A Project Report on

INFLUENCE OF ACCELERATED CURING ON THE COMPRESSIVE STRENGTH OF CONCRETE INCORPORATING FLY ASH

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CERTIFICATE

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DECLARATION

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ABSTRACT

Quality of concrete is an important factor in assimilating the strength of a structure. The factors that influence the quality of concrete more or less depend on the curing conditions. The type of curing used in this study are normal water curing and accelerated curing by boiling water method. The important aspect of any construction is time constraint that leads to the high impact on the economy of any project. The strength and the curing of concrete can be expedited by raising the temperature and thereby increasing the rate of hydration. This study aimed to investigate the behavior of the strength of M30 grade of concrete when cured under both conditions. The mix design was prepared by referring IS 10262:2009. The types of sample that were prepared was nominal mix and binary mix that incorporated fly ash with varying percentage i.e.25%, 30% and 35%. The specimen was prepared and tested according to IS 516:1959. The results obtained were then tabulated and compared. The comparison was done according to the curing conditions and respective percentage of fly ash. The optimum dosage of fly ash was concluded.

Keywords- Accelerated Curing, Boiling Water, Rate of Hydration, Mix Design, Binary Mix, Fly Ash

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ABBREVIATION NOTATION AND NOMENCLATURE

SCM	Supplementary cementitious material
OPC	Ordinary Portland cement
FA	Fly ash
HVFA	High volume fly ash
GGBS	Ground granulated blast furnace slag

Chapter 1

Introduction

1.1 General

Supplementary cementitious materials (SCMs) may be divided into natural materials and artificial ones. To the former belong true pozzolona and volcanic tuffs. To the second category belong siliceous by-products, such as fly ashes, condensed silica fume and metallurgical slags (blast furnace slag, steel slag and nonferrous slags). Fly ash is the combustion residue (coal mineral impurities) in coal-burning electric power plants, which flies out with the flue gas stream and is collected by mechanical separators, electrostatic precipitators or bag filters. Condensed silica fume, sometimes known simply as silica fume or micro silica, is produced by electric arc furnaces as a by-product of the production of metallic silicon or ferrosilicon alloys. Slags are by-products of metallurgical furnaces producing pig iron, steel, copper, nickel and lead. According to ASTM C 595, a pozzolan is defined as ‘‘a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide to form compounds possessing cementitious properties (pozzolanic activity).’’ Thus, a pozzolanic material requires Ca(OH)2 in order to form strength products, whereas a cementitious material itself contains quantities of CaO and can exhibit a self-cementitious (hydraulic) activity. Usually, the CaO content of the latter material is insufficient to react with all the pozzolanic compounds. Thus, it also exhibits pozzolanic activity (pozzolanic and cementitious materials). However, all these materials are often used in combination with Portland cement, which contains the essential for their activation, Ca(OH)2 from its hydration.

A quantitative understanding of the efficiency of fly ash as a mineral admixture in concrete is essential for its effective utilisation. Research efforts in the past have not been successful in quantifying this efficiency because of the numerous variables involved, both in terms of the characteristics of fly ash and cement as well as the parameters influencing the concrete mix design itself. Initially, the use of fly ash started as direct replacement of cement in concrete, which is still advocated by a few. Later efforts towards an effective utilization led to rational methods of incorporating fly ash in concrete, considering the fact that the two concretes (with or without fly ash) can be made to reach the same strength at a given age by adjusting the water cementitious materials ratios. This was done either by adjusting the quantity of fly ash introduced for replacing the cement or through the “cementing efficiency factor” of fly ash.

In general, it was observed that fly ash exhibits very little cementing efficiency at the early ages and acts rather like fine aggregate (filler), but at later ages the pozzolanic property becomes effective leading to a considerable strength improvement. This obviously means that the cementing efficiency of fly ash improves with age due to the pozzolanic reaction. It is also observed that that cementing efficiency of fly ash depends on many of its characteristic-physical properties like particle shape, size and distribution, chemical properties like composition, glass content etc. other parameters related to cement and the ones effecting mix proportioning can also influence the resulting concrete behaviour significantly. Several investigators reported the effect of fly ash in concrete through a comparison of the compressive strength of fly ash concretes with the normal concretes. The variation of strength with age was also discussed by a few. In spite of all these investigations, it is felt that there is a lack of quantitative understanding of the behaviour of fly ash in concrete.

1.2 Fly ash in concrete

The quantity of fly ash produced from thermal power plants in India is approximately 80 million tons per year and its percentage utilization is less than 10%. The use of fly ash in concrete has gained significant attention over the recent years due to environmental concerns regarding its disposal from one hand and significant benefits to concrete on the other, when it is used as a supplementary cementitious material. Fly ash is widely used as a pozzolanic supplementary cementitious material in different concrete applications. Also recent environmental policies and regulations concerning the disposal of by products have necessitated the use of fly ash in concrete. During the last few years, some cement companies have started using fly ash in manufacturing cement, known as “Pozzolona Portland Cement”, but the overall percentage utilization remains very low and most of the fly ash are dumped as landfills (Siddique 2003). Class C Fly ash is high lime ash originating from lignite coal. It may occasionally have a lime content of 24 percent. High lime ash has some cementitious properties of its own (Neville 1995).

Chapter 2

Literature Review

2.1 General

The work done by the various investigators is referred and summarized here in this chapter. The referred journal and conference papers and reports are presented in the following three phases;

- Phase-I Accelerated Curing
- Phase-II Review Papers
- Phase-III Application of Accelerated Curing

At the end, the research gaps have been reviewed from each of the above three phases

2.2 Phase-I Accelerated Curing

The compressive strength of cement concrete obtained after 28 days of moist curing is considered for quality of concrete in construction works. To get this strength for good quality control one has to wait for 28days. In order to get high early strength and also to reduce time for economical quality control, accelerated curing is used. In this method of curing the temperature of water is increased, which results in increase in concrete temperature and rate of development of strength accelerates which will be more comparing to normal moist curing. There are different ways of accelerated curing, like warm water curing, boiled water curing, autoclave curing, microwave curing, electric curing etc. Generally, the accelerated curing is used for precast products and for high early strengths. To complete the project within the time and to develop economic concrete, the high early compressive strength of concrete can be determined in a laboratory by accelerated curing. It also predicts the 28 days compressive strength within 28 hours.

IS 9013 evolved a standard method of determining compressive strength of test specimens by accelerated curing. The method laid down in this standard can be used for quality control purposes, or for the prediction of normal strength of concrete at later ages, by the use of an appropriate correlation-curve obtained by testing normally cured and accelerated cured concrete specimens of the mix proportion and materials to be used at the site. Jayadevan et al (9) conducted studies for reliability of accelerated curing proposed by IS 9013:1978, which has given discouraging results about the prediction of 28 days compressive strength, and suggested to revise the code.

Neelakantan et al (12) predicted 28 days strength of concrete from accelerated curing parameters and proved that conduction curing is better than microwave curing. Shelke et al (13) compared a concrete compressive strength by normal moist curing and accelerated curing, and obtained desired strength as per IS 9013:1978

2.3 Phase-II Review Papers

Pawar A.J. et al had explained that the quality of concrete is calculated in terms of its 28days compressive strength. This period is too long for either control of concrete construction or applying timely corrective measures particularly in today’s fast construction practices. Curing of concrete and its gain of strength can be expedited by raising the temperature of curing, thereby speeding up of the hydration reaction. Two methods of accelerated curing – warm water method and boiling water method have been covered by IS 9013. The objective of this study is to compare 28 days compressive strength of concrete with accelerated curing methods developed by IS 9013: 2004. One more method of curing in which temperature was increased gradually was also attempted. In order to achieve these, total 48samples of two different mix proportions were cast and cured by normal water curing for 28 days, and by accelerated curing methods. The reliability of these accelerated curing methods was checked.

