53F respectively in the form of supplementary cementitious material.

The increase in strength by using 53 grade OPC cement at 450 kg/m^3 with 20 and 30 percent fly ash used as supplementary cementitious material is of the order of 6.4 percent and 11.1 percent respectively over corresponding plain concrete mix by using 20mm maximum size coarse aggregate. The percentage increase using 12.5mm maximum size coarse aggregate along with cement and supplementary cementitious material as in the just preceding mixes is 7 percent and 9.5 percent respectively for 20 and 30 percent fly ash usage.

This shows that with 30 percent fly ash used as supplementary cementitious material increases the strength over its corresponding plain concrete mix more incase of 20 mm maximum size aggregate a compared to 12.5mm maximum size aggregate.

The strength of mixes in series 5 is more than the strength of corresponding mix in series 4.this increase in strength is due to the use of 12.5mm maximum size coarse aggregate in place of 20mm maximum size aggregate. Further this increase is attributable to the more surface area occupied by 12.5mm maximum size aggregate as compared to 20mm maximum size aggregate.

The percentage increase using 12.5mm maximum size aggregate as compared to 20mm maximum size aggregate is 5 percent for plain mixes and 5.3 percent and 3 percent respectively where fly ash is used as supplementary cementitious material.

6.2 CONCLUSIONS

1. Reduction in flakiness index of coarse aggregate results in increase in compressive strength.

2. Reduction in fineness modulus of fine aggregate leads to decrease in compressive strength and vice versa.

3. Increase in fineness modulus of fine aggregate and better grading of coarse aggregate or better combined grading leads to increase in strength as well as workability. By maintaining higher fineness modulus of fine aggregate, capable of giving required workability along with properly graded coarse aggregate having low elongation and flakiness index are capable of giving up to 20(average) percent more strength even inspite of 10 percent reduction in cement content.

4. Increase in fines (i.e. cement) coupled with reduction in total quantity of fine and coarse aggregate leads to increase in slump value.

5. Improvement in gel/space ratio leads to improvement in strength.

6. Increase in quantity of fine aggregate and reduction in quantity of coarse aggregate per cubic meter of concrete results in decrease in compressive strength.

7. Decrease in quantity of fine aggregate per cubic meter of concrete with increase in fineness modulus of fine aggregate results in increase in workability.

8. Fly ash when used as mineral admixture to partially replace cement, it results in decrease in compressive strength of concrete up to 28 days.

9. Fly ash when used as mineral admixture to partially replace cement, it results in increase in strength of concrete at an age of 56 days. The average increase in strength during 28 day to 56 day is about 12 percent using 450kg/m^3 cement with 20 percent fly ash as cement replacing material. The average increase in strength when compared with 90 days (anticipated probable) compressive strength is about 6 percent. This helps to derive advantage in the following ways:

a Fly ash an industrial waste product having very few applications, gets utilized.

b Increase in gain of strength at later age.

c Reduction in cost of concrete.

d Helps saving in cement by replacing it with Fly ash there by reducing pressure on the natural resources used in making cement.

e Reduction in impact on environment by consumption of waste product, the disposal of which is a big problem.

f By proper knowledge of strength of concrete at specified age, the optimum design can be worked out for affecting economy. Rough estimates indicates that construction industry in India consumes approximately 150 million tonnes of cement annually by proper mixed design and economic use of cement minimum saving of approximately 2 percent of the consumption level can be affected. This saving in rupee terms is approximately 15 million per year.

10. At prescribed maximum cement content level the fly ash mixes using fly ash as supplementary cementitious material show increase in 28 days strength as compared to

concrete mix without fly ash. At the age of 56 days the strength further increases when compared with non fly ash mixes. The increase in strength at the age of 56 days when compared with 28 days strength using 20 percent fly ash as supplementary cementitious material with maximum cement content of 450kg/$m^3$of grade 43 OPC rages from 16 percent to 21 percent (average 18 percent)

11. By the use of Superplasticizer the water cement ratio can be reduced considerably keeping the concrete still in workable range. The reduction in water cement ratio leads to reduction in gel pores therefore increasing the strength of concrete.

12. There is increase in strength of mix using 30 percent fly ash as supplementary cementitious material compared with mix using 20 percent fly ash as supplementary cementitious material. The increase using 20mm maximum size aggregate is 4.5 percent while using 12.5 mm maximum size aggregate which is marginal. At 30 percent supplementary cementitious material as compared to plain mix increase in strength is 11 percent using 20mm maximum size aggregate and the same is 9.5 percent using 12.5mm size coarse aggregate.

