" EFFECT OF ELEVATED CURING TEMPERATURE ON CONCRETE COMPRESSIVE STRENGTH "

A PROJECT REPORT

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

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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By

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CERTIFICATE

This is to certify that the work which is being presented in the project report **"EFFECT OF ELEVATED CURING TEMPERATURE ON CONCRETE COMPRESSIVE STRENGTH "** in partial fulfillment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **MANISH THAKUR** during a period from July 2015 to June 2016 under the supervision of **Mr. LAV SINGH** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

Generally, concrete mechanical properties are determined under laboratory conditions of ideal air temperatures between 27° ± 2°C as per IS : 516 - 1959. and relative humidity between 40 and 60 percent. In this project work, the effect of high curing temperature on compressive strength of concrete was investigated.

The project shows the effect of curing temperature on compressive strength of concrete for Various grades for different curing age for various temperatures (60°C, and 100°C). These tests describes the development of concrete compressive strength when cured under different temperature conditions. Tests to measure compressive strength are conducted on concrete cured at different temperatures conditions to examine what is their effects on normal concrete. Also, some of the methods for strength prediction are also discussed in this report under the scope of this project.

Keywords :

Compressive strength, Curing, Accelerated curing, Temperature/thermal differential, Strength prediction, etc.

CHAPTER-1

INTRODUCTION

1. 1 BACKGROUND

Standard concrete specimens are usually cured and tested under ideal laboratory conditions at temperature 27° ± 2°C as per IS : 516 - 1959. To date, the information available on the performance on concrete, under high temperature conditions is limited. Therefore, to design a long lasting concrete structure, there is a need for such studies that can be used to estimate concrete mechanical properties such as compressive strength and tensile strength based on the standard condition properties and magnitude of temperature. This would enable the designer to check the factor of safety and the adequacy of the structure to sustain all applied loads safely.

This project will experimentally study the change pattern in one of the mechanical properties of concrete i.e compressive strength, as variation in curing temperature is made for M15, M20 and M25 grades of concrete.

Also, the project will spread some light on various theories for estimation of 28 day compressive strength from early age compressive strength results and some of the regression techniques for the same.

1.2 PROBLEM STATEMENT

In today's construction industry, time is money. To save time, construction practice demands faster concrete strength development. In the precast concrete industry, a pre-caster wants to strip forms as quickly as possible, believing that the benefits of accelerated concrete strength gain overshadow any increase in material costs. Thus, 28-day design compressive strengths are often achieved in 1 day by increasing the curing temperature of the concrete. This increased or elevated curing temperature can generate higher internal member temperatures and the effect of the higher temperature yields concrete that differs substantially from the quality control specimens intended to represent that concrete in the member.

Since the available information on the properties of concrete cured under high curing temperature is limited and the use of precast concrete elements is increasing, the need of understanding the concrete properties cured under high curing temperature is highly magnified.

1.3 IMPORTANCE OF THE PROJECT

Concrete is widely used in various structures that are exposed to continuous variations in temperature and moisture content. The mechanical and physical properties of concrete are more complex than most materials as they are impacted by the environmental conditions when it is poured and cured. It may be either after it has been placed in position (or during the manufacture of concrete products), thereby providing time for the hydration of the cement to occur. Since the hydration of cement does take time (days, and even weeks rather than hours), curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Curing may also encompass the control of temperature since this affects the rate at which cement hydrates.

The mechanical and physical properties of the concrete varies as the curing conditions differs i.e during extreme cold and dry conditions, cool and damp conditions, warm and humid conditions, as well as extreme hot and dry conditions . As a result, in extreme weather conditions such as extreme cold or hot, construction may be delayed until the environment improves unless precautions are taken for concrete curing.

For example, normal concrete can be poured in sub-freezing temperatures if the surfaces are heated and the concrete is covered. Normal concrete can also be poured in hot dry conditions if the surface is wet periodically and covered. However, the main concern is how such a concrete would behave after curing under very high temperature conditions.

Also, wherever there is absence of time and absence of accelerated curing procedures for early estimation of 28 days compressive strength, to maintain quality control some of the prediction methods to predict 28 days compressive strength from early age strength may come handy.

1.4 SIGNIFICANCE OF THE PROJECT

The issues facing engineers in dealing with concrete curing as follows:

i. Curing can be shown to have a marked effect on the hydration of cements. The transfer of this benefit to the performance of concrete structures is more difficult and variable. The particular performance requirements to resist different aggressive situations need to be considered carefully in the light of the potential benefits of curing. It is clear from the available evidence that compressive strength development in structures is one of the properties highly sensitive to curing.

ii. The specification of curing is currently based on vague scientific evidence, and is much influenced by preconception of the requirements and what appears to have been satisfactory previously. The final application of curing measures to real concretes is not taken sufficiently seriously by specifiers or contractors. Part of this problem may be due to a lack of any compliance testing and to contract documentation that makes no provision for penalties in the event of curing not being carried out.