Rao G.S. et al had explained that the advancement of concrete technology can reduce the consumption of natural resources and lessen the burden of pollutants on environment. Presently large amounts of fly ash are generated in thermal and steel industries with an important impact on environment and human health. In recent years, many researchers have established that the use of supplementary cementitious materials (SCMs) like fly ash (FA), blast furnace slag, silica fume, metakaolin (MK) and rice husk ash (RHA) etc. can, not only improve the various properties of concrete - both in its fresh and hardened states, but also can contribute to economy in construction costs. The use of fly ash in concrete formulations as a supplementary cementatious material was tested as an alternative to traditional concrete. This project work describes the feasibility of Fly Ash in concrete world. Fly Ash was collected from NTPC (National Thermal Power Corporation) which is located at paravada in Visakhapatnam. The cement has been replaced by fly ash in various dosages such as 10, 20, 30 and 40 percentages by weight of cement for M25 and M30 mixes. Concrete mixtures were produced, tested and compared in terms of compressive strength with the conventional concrete. These tests were carried out to evaluate the mechanical properties and compressive strengths at various curing periods such as 3, 7 and 28 days. Tests conducted for fresh concrete are workability tests like slump, vee-bee consistometer and compaction factor and for hardened concrete compressive strength is done. The 28 Days Cured concrete cubes of all proportions were cured in Accelerated Curing tank for 3hours in boiled water(at 1000C) to obtain 28 days curing strength at earlier stage. From the experimental investigations it has been observed that the compressive strength of the concrete is optimum at 20% fly ash replacement with cement.

Arora V.V. et al stated that early prediction of 28 days compressive strength is required basically for two purposes. Firstly, to finalize the concrete mix proportions in the laboratory and secondly, for quality control purpose during construction. In past few years focus has shifted from Ordinary Portland Cement (OPC) to Portland Pozzolana Cement (PPC). Fly ash is also being used widely at site as replacement of OPC. In the present study an attempt has been made for prediction of expected 28 days compressive strength of concrete having PPC or OPC with fly ash using accelerated temperature regime methods. The experimental study includes use of 2 brands of PPC, 5 brands of OPC and 2 sources of fly ash for replacement of

OPC ranging from 20% to 45 %. Two temperature regimes 900C and 820C were used for accelerated curing. The samples were cured for 7.5 hours and 20hours respectively in each regime for expected 28-day compressive strength.

Yazdain N. Et al stated that silica fume is a common addition to high-performance concrete mix designs. The use of silica fume in concrete leads toincreased water demand. For this reason, Florida Department of Transportation FDOT- allows only a 72-h continuous moist cure process for concrete containing silica fume. Accelerated curing has been shown to be effective in producing high-performance characteristics at early ages in silica-fume concrete. However, the heat greatly increases the moisture loss from exposed surfaces, which may cause shrinkage problems. An experimental study was undertaken to determine the feasibility of steam curing of FDOT concrete with silica fume in order to reduce precast turnaround time. Various steam-curing durations were utilized with small laboratory specimens. The concrete compressive strength, surface resistivity, and shrinkage were determined for various durations of steam curing. Results indicate that steam cured silica-fume concrete met all FDOT requirements for the 12, 18, and 24 h of curing periods. All steam cured samples demonstrated excellent durability up to 1 year of age. It was recommended that FDOT allow12 h steam curing for concrete with silica fume.

Dr. Ghalib M.H. et al aimed to investigate the effect of different accelerated curing method on compressive strength of high strength concrete with Nano-silica by using two types of cement. The curing methods are the normal (bonding) curing method at 21℃, hot water method at 80℃ according to (ACI C517, 1992) and boiling water method at 100℃ according to (ACI 214 .1R-1987) .Nano-silica (of the size of 35 nm) is used as mineral admixture with variable content (1, 2 and 3)% by weight of cementitious materials as an addition. The constant w/p of 0.30 is used for all mixtures and slump has been maintained in range (250 – 275) mm by adjusting the dosage of super plasticizer. The best performance is demonstrated with hot water by concrete with, 3% Nano-silica,2.5% of super plasticizer and sulfate resistance Portland cement. This concrete had the highest compressive strength at all ages.

Sethe M. N. et al carried out the experiment to assess the effect of chemical admixture on the curing of concrete bricks. The effect was assessed in terms of compressive strength gained by the bricks during predetermined period in days. After manufacture, the batches of bricks cured by conventional method. Four sample batches were prepared viz. 0.0, 1.0, 1.5, 2.0 percentage of chemical admixture of the cement used. The compressive strength of the bricks was made on compression testing machine. The plot of the average compressive strength of each batch versus curing time in days obtained on the basis of findings during the tests. It was found that the use of the chemical admixtures improves the rate of curing and helps the concrete to gain earlier strength.

Kwan W.H. Polymer-modified materials provide numerable enhancements to cementitious composites. However, the curing hardening conditions for cementitious and polymeric materials differ significantly, although they are mixed to form a single entity. Cement requires a moist environment for the hydration process to occur, while polymers require a hot and dry environment. Consequently, the polymer-modified composite exhibits lower compressive strength than the ordinary cementitious product. The objective of the present study was to resolve this issue by using accelerated curing regimens, following the fundamental concept that the dominant contribution to the toughness of the composite matrix is from the cement system, while polymer films refine the microstructure. Hygrothermal treatment for plain mortar was first developed in order to achieve 100% of the 28-day strength after treatment is completed. The hot + dry treatment required for the formation of polymer film was studied in the second phase of this study, together with an investigation of the microstructure using scanning electron microscopy. The results show that, after being subjected to the hygrothermal and hot + dry treatment, polymer-modified mortar can achieve low intrinsic permeability without compromising the compressive strength. A 15% polymer loading in styrene–butadiene rubber-and epoxy-modified mortar led to 46% and 18% higher compressive strengths, and 660% and 460% lower intrinsic permeabilities, compared with unmodified mortar, respectively.

Shyamala K. found that Ground granulated blast-furnace slag (GGBS) is the granular material formed iron ore is molted blast furnace slag is by-product of steel manufacture which is sometimes used as a substitute for Portland cement. In steel industry when iron ore is molted, then in the molted state all the impurities come at its surface which are removed called slag. It consists mainly of the silicates and alumino silicates of calcium, which are formed in the blast furnace in molten form simultaneously with the metallic iron. Blast furnace slag is blended with Portland cement clinker to form portland blast furnace slag cement. GGBS is used to make durable concrete structures in combination with ordinary Portland cement and or other pozzolanic materials. GGBFS has been widely used in Europe, and increasingly in the United States and in Asia (particularly in Japan and Singapore) for its superiority in concrete durability, extending the lifespan of buildings from fifty years to a hundred years. This project presents the feasibility of the usage of GGBS as hundred percent substitutes for Ordinary Portland cement in concrete. Design mix for M20 and M30 has been calculated using IS 10262-2009 for both accelerated curing in warm water and accelerated curing in boiling water method. Tests were conducted on cubes to study the strength of concrete by using GGBS and Ordinary portland cement.

S.J. Barnett, M.N. Soutsos, S.G. Millard, J.H. Bungey had done a brief study on the topic 'Strength development of mortars containing ground granulated blast-furnace slag' and has later published in the journal 'Cement and Concrete Research'. He concluded that all mortars gain strength more rapidly at higher temperatures and have a lower calculated ultimate strength and the water–binder ratio appears to have little or no effect on the apparent activation energy.