13. By replacing the 20mm maximum size coarse aggregate with 12.5 mm maximum size aggregate increase in strength at 28 days can be achieved. The percentage increase in 28 day compressive strength using 12.5mm coarse aggregate compared with 20mm coarse aggregate is 3 percent for the tailored aggregate and 5 percent for the aggregate generally available in the market.

14. from the test results it is evident that by using 43 grade OPC considering 56 day strength of fly ash concrete mixes(which can generally be adopted in case of buildings with limited exceptions) the 56 day increased strength can help to economize the design by about 10 percent considering variation and minimum percentage of increased strength.

15. During the project work on real concrete mixes approximate maximum strength of 60 Mpa has been achieved without using any mineral admixture(mix number 51/table 6.1 /page 73) by keeping the cement content of 450kg/m^3 and keeping the concrete workable even after using the coarse aggregate of flaky type. Hence, it can be concluded that further increase in strength can be achieved by using cubical shaped graded coarse aggregate.

16. In the trial mix number 6(refer table 5.15/page68) the compressive strength of the order of 72Mpa could be achieved using Superplasticizer at 1.5 percent dosage. The marsh cone apparatus was not available in the laboratory at that point of time. However, the same could be arranged later on and test on compatibility of Superplasticizer was performed. Results revealed that the plasticizer is compatible and Superplasticizer upto 2 percent dosage level (fig.5.1/page53)would have effective. Thus, the trail mix number 6 could be made workable by the use of Superplasticizer at 2 percent dosage level. Thereby, reducing the water cement ratio resulting in increased strength or strength equal to trail mix could have been achieved.

6.3 FURTHER SCOPE OF WORK

The studies under this project were to be completed in the specified time frame. Due to time constraints some of the related aspects of study covering wide variety of materials available in the market could not be carried out under this project. Thus scope exists for further work to be done as under:

In the present study ordinary Portland cements of 43 grade and 53 grade each one of particular brand manufactured by its manufacturer have been used. The study may further be extended to cover similar cements of other manufacturers to ascertain variability in results.

The present study has been carried out by using only one type of fine aggregate i.e. Badarpur sand generally available in Delhi. Hence, further studies may be carried out using other types of fine aggregates like river sand, crushed stone dust etc.

In the major part of this study, coarse aggregate as available in the market has been used which generally consisted of flaky and elongated type of particles. By making minor adjustments in the available aggregate, the maximum strength that could be achieved is 72 Mpa on trial mix number 6(listed under trail mixes).work may further be extended by using properly graded cubical shaped coarse aggregate to substantially enhance the workability and strength properties of concrete.

Work may further be extended by using mineral admixtures like rice husk ash, metakaolin and silica fume to study their effects on parameters like strength, permeability, durability and workability etc.

REFRENCES

1. Mavinkurve Shreeti S, Basu Prabir C and. Kulkarni Vijay R. High performance concrete using high reactivity metakaolin. May 2003 The Indian concrete journal,1077-1085.

2. Malhotra V.M. and Carette G.G. Performance of concrete incorporating limestone dust as partial replacement for sand. ACI journal/ May-June 1985 title no 82-33, 363-371.

3. Gutmann Paul F. Bubble characteristics as they pertain to compressive strength and Freeze-thaw durability. ACI Materials JournalSeptember-October1988 title no 85-M40, 361-366.

4. Desai J. P. Construction of HVFA concrete pavements in India: Four case studies. November 2004* The Indian concrete journal 67-71.

5. Ashraf Mohamed, Sharma Amit and Mokal Manish. HVFA concrete for tremie seal and pylon pile cap of Bandra - Worli sea link project. November 2004* The Indian concrete journal, 31-36.

6. Venkatesh Babu D.L. and Natesan S.C. Some investigations on silica fume concrete. September 2004 * The Indian concrete journal 57-60.

7. Tike G.K., Kumar Satander and Sood V.K. Use of chemical admixtures for pavement quality concrete. September 2004* The Indian concrete journal. 46- 50.

8. Balasubramanian K., Krishnamoorthy T.S., Gopalakrishnan S, Bharat Kumar B.H. and Kumar Girish. Bond characteristics of slag-based HPC. August 2004* The Indian concrete journal 39-44.

9. Bamforth P.B. The water permeability of concrete and its relationship with strength Magazine of Concrete Research, 1991.43. No. 157. Dec. 233-241.