Indian curing specifications and operations are not exceptions to the above description, especially "the specification of curing is currently based on vague scientific evidence," and "Part of this problem may be due to a lack of any compliance testing." This does not mean the specifications need to be more complicated than they are. What needs to be done is to develop simple and straight forward specifications, based on solid engineering evidence, with simple testing procedures conducted during concrete placement that evaluate the compliance with the specification requirements.

In concrete (PCC) structures, the concrete near the surface is subject to the most-severe stresses due to environmental and other loadings. To provide long term (more than 20 years) satisfactory performance of PCC elements with minimal maintenance required, it is vital to provide conditions to sufficiently hydrate concrete near the top surface. The significance of this project is to evaluate the effect of elevated curing temperature on concrete strength and to make recommendations for potential improvements.

1.5 OBJECTIVES OF THE PROJECT

The objectives of this dissertation were as follows:

- To evaluate the effect of curing temperature and curing age on concrete compressive strength . The evaluation only includes compression test.
- To determine the effects on concrete compressive strength of elevated curing temperature of 60° C, on 7,14 and 28 days strength of concrete, using M15, M20 and M25 grades of concrete.
- To determine the propensity of M15, M20 and M25 grades of concrete mix when cured at 60° C .
- To determine the effects on concrete compressive strength of elevated curing temperature of 100° C, on 1,2 and 3 days strength of concrete, using M15, M25

and M25 grades of concrete.

- Plot the findings and conlusion on a graph to clearly show variations.
- Analyze the test results and specify the variations.
- Discuss in brief various compressive strength prediction methods.

1.6 REPORT SCOPE

This project i.e. Effect of elevated curing temperature on concrete compressive strength, is carried out between July 2015 to June 2016. The scope of this project is as following:

i. Chapter 2 gives a little information about curing.

ii. Chapter 3 briefs about some of various studies and theoretical aspects that are related to this project (i.e literature reveiw).

iii. Chapter 4 covers the prerequisites and pre-lab work. It also tells about the project approach and project methodology , describing the plan of action.

iv. Chapter 5 details the experimental testing plan used for this study, including compression strength tests performed on hardened concrete.

v. Chapter 6 includes casting procedures for concrete specimens, mixing procedures and all the lab tests that were carried out under this project.

vi. The data collected from tests is performed is presented in chapter 7.

vii. The data collected and the results found from of data collected from the lab tests shown in Chapter 8. In addition to this, variations in these results are presented in graphical models in this very chapter.

viii. Chapter 9 explains various proposed theories for the prediction of later age concrete compressive strength.

ix. Chapter 10 presents conclusion drawn from the project results and various findings of the project and suggestions that can be beneficial for future work.

x. In Chapter 11, the scope for future work is discussed. This future work can help in refining, redecorating and redesigning of the mathematical model. This will produce much more accurate and reliable mathematical model and will also increase the scope of the project.

The project scope can be summarized as :

i. To determine the propensity and the effects on concrete compressive strength of elevated curing temperature of 60° C, on 7,14 and 28 days strength of concrete, using M15, M20 and M25 grades of concrete.

ii. To determine the propensity and the effects on concrete compressive strength of elevated curing temperature of 100° C, on 1,2 and 3 days strength of concrete, using M15, M25 and M25 grades of concrete.

iii. Plotting the results on the graphs and performing analysis.

iv. Discuss in brief some of the various concrete compressive strength predicting methods.

CHAPTER 2

CURING

2.1 DEFINING CURING

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. It may be either after it has been placed in position (or during the manufacture of concrete products), thereby providing time for the hydration of the cement to occur. Since the hydration of cement does take time (days, and even weeks rather than hours) , curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability.

Curing may also encompass the control of temperature since this affects the rate at which cement hydrates.The curing period may depend on the properties required of the concrete, the purpose for which it is to be used, and the ambient conditions, i.e the temperature and relative humidity of the surrounding atmosphere. Curing is designed primarily to keep the concrete moist, by preventing the loss of moisture from the concrete during the period in which it is gaining strength.

Concrete properties vary considerably depending upon the temperature and humidity that they have been subjected to early on in their life. The standards defines two different curing conditions to be used for specific purposes.

i. **Standard curing:** This condition involves subjecting the specimens to standard temperature and humidity conditions and the strength results are primarily used for concrete acceptance and quality control.

ii. **Field curing:** This condition involves subjecting the specimens to the temperature and humidity that the actual structure experiences and the strength results are primarily used for determining whether a structure is capable of being put in service and scheduling form work removal.

2.2 CURING METHODS

Curing may be applied in a number of ways and the most appropriate means of curing may be dictated by the site or the construction method.