J.Temuujin, R.P.Williams, A. van Riessen had done a brief study on the topic 'Influence of Mineral Admixtures on the Short and Long-term Performance of Steam-cured Concrete' and has later published in the journal ''.Effect of mechanical activation of fly ash on properties of geo-polymer. He concluded that Addition of free-water in the reaction mix decreases mechanical properties of the geo-polymer samples. After 28 days, compressive strength of the room temperature cured samples was 16 (2) MPa and 45 (8) MPa for unmilled and mechanically activated fly ash based samples, respectively.

Partha Sarathi Deb, Pradip Nath, Prabir Kumar Sarker had done a brief study on the topic 'The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geo-polymer concrete cured at ambient temperature' and has later published in the journal 'Sci Verse Science Direct' has concluded that Inclusion of GGBFS with class F fly-ash can have a significant effect on the setting and strength development of geo-polymer. Parha et al, found increase in strength and some decrease in the workability were observed in geo-polymer concretes with higher GGBFS. Similar to OPC concrete, development of tensile strength correlated well with the compressive strength of ambient-cured geopolymer concrete

Talakokula V; Singh, R; Vysakh, K carried out a research experiment on 'Effect of time delay & duration of Steam Curing on Compressive Strength & Micro-structure of Geo-polymer Concrete' in the journal 'Advances in Structured Engineering' concluded that FA based geo-polymer specimens has greater compressive strength for steam curing of 3 hrs followed by 2 hrs delay at 100°C compared to steam curing of 18 hrs followed by 2 hrs delay. Increase in curing time causes breaking of FA particles.

Andreu Gonzalez Coromina and Miren Etexberri carried out a research experiment on ‘Steam Curing Effect on the Properties of Fly Ash High Performance Recycled Aggregates Concrete’ in the journal ‘Sustainable Construction Materials and Technologies’ concluded that Result was Lower quality RCAs decreased the mechanical and durability behavior of HPC. However, the properties of RAC had higher long-term improvements than those from NAC due to the influence of fly ash.. Despite steam curing produced higher early-age compressive strength, it had long-term negative effects. Nevertheless, RACs were less affected by long term effects of steam curing

Mengyuan Li, Qiang Wang, & Jun Yang, published a research paper in the journal ‘Advances in Material Science & Engineering’ found that Performance of concrete containing
Fly Ash can be achieved by improving the temperature. Hydration degree is temperature controlled between 60°C-90°C.Form removal strength is best at 80°C steam curing.

Wonsuk Jung1 and Se-Jin Choi2 have done a experimental study on the topic ‘Effect of High-Temperature Curing Methods on the Compressive Strength Development of Concrete Containing High Volumes of Ground Granulated Blast-Furnace Slag. Published in the journal’. Advances in Materials Science & Engineering’ had given results that GGBS was used to replace Portland cement at a replacement ratio of 60% by binder mass. Wonsuk et al found there might be optimum high-temperature curing conditions for preparing a concrete containing high volumes of GGBS, and incorporating GGBS into precast concrete mixes can be a very effective tool in increasing the applicability of this by-product.

Yukihiko Nagao, Koji Suzuki has done an experimental study on the topic ‘Basic Properties and utilization of steam cured concrete using granulated blast furnace slag’, under journal named ‘Nippon Steel & Sumitomo Metal Technical’. Author investigates that the precast concrete factories, the ground granulated blast furnace slag has been used concrete products for the purpose of the durability improvement on the resistance of the suppression of alkali silica reaction. The other purposes are the application to the high fluidity concrete reduction of CO2 emission, etc. this paper shows the effect of steam curing and the properties of the strength, the water tightness, the salt diffusivity and the examples of utilization.

Nozomi Nakajima et al has done a research work on topic 'Effect of steam curing on initial strength development of mortar', under journal named 'International Journal of Engineering and Technology'. Author investigates that the steam curing process is being applied to produce concrete to accelerate production cycle. A prediction of initial strength is required to determine optimized production cycle and provide economical mix proportions. As for this, the strength estimate by the Maturity method is being used widely so far. However, this method is pointed that the accuracy of the estimated strength of the concrete which has been steam cured is low. This is one of the problems on the precast concrete production in this study, the relationship between initial strength at early age and effective material age calculated by maturity method and Arrehenius's law was evaluated. As a result, it showed higher estimation accuracy of the Arrehenius's law than the maturity method. However, the accuracy of the prediction was different each condition such as cement type, water-cement ratio and steam curing temperature and material age.

Eugedijuz Juozas et al has done a research work on topic 'Influence of steam curing n high-cyclic behavior of prestressed concrete bridge elements', under journal named 'The Baltic Journal Of Road And Bridge Engineering'. Author investigates that the influence of curing conditions (steam and normal curing) on high-cyclic creep and fatigue of reinforced concrete bridge elements. The present analysis is based on experimental investigation performed by the first author: 46 plain concrete prisms and 13 prestressed concrete beams were subjected to the high-cycle loading (up to four million cycles). A comparative regression analysis of the fatigue strength of compressive concrete, in terms of a number of load cycles for given max stress level (S-N relationship) has been performed. The analysis has shown that curing conditions had no significant effect on the S-N relationship. On average, the steam cured members had from 30 up to 80% larger deformations than the specimens cured under normal conditions. The difference was larger for higher numbers of loading cycles.

Richard R. Merritt et al has done a research work on topic 'Steam curing of Portland cement concrete at atmospheric pressure.' under journal named 'Highway Research Board, Washington, D.C.' Author investigates that the primary reason for using steam in the curing of concrete is to produce a high early strength. This high early strength is very desirable to the manufacturers of precast and prestressed concrete units, which often require expensive forms or stress beds. They want to remove the forms and move the units to storage yards as soon as possible. The minimum time between casting and moving the units is usually governed by the strength of the concrete. Steam curing accelerates the gain in strength at early age, but the uncontrolled use of stress may seriously affect the growth in strength at later ages. The research described in this report was prompted by the need to establish realistic controls and specifications for the steam curing of pre-tensioned, prestressed concrete bridge beams and concrete culvert pipe manufactured in central plants. The complete project encompasses a series of laboratory and field investigation conducted over a period of approximately three years.

Soo-Duck Hwang, Rami Khatib, Hoi Keun Lee, Seung-Hoon Lee, Kamal H. Khayat has done a research on topic ‘Optimization of steam curing regime for high strength, self-consolidating concrete for precast, prestressed concrete application’ under journal named ‘PCI Journal’. This study examined the effects of various steam curing parameters on the early age compressive strength and modulus of elasticity of self-consolidating concrete (SCC). For the 80 MPa (11,600 psi) SCC, the maximum chamber temperature had the most significant effect on both strength and modulus of elasticity, followed by the rate of heating and the length of the preset period. For the 60 MPa (8700 psi) SCC and high –performance concrete, steam curing appeared to provide little additional benefit in terms of early-age strength.

Kadir Guclear et al has done a research work on topic ‘An investigation of steam curing pressure effect on Pozzolan additive autoclaved aerated concrete’ published under journal named ‘TEM JOURNAL’ Author investigated that autoclaved aerated concrete (AAC) is a porous lightweight concrete obtained by adding a pre-forming material to a mixture made of finely pulverized siliceous aggregate and inorganic binder (lime and/or cement) and hardened by steam cure. In this study fly ash was used instead of siliceous aggregate and experiment samples were obtained by adding 3%, 6%, 9% and 12% silica fume to the cement. Samples were cured under 156ºC and 4bars and 177ºC and 8 bars, and were investigated for compressive strength, bulk density and ultrasound pulse velocity to determine their mechanical and physical properties. Microstructure of samples was observed by using SEM and XRD techniques. Samples bulk density values and compressive strengths are changing between 0.6-0.7 kg/dm3 and 2.5-4.4 MPa respectively.