10. Lee I.K., Lee K.M. and. Kim B. G. Autogenous shrinkage of high –performance concrete containing fly ash. Magazine of Concrete Research.2003.55.No.6 Dec.507-515.

11. Prakash Rao D. S. and Giridhar Kumar V. Investigations on concrete with stone crusher dust as fine aggregate. July 2004* The Indian concrete journal 45-50.

12. Gardner N. J., Sau P. L. and Cheung M. S. Strength development and durability of concretes cast and cured at 0^0C. ACI Materials Journal/November-December1988 title no85-M52, 529-536.

13 Dhir. R. K. and Byars E. A. PFA Concrete: Permeation properties of cover to steel reinforcement. Cement and Concrete research volume 23 no. pp.554-566.

14. Bharat Kumar B. H. NarayananR, Raghuprasad B. K. and Ramachandramurthy D. S. Mix proportioning of high performance concrete. Cement and concrete composites. 23 (2001) 71-80

15. Khatri R. P. and Sirivivatnanon .V. Effect of different supplementary cementitious materials on mechanical properties of high performance concrete. Cement and Concrete research volume 25 No. 1/.pp.209-220.

16. Mak Swee Liang and Torii Kazuyuki. Strength development of high strength concretes with and without silica fume under the influence of high hydration temperatures .Cement and Concrete research volume 25 no. 8pp.1791-1802.

17. Dhir R.K. and Byars E.A. PFA concrete: near surface absorption properties. Magazine of Concrete Research.1991.43. no. 157. Dec.219-232.

18. Neville A.M. and Brooks J.J. Addison Wesley Longman Limited, England. Concrete technology. reprinted 1997.

19. Shetty M. S. S.Chand and Company Limited, New Delhi. Concrete technology. Fifth revised edition 2002.

20. Neville A. M. Pearson Education (Singapore) Pvt. Ltd. Properties of concrete. Fourth Indian reprint. 2005.

21 Gambhir M.L. Tata McGraw Hill Publishing Company Limited New Delhi. Concrete technology. Eighth reprint 2007.

22. Bureau of Indian Standards, New Delhi. SP 23:1982: Handbook on concrete mixes Second reprint December 1990.

23. BUREAU OF INDIAN STANDARDS IS383:1970: Specification for coarse and fine aggregates from natural sources for concrete (second revision).

24. BUREAU OF INDIAN STANDARDS IS456:2000. Code of practice for plain and reinforced concrete (fourth revision).

25. BUREAU OF INDIAN STANDARDS IS516:1959.Method of test for strength of concrete.

26. BUREAU OF INDIAN STANDARDS IS2386 (part 1): 1963.Method of test for aggregates for concrete part 1 Particle size and shape.

27. BUREAU OF INDIAN STANDARDS IS2386 (part 3):1963.Method of test for aggregates for concrete part 3 Specific gravity, density, voids, absorption and bulking.

28. BUREAU OF INDIAN STANDARDS IS2386 (part 4):1963.Method of test for aggregates for concrete part 4 Mechanical properties.

29. BUREAU OF INDIAN STANDARDS IS3812:1981.Specification for fly ash for use as pozzolana and admixture (first revision).

30. BUREAU OF INDIAN STANDARDS IS4031 (part 1):1996.Method of physical tests for hydraulic cement part 1 Determination of fineness by dry sieving(second revision).

31. BUREAU OF INDIAN STANDARDS IS4031 (part 4):1988.Methods of physical tests for hydraulic cement part 4 Determination of consistency of standard cement paste(first revision).

32. BUREAU OF INDIAN STANDARDS IS4031 (part 5):1988.Methods of physical tests for hydraulic cement part 5 Determination of initial and final setting times(first revision).

33. BUREAU OF INDIAN STANDARDS IS4031 (part 6):1988.Methods of physical tests for hydraulic cement part64 Determination of compressive strength of hydraulic cement (other than masonry cement)(first revision).

34. BUREAU OF INDIAN STANDARDS IS8112:1989:.Specifications for 43 grade ordinary Portland cement (first revision).

35. BUREAU OF INDIAN STANDARDS IS9013:1978.Method of making, curing and determining compressive cement strength cured concrete test specimen.

36. BUREAU OF INDIAN STANDARDS IS9103:1999.Specification for admixtures for concrete (first revision)

37. BUREAU OF INDIAN STANDARDS IS12269:1987.Specification for 53 grade ordinary Portland cement.