2.2.1 General

Methods of curing concrete fall broadly into the following categories:

i. Curing by preventing excessive loss of moisture from the concrete: either by

a. leaving formwork in place

b. covering the concrete with an impermeable membrane after the formwork has been removed

c. by the application of a suitable chemical curing agent (wax etc)

d. or by a combination of such methods

ii. Those that keep the surface moist and, at the same time, raise the temperature of the concrete, thereby increasing the rate of strength gain. This method is typically used for precast concrete products and is used in this project.

iii. Curing by continuously wetting the exposed surface thereby preventing the loss of moisture from it. Ponding or spraying the surface with water are methods typically employed to this end.

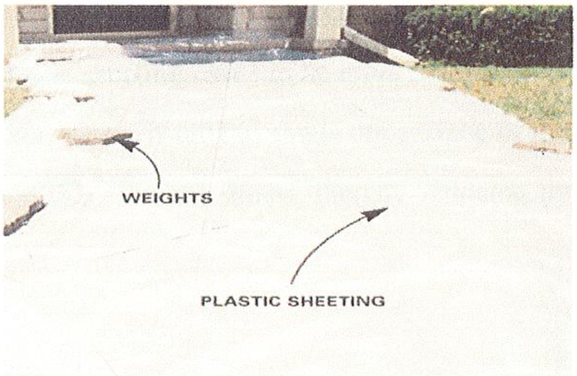
2.2.2 Impermeable-Membrane Curing

_A._ Formwork

Leaving formwork in place is often an efficient and cost-effective method of curing concrete, particularly during its early stages. In very hot dry weather, it may be desirable to moisten timber formwork, to prevent it drying out during the curing period, thereby increasing the length of time for which it remains effective.It is desirable that any exposed surfaces of the concrete (e.g the tops of beams) be covered with plastic sheeting or kept moist by other means. It should be noted that, when vertical formwork is eased from a surface (e.g from a wall surface) its effectiveness as a curing system is significantly reduced.

***B.* Plastic sheeting**

Plastic sheets, or other similar material, form an effective barrier against water loss, provided they are kept securely in place and are protected from damage. Their effectiveness is very much reduced if they are not kept securely in place. The movement of forced droughts under the sheeting must be prevented. They should be placed over the exposed surfaces of the concrete as soon as it is possible to do so without marring the finish. On flat surfaces, such as pavements, they should extend beyond the edges of the slab for some distance, e.g or at least twice the thickness of the slab, or be turned down over the edge of the slab and sealed.For flat work, sheeting should be placed on the surface of the concrete and, as far as practical, all wrinkles smoothed out to minimize the mottling effects (hydration staining), due to uneven curing, which might otherwise occur. Flooding the surface of the slab under the sheet can be a useful way to prevent mottling. Strips of wood, or windrows of sand or earth, should be placed across all edges and joints in the sheeting to prevent wind from lifting it, and also to seal in moisture and minimize drying. For decorative finishes or where colour uniformity of the surface is required sheeting may need to be supported clear of the surface if hydration staining is of concern. This can be achieved with wooden battens or even scaffolding components,



Picture 2.1 : Plastic sheeting

provided that a complete seal can be achieved and maintained.For vertical work, the member should be wrapped with sheeting and taped to limit moisture loss. As with flatwork, where colour of the finished surface is a consideration, the plastic sheeting should be kept clear of the surface to avoid hydration staining.Care must also be taken to prevent the sheeting being torn or otherwise damaged during use. Picture 2.1 illustrates plastic sheeting .

Plastic sheeting may be clear or coloured. Care must be taken that the colour is appropriate for the ambient conditions. For example, white or lightly coloured sheets reflect the rays of the sun and, hence, help to keep concrete relatively cool during hot weather. Black plastic, on the other hand, absorbs heat to a marked extent and may cause unacceptably high concrete temperatures. Its use should be avoided in hot weather, although in cold weather its use may be beneficial in accelerating the rate at which the concrete gains strength.Clear plastic sheeting tends to be more neutral in its effect on temperature (except in hot weather, where it fails to shade the surface of the concrete) but tends to be less durable than the coloured sheets, thereby reducing its potential for re-use.

***C.* Membrane-forming curing compounds**

Curing compounds are liquids which are usually sprayed directly onto concrete surfaces and which then dry to form a relatively impermeable membrane that retards the loss of moisture from the concrete shown in Picture 2.2.

Picture 2.2 : Spraying of curing compounds

D. **Internal curing compounds**

These are incorporated into the concrete as an admixture hence known as internal curing compounds. They inhibit moisture loss and thereby improve long term strength and reduce drying shrinkage. Internal curing compounds are relatively new and care should be taken when utilized. They have been used in tunnel linings and underground mines to provide at least partial curing when traditional methods are difficult or even impossible to employ.

2.2.3 Water Curing

General 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 crazing and cracking.