A.G.A Saul has done a research work on topic ‘Principles underlying the steam curing of concrete at atmospheric pressure’ published under journal ‘Magazine of concrete research’. Author concluded that If the temperature gradient concrete after the time of mixing does not exceed a certain value, the concrete gains strength during and after treatment in relation to its maturity approx. Same low as holds for normally cured concrete.

Sven G. Bergstorn has done a research work on topic ‘Curing temperature age AMD strength of concrete’ published under journal ‘Magazine of concrete research’. Author concluded that the protection of concrete from freezing during the initial period after placing and the humidity of the ambient air must be taken into account.

J.M. Plowman has done a research work on topic ‘Maturity and the strength of concrete’ published under journal ‘Magazine of concrete research’. Author concluded that the relationship between concrete and its maturity is examined and the datum temperature for maturity calculations determined.

J.A. Hanson has done a research work on topic ‘Optimum steam curing procedure in precasting plants’ published under journal ‘Journal proceedings’. Author concluded that this steam curing has emphatically demonstrated the adverse effect of delays in the neighborhood of only 1hr.if such early application of steam is required by plant procedure the temperature rise rate should be limited to 20F per hr or less.

Nur yazdani has done a research work on topic ‘Accelerated curing of silica fume concrete’ published under journal ‘Journal proceedings’. Author concluded that steam curing 12-24 hrs in duration can be effectively used for FDOT (Florida Department of transportation) concrete with silica fume.

Ramesh babu C and Manu Santhanam had done a research work on topic Early age properties of high early strength concrete subjected to steam curing’ published under journal Our world in concrete & journal’. Author concluded that the effect of cement composition on the early age compressive strength and water absorption of concrete mixtures subjected to steam curing were evaluated and found there is no reduction in 28days strength of steam cured specimen due to optimum steam curing cycle is used.

Gawatre et al had done a research work on topic ‘Effectiveness of curing compound on concrete’ published under journal ‘IOSR journal of mechanical and civil engineering ’. In this, it compare results of different grade of concrete and curing compounds with various climatic changes and found ,using conventional method increased percentage of GGBS strength will increased but by membrane curing not gain properly.

Ming-Gin Lee had done a research work on topic ‘Preliminary study for strength and freeze and thaw durability of microwave and steam curing concrete.’ published under journal ‘Journal of Materials in Civil Engineering, ASCE ’. Author investigates the effect of steam curing &microwave curing on the strength development and freeze-thaw durability of concrete. Author used two steam-curing treatments, four microwave curing times and four types of concrete mix were used in his study. In his study author conducted to determine the strength development by steam curing and/or microwave heating and to evaluate the strength and durability of these concretes. Two steam-curing temperatures (65 and 75°C) and one curing time (7 h) were used in his investigation. Two combinations of steam-curing cycle were chosen as (1) 65°C and 7 h and (2)75°C and 7h. After the steam-curing cycle and demolding, the concrete samples were cured in water for 17 h. The test results indicated that microwave heating could further increase the early strength of concrete. Author was also observed, Pozzolanic reaction of silica fume, fly ash and blast-furnace slag be further promoted by steam-microwave curing. The strength gain development of concrete appeared to level off after 40 min of microwave curing. Thus, a 40-min microwave heating time appeared to be the optimal curing time.

C.S Poon, S.C.Kou and D.Cha had done a research work on topic ‘Influence of steam curing on hardened properties of recycled aggregate concrete’ published under journal ‘Magazine of Concrete Research ’.Poon et al was investigate in his study, the effects of steam curing on the hardened properties of recycled aggregate concrete. Poon et al in his study, two series of concrete mixtures with water/cement ratios of 0.55 and 0.45 were prepared. Recycled aggregates were used as 0, 20, 50 and 100% by volume replacements of natural coarse aggregate in the concrete mixture by Poon et al. The concrete specimens underwent standard water-curing and steam-curing regimes. Poon et al observed that the strength of concrete decreased as the recycled aggregate content increased. Poon et al observed that, the negative effect of steam curing diminished as the recycled aggregate content increased. & steam curing decreased the drying shrinkage and increased the resistance against chloride ion penetration of the recycled aggregate concrete. The results demonstrate that one of the practical ways to utilize a higher percentage of recycled aggregates in concrete is ‘precasting’ with an initial steam curing stage immediately after casting.

Guangcheng Long, Ahmed Omran & Zhimin He had done a research work on topic ‘Heat damage of steam curing on the surface layer of the concrete’ published under journal

‘Magazine of Concrete Research’. Ahmed et al considered that the quality of concrete cover and the homogeneity of concrete are very important factors for the performance of structural concrete elements in his investigation. Ahmed et al perform a series of experiments is carried out to investigate the excessive heat-damage effect of steam curing on the exposed surface layer of concrete & Measures to prevent heat damage are also proposed in his study. Due to the heat-damage effect caused by elevated temperature, there is a larger gradient distribution in the pore structure and water sorptivity between the exposed surface and the interior of the steam-cured concrete compared to normal-cured concrete. Ahmed et al Use a moisture fabric sheet, which can effectively reduce such damage, which saw in his investigation & also found the heating effect at elevated temperatures during the steam curing period results in excessive deformation of the exposed surface layer of concrete and thus more damage of the microstructure for the exposure surface than for the interior of the concrete.

Turanli et al had done a research work on topic ‘Effects of Different Curing Temperatures and Durations on Some Mechanical properties 0f Steam Cured Concrete’ published under journal ‘ICE Publishing’. Turanli et al investigate the effects of steam curing on some mechanical properties of concrete; compressive and split tension strength, and modulus of elasticity of hardened concrete. For his investigation Turanli et al use three different concrete mixes C30, C40& C50 of W/C 0.48, 0.46, 0.44 respectively were prepared. Three different curing temperatures as 40 °C, 60 °C, and 75 °C, and also two different curing durations as 4h and 8h were applied in the program. After investigation the results of tests revealed that the rate of development in early strength values of steam-cured specimens were relatively higher with respect to their controls as the steam curing temperatures were increased. Turanli also found in his investigation the gain in early strength values became smaller according to the control specimens for higher strength classes of concretes & the rate of improvement in early strength values of steam-cured specimens was also greater according to the controls when the steam curing durations were increased and slight reductions in late strength values of all steam-cured specimens were observed when they were compared with the control specimens.

Asad et al had done a research work on topic ‘Influence of cement & aggregate type on steam cured concrete’ published under journal ‘Magazine of Concrete Research’. Asad et al were explored the effects of aggregate and cement type on the properties of steam-cured concrete. Asad et al for his investigation, Ordinary Portland cement (OPC) and high early strength cement (HESC) were used as binders and recycled and natural aggregates were used as inert mineral filler aggregates in the concrete. Asad et al are found the developed concretes exhibited adequate levels of compressive strength after steam curing. Asad et al also observed that, the depending on the type of coarse and fine aggregates utilized, the concretes incorporating OPC developed 42–72% of their design strength after 1 d; the range was 52–83% for concretes made with HESC. Asad et al after finalize his investigation they conclude, the concretes incorporating HESC and recycled aggregates had lower mechanical strength, the abrasion and skid resistance parameters were superior to the other mixtures, meaning they could be usefully utilized in pavement structures, flooring and slabs. With proper mixture proportioning, adequate strength can be achieved.

Andreu et al had done a research work on topic 'Steam Curing Influence on Fly Ash High-Performance Recycled Concrete' published under journal 'ACI Materials Journal'. Andreu et al for his investigation use, High-performance concrete (HPC) mixtures were produced using 100% coarse recycled concrete aggregates (RCAs) from three different qualities. The concretes were produced using two binders: portland cement and portland cement with 30% of fly ash. For the fly ash mixtures Andreu et al use two different curing methods: conventional and steam curing. Andreu et al completely replace the natural aggregate by recycled concrete aggregate sourced from the same quality HPC. Andreu et al determined that when using lower-quality aggregates, the use of fly ash produced low 1-day compressive strength, with the consequent necessity to use steam curing to fulfill the standard requirements to be used in the production of prestressed elements. Andreu also observed that the steam curing had negative effects on the long-term mechanical properties. But, these effects were attenuated by using RCAs, which maintained their great durability.

Elmo C. HIgginson had done a research work on topic 'Effect of Steam Curing On the Important Properties of Concrete' published under journal 'Journal Of The American Concrete Institute'. Elmo C. HIgginson, investigation were conducted in the Bureau of Reclamation laboratories to determine the effect of steam temperatures from I00 to 160 F, length of steam curing from 6 to 48 hr, and of a I- and 3-hr delay prior to steaming, on the important properties of concrete. Research was also conducted to determine steam curing effect on drying shrinkage, dynamic modulus, weight change to 6 months' age, and modulus of rupture.

Prof. Allan Dawson Ross had done a research work on topic 'Heat Flow in the Steam Curing of Concrete products' published under journal 'Proceedings of the Institution of Civil

Engineers'. He concluded that large concrete blocks achieves maturity more than the small ones, during curing cycle.

2.4 Phase-III Application of Accelerated Curing

1. This method is also used to find out 28 days compressive strength of concrete in 28 hrs. (IS 9013)
2. Accelerated curing is useful in the prefabrication industry where in high early strength enables the removal of formwork within 24 hours.
3. Accelerated curing helps in reducing the cycle time, resulting in the cost saving benefit.
4. Accelerated curing method gives high early age strength is achieved in concrete.

Chapter 3

Materials and Methodology

3.1 General

The materials to be used in the project are cement, fly ash, aggregates, admixture, and water. The methods to be used are curing in pond and accelerated curing by ACT.

3.2 Materials

The materials used in this work are broadly classified as base material, filler material, binders and admixtures. Both inert and reactive materials are used for this study. The various materials used in this work are discussed with their properties and with the test results as follows.

3.2.1 Cement

Ordinary Portland Cement of 53 grade was used in this study which was provided by Ultratech Cements Ltd. The oxide composition limits of OPC are given in Table 3.2.

Table 3.1 Oxide composition limits of OPC (Neville 1995)

Chemical composition	Content in percent
CaO	60-67
SiO2	17-25
Al2O3	3-8
Fe2O3	0.5-6
MgO	0.5-4
Na2O	2-3.5
SO3	2-3.5

Specific gravity value of OPC 53 grade is 3.15 (IS: 12269- 1987). The initial and final setting times of cement were provided by suppllier, and the values are 92 minutes and 440 minutes respectively

3.2.2 Fly ash

The Fly Ash is finely divided residue resulting from the combustion of ground or powdered coal. Fly ash is generally captured from the chimneys of coal-fired power plants; it has pozzolanic properties and is blended with cement for this reason. Fly ash is finely divided residue resulting from the combustion of pulverized coal and transported by the flue gases of boilers by pulverized coal. It was obtained from thermal power station, dried and used. Class F fly ash is designated in ASTM C 618 and originates from anthracite and bituminous coals. It consists mainly of alumina and silica and has a higher loss of ignition (LOI) than Class C fly ash. The class F fly ash was used in this study, the chemical composition of Class F fly ash (ASTM C618) is given in Table 3.2.

Table 3.2 Class F fly ash chemical composition (Neville 1995)

Property	ASTM C618 requiremets
SiO2+Al2O3+Fe2O3	70% (min)
SO3	5% (max)
Moisture content	3% (max)
Loss of ignition	6% (max)

3.2.3 Coarse aggregate

Crushed angular granite stones of maximum particle size 10 mm were used as coarse aggregate, sourced from a quarry in Turbe in Mumbai, India. The materials were collected and cleaned for impurities. The aggregates were tested as per IS: 383- 1970. The specific gravity and fineness modulus of fine aggregate were determined and they were 2.69 and 6.8 respectively.

3.2.4 Fine aggregate

The fine aggregate (FA) taken for this work is the locally available crushed sand sourced from a quarry in Turbe in Mumbai, India. Sand particles passing through IS sieve of 4.75 mm were used in this work. It was tested in the laboratory as per specifications recommended by IS: 383-1970. The specific gravity and fineness modulus of fine aggregate were determined and they were 2.52 and 2.62 respectively.

3.2.5 Chemical admixture

Extreme workability can be produced with the help of superplastcizers. And thus, reduction in water content can be achieved. The increased workability is produced due to electrochemical activity. Superplasticizer molecules and cement particles are oppositely charged and hence they repel each other. This increases the mobility and hence makes concrete to flow. Also superplasticizers enable savings in cement for given strength (Santhakumar 2007). The various superplasticizer of brand names Sikament 5204 NS, Sikaplast 5201 NS and Sikaviscocrete 5210 NS was used in this work and conforming to IS: 9103-1999 and ASTM C- 494 requirements.

3.2.6 Mixing water

Free water encountered in freshly mixed concrete, reacts with the cement powder thus producing hydration, acts as a lubricant to contribute workability to fresh concrete and secures necessary space in the paste for the development of hydration products (Popovics 2002).

Generally, water that is suitable for drinking is satisfactory for use in concrete. Boring water has been used for this project which conformed to IS 456-2000 requirements

3.3 Mix design

Concrete mix design is a step by step procedure to work out the various proportions of ingredients which makes the concrete. Mix design can be defined as the process of selecting suitable ingredients of concrete a determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The mix design depends on the type of structure being built, how the concrete will be mixed and delivered and how it will be placed to form this structure. Design of concrete mix requires complete knowledge of various properties of the materials, the changes in their quantity as per environmental conditions, the impact of properties of plastic concrete and hardened concrete and interrelationship between ingredients. All these make the task of mix design more complex. Table 3.3. shows a mix proportion which is obtained by DOE (Department of environment) method and further evaluated these replacements of fly ash for efficiency factor.

In this experimental work, mix design is done by DOE method. The DOE method was first published in 1975 and then revised in 1988. This method is applicable to concrete for most purposes; including road. The method can be used for concrete containing fly ash. DOE method presently is the standard British method of concrete mix design. The baseline of the grade up to M40 concrete was provided by Navdeep Construction Company, Mumbai, RMC plant and according to the materials and other factors, the final mix was to be designed. The baseline was obtained by DOE method of Mix design and the modifications were done on the basis of the workability and compressive strength tests results of the trials. The ultimate aim was to design various grades of fly ash concrete for finding efficiency factor.

3.4 Methodology

3.4.1 General

Initially, M30 grade concrete is prepared as per the mix proportion. Types and properties of concrete components are gathered by performing various test in the laboratory. The test that are performed are stated as:

1. Fineness of Sand
2. Bulking of Sand
3. Water Absorbtion Test
4. Specific Gravity

3.4.2 Specimen for Normal Curing

A total of 36 cubes were prepared to be tested after normal curing

Sample to be tested after 3 Days curing

<u>Total 12 specimens</u>

3 cube of nominal mix according to the mix proportion.

3 cube of binary mix i.e having cement replacement by fly ash (25%).

3 cube of binary mix i.e having cement replacement by fly ash (30%)

3 cube of binary mix i.e having cement replacement by fly ash (35%)

Sample to be tested after 7 Days curing

<u>Total 12 specimens</u>

3 cube of nominal mix according to the mix proportion.

3 cube of binary mix i.e having cement replacement by fly ash (25%).

3 cube of binary mix i.e having cement replacement by fly ash (30%)

3 cube of binary mix i.e having cement replacement by fly ash (35%)

Sample to be tested after 28 Days curing

<u>Total 12 specimens</u>

3 cube of nominal mix according to the mix proportion.

3 cube of binary mix i.e having cement replacement by fly ash (25%).

3 cube of binary mix i.e having cement replacement by fly ash (30%)

3 cube of binary mix i.e having cement replacement by fly ash (35%)

Figure 3.1 Preparation for the cube for normal curing

3.4.3 Specimen for Accelerated Curing

Total 12 specimens

3 cube of nominal mix according to the mix proportion.

3 cube of binary mix i.e having cement replacement by fly ash (25%).

3 cube of binary mix i.e having cement replacement by fly ash (30%)

3 cube of binary mix i.e having cement replacement by fly ash (35%)

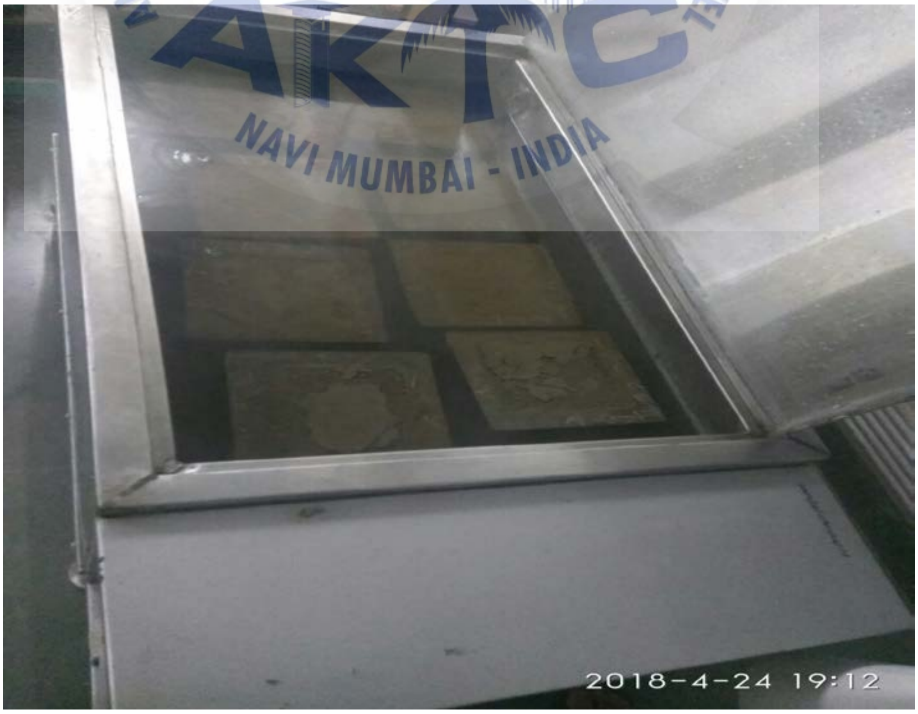

Figure 3.2 Specimen for Accelerated curing tank

3.4.4 Normal Curing

Water curing is carried out by supplying water to the surface of concrete in a way that ensures that it is kept continuously moist.The water used for this purpose should not be more than about 5°C cooler than the concrete surface. Spraying warm concrete with cold water may give rise to 'thermal shock' that may cause or contribute to cracking. Alternate wetting and drying of the concrete must also be avoided as this causes volume changes that may also contribute to surface cracking.

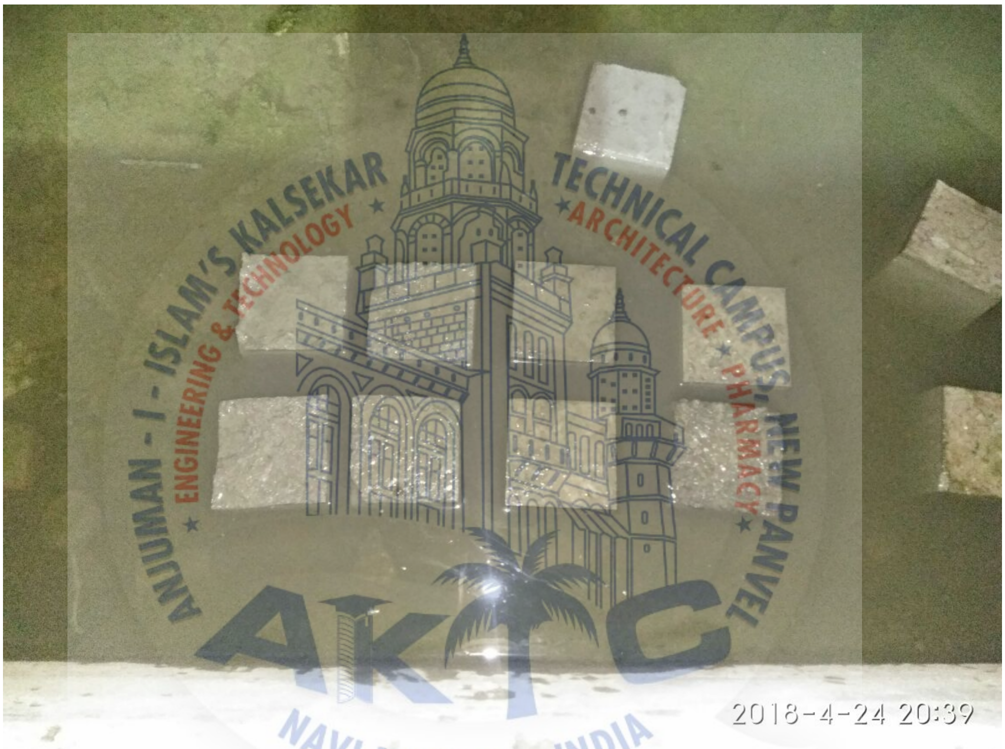

Figure 3.3 Normal Pond Curing

3.4.5 Accelerated Curing by boiling water method (IS 9013:1978)

Accelerated Curing Method is used to get early high compressive strength in concrete. This method is also used to find out 28 days compressive strength of concrete in 28 hours. (As per IS 9013-1978-Method of making, curing and determining compressive strength of accelerated cured concrete test specimens). Accelerated curing is useful in the prefabrication industry wherein high early age strength enables the removal of the formwork within 24 hours thereby reducing the cycle time resulting in cost saving benefits. The most commonly adopted curing techniques are steam curing at atmospheric pressure, warm water curing, boiling water curing and autoclaving.

3.5 Compressive Strength Test using Accelerated Curing Method

1. After the test specimens (whose 28 days strength to be determined) have been made, store it in moist air of at least 90 percent humidity for 23 hours ± 15 min.
2. Cover the specimens with flat steel cover plate to avoid distortion during the use.
3. Carefully and gently lower the specimens into the curing tank and shall remain totally immersed for a period of 3½Hours ± 15 min.
4. The temperature of water in the curing tank shall be at boiling (100 ^{o}C) when the specimens are placed.
5. After curing for 3 ½ hours in boil water, the specimen shall be carefully removed from the boiling water and cooled by immersing in cooling tank at 27 ±2^{o}C for 2 hrs.
6. After cooling remove the specimens from the mould and tested for its accelerated compressive strength (Ra) in N/mm^2.

The 28 days can be found out using following formula.

Predicted 28 days compressive strength (**R28) = 8.09 + 1.64 Ra**, where Ra is accelerated compressive strength and R28 is predicted compressive strength at 28 days.

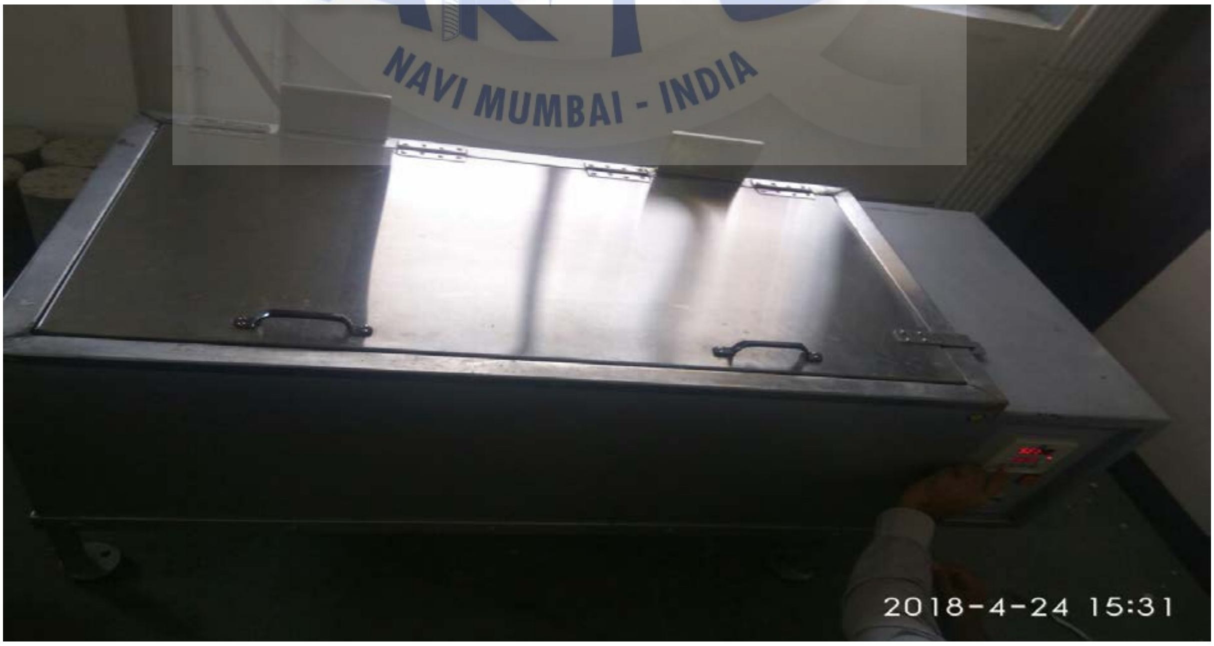

Figure 3.4 Equipment for Boiling Water Method

3.5.1 Accelerated Curing by warm water method (IS 9013:1978)

1. After the specimens have been made, they shall be kept in their moulds in a place free from vibration at a temperature of 27 ± 20C for at least one hour, before immersing in the curing tank.

2.The time between the addition of water to the ingredient and immersion or the test specimens in the curing tank shall be at least one and half hours but shall not exceed three and half hours. The specimens in their moulds shall be gently lowered into the curing tank and shall remain totally immersed at 55 ± 2°C for period of not less than 19 hours 50 minutes.

3. The specimens shall then be removed from the water, marked for identification, removed from the mould and immersed in the cooling tank at 27 ± 2°C before the completion of 20 hours 10 minutes from the start of immersion in the curing tank.

4. They shall remain in the cooling tank for period of not less than one hour. The strength is calculated by formula R28=12.65+Ra.

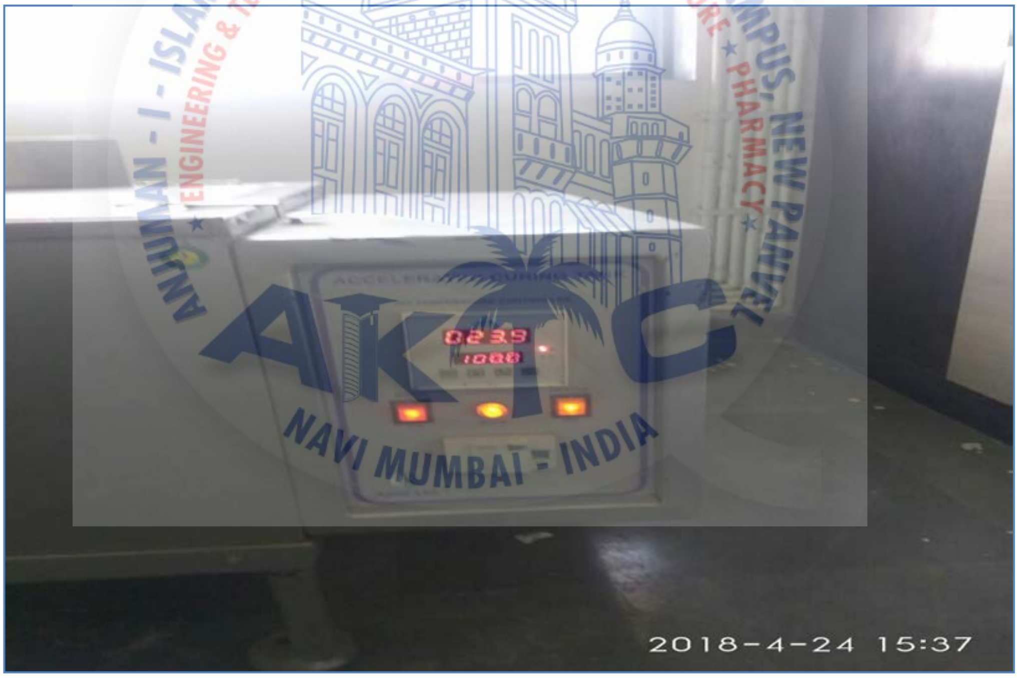

Figure 3.5 Equipment for Warm Water Method

Chapter 4

Results and Discussions

4.1 General

The concrete mix was designed for M30 grade and the mix design was done as per DOE (Department of environment) method. Mix design for concrete was made considering the properties of constituents of concrete. Different concrete mixes with varying fly ash content percentage were produced, replacing 25%, 30%, and 35% cement in terms of weight. Cubic specimens of 150 mm size were casted for compressive strength test and tamping was done as per Indian standard. The cubes were casted in stainless steel moulds and wet cured at standard temperature until the time of test. The cubes were cured for 3 days, 7 days and 28 days

Figure 4.1 Casted Concrete

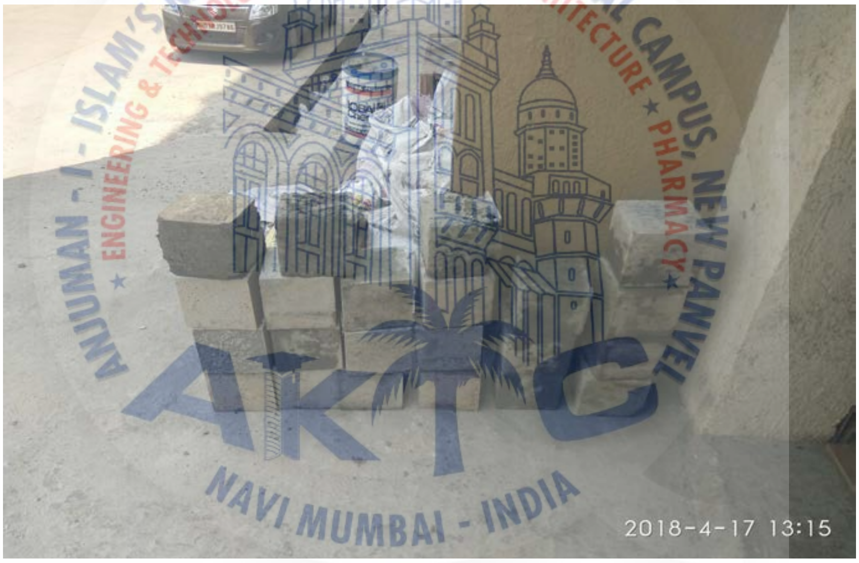

Figure 4.2 Cubes after Normal Curing

4.2 Variation in strength at different replacement level of fly ash

4.2.1 Normal water Curing

The cubes were tested under normal water curing and the results are tabulated below.

4.2.2 Nominal Mix

Table 4.1 Results of Nominal water cured mix

SAMPLE NO.	3 DAYS	7 DAYS	28 DAYS
1.	16.8	43.2	46.6
2.	17.2	36.7	45.7
3.	16.9	39.7	46.2
AVERAGE	**17**	**39.7**	**46.2**

These are the results of nominal mix which was cured under normal curing and also the average of the above was calculated.

4.2.3 Replacement by Fly Ash (25%)

Table 4.2 Results of Binary water cured mix(25%FA)

SAMPLE NO.	3 DAYS	7 DAYS	28 DAYS
1.	14.9	31.4	33.5
2.	18.8	31.4	35.8
3.	21.8	33.5	34.6
AVERAGE	**18.5**	**32.1**	**34.6**

These are the results of binary mix (25% FA) which was cured under normal curing and also the average of the above was calculated.

4.2.4 Replaceent by Fly Ash (30%)

Table 4.3 Results of Binary water cured mix(30%FA)

SAMPLE NO.	3 DAYS	7 DAYS	28 DAYS
1.	24.7	26.8	39.8
2.	25	29	40.7
3.	26.7	31.7	34.9
AVERAGE	**25.5**	**29.2**	**38.5**

These are the results of binary mix (30% FA) which was cured under normal curing and also the average of the above was calculated.

4.2.5 Replacement by Fly Ash (35%)

Table 4.4 Results of Binary water cured mix(35%FA)

SAMPLE NO.	3 DAYS	7 DAYS	28 DAYS
1.	19.3	25.7	32
2.	23.7	28.9	33.5
3.	20	28.7	34
AVERAGE	**21**	**27.8**	**33.2**

These are the results of binary mix (30% FA) which was cured under normal curing and also the average of the above was calculated.

4.2.6 Accelerated Curing (Boiling water method)

The cubes were tested by ACT and the results are tabulated below.

4.2.7 Strength of concrete after test by ACTM

Table 4.5 Results of Binary water cured mix(35%FA)

MIX	Sample 1	Sample 2	Sample 3	Average
Nominal Mix	16.3	20.2	19.0	**18.5**
25% FA	16.7	23.1	22.0	**20.6**
30% FA	20.3	20.7	19.2	**20.0**
35% FA	12.3	14.9	14.6	**13.9**

4.2.8 Strength of concrete by applying formula (IS 9013:2004)

Table 4.6 Results of AC (R28)

MIX	Sample 1	Sample 2	Sample 3	Average
Nominal Mix	34.9	41.2	39.2	**38.43**
25% FA	35.5	46.0	44.1	**41.9**
30% FA	41.4	42.1	39.5	**41.0**
35% FA	28.3	32.5	32.1	**31.0**

R28= 8.09+[1.64 (RA)]

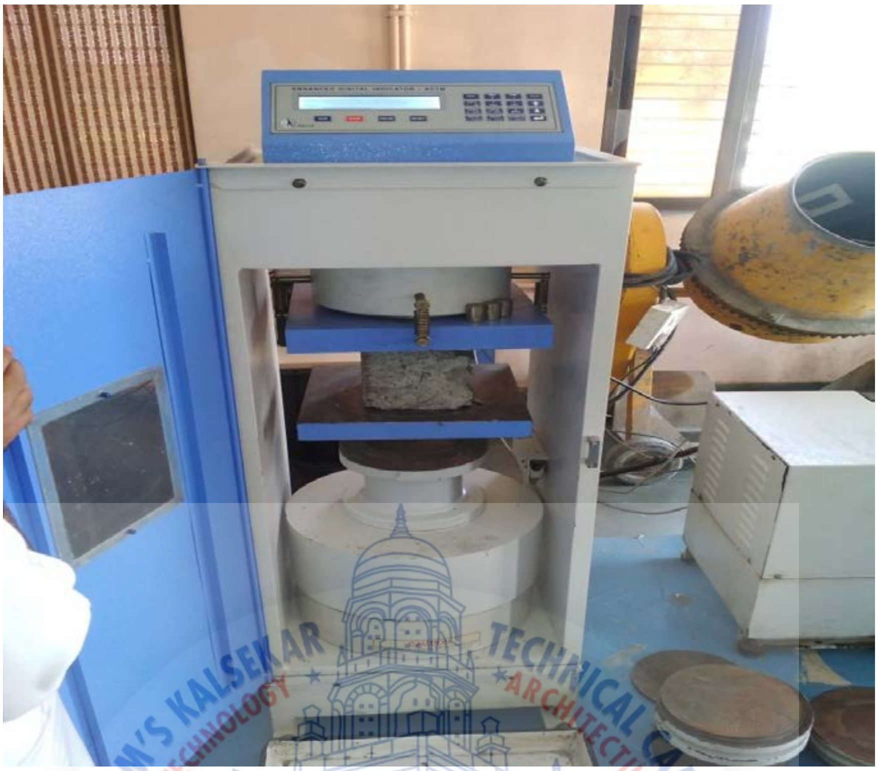

Figure 4.3 Automatic Compression Testing Machine

Chapter 5

Summary and Conclusions

5.1 Summary

This work consists of strength and optimum dosage of fly ash with replacement of cement. The strength of the concrete is assessed by parameters such as compressive test, workability, percentage of replacement of fly ash etc. The optimum percentage of fly ash is studied by comparing the result of the experiment. For normal water curing maximum strength of concrete is achieved after 28 days. For accelerated curing approximate 70% of strength is achieved in 24 hours. This behavior of concrete when cured by accelerated curing of achieving higher early strength helps in removing formwork early. Proportions of various cementitious materials were decided by mix design. Based on the experimental work, the following conclusions are arrived.

5.2 Conclusions

- The optimum dosage of Fly Ash addition was decided as 30% Fly Ash in Cement for M30 grades of Concrete in normal curing and 25% Fly Ash when cured in ACT

- The maximum Compressive Strength obtained at optimum Dosage for normal curing is 40.7Mpa and for accelerated curing is 46.0MPa
- It is concluded that nominal mix concrete cubes have shown better results for water curing than accelerated curing samples.
- 28 Days was considered as Optimum Curing period because maximum strengths were obtained at this period for all proportions of mixes.

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