A. **Ponding**

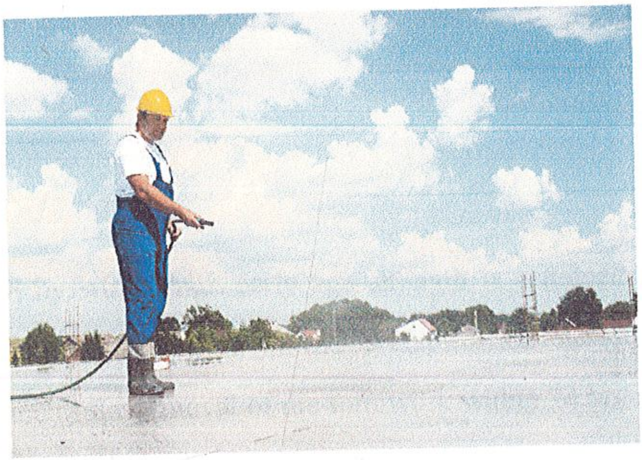
Flat or near-flat surfaces such as floors, pavements, flat roofs and the like may be cured by ponding. A 'dam' or 'dike' is erected around the edge of the slab and water is then added to create a shallow 'pond' as shown in Picture 2.3. Care must be taken to ensure the pond does not empty due to evaporation or leaks. Ponding is a quick, inexpensive and effective form of curing when there is a ready supply of good 'dam' material (e.g. clay soil), a supply of water, and the 'pond' does not interfere with subsequent building operations. It has the

Picture 2.3 : Ponding

added advantage of helping to maintain a uniform temperature on the surface of the slab. There is thus less likelihood of early age thermal cracking in slabs that are cured by water ponding.

***B.* Sprinkling or fog curing**

Using a fine spray or fog of water as shown in Picture 2.4 can be an efficient method of supplying additional moisture for curing and, during hot weather, helps to reduce the temperature of the concrete.



Picture 2.4 : Sprinkling or fog curing

As with other methods of moist curing, it is important that the sprinklers keep the concrete permanently wet. However, the sprinklers do not have to be on permanently; they may be on an intermittent timer. Sprinklers require a major water supply, can be wasteful of water and may need a drainage system to handle run-off. The alternative is to have a 'closed' system where the water is collected and recycled. Sprinkler systems may be affected by windy conditions and supervision is required to see that all of the concrete is being kept moist and that no part of it is being subjected to alternated wetting and drying. This is not easy to achieve.

***C.* Wet coverings**

Fabrics such as hessian, or materials such as sand, can be used like a 'mulch' to maintain water on the surface of the concrete. Picture 2.5 shows wet covering method for the curing of the concrete.

Picture 2.5 : Wet coverings

2.3 ACCELERATED CURING

Accelerated curing is any method by which high early age strength is achieved in concrete. These techniques are especially 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.

Internal concrete temperature is the most important factor affecting early compressive strength of concrete. Temperature is critical to meeting the dual concerns of higher early strength or reduced curing time. Once the proper concrete materials and mix proportions have been selected, pre-stressed concrete element producers can use several different techniques to apply heat. However, it's worthwhile to review the basics of accelerated curing because this production phase affects the cost of curing.

2.3.1 Mechanism

At heightened temperatures, the hydration process moves more rapidly and the formation of the Calcium Silicate Hydrate crystals is more rapid. The formation of the gel and colloid is more rapid and the rate of diffusion of the gel is also higher. However, the reaction being more rapid leaves lesser time for the hydration products to arrange suitably, hence the later age strength or the final compressive strength attained is lower in comparison to normally cured concrete. This has been termed as the crossover effect.

The optimum temperature has been found to be between 65 and 70 °C, beyond which the losses in later age strength have been found to be considerably higher.

2.3.2 Delay Period

Accelerated curing techniques invariably involve high temperatures. This may induce thermal stresses in the concrete. Further, the water in the pores starts to exert pressure at higher temperatures. The combined effect of the pore pressure and thermal stresses causes a tensile stress within the body of the concrete. If the accelerated curing process is begun immediately after the concrete has been poured, then the concrete will not be able to withstand the tensile stresses as it requires time to gain some strength. Moreover, these micro-cracks formed may then lead to the delayed formation of ettringite, which is formed by the transformation of meta-stable mono sulfate. Delayed ettringite formation (DEF) induces expansion in the concrete thereby weakening it. DEF is promoted by the formation of the cracks which enables the easy entry of water. Therefore, a delay period is allowed to elapse before the commencement of the curing process to allow the concrete to gain a certain minimum tensile strength. The setting time of the concrete is an important criterion to determine the delay period. Generally, the delay period is equal to the initial setting time which has been found to give satisfactory results. Lesser delay periods result in compressive strength losses.

2.3.3 Accelerated Curing Methods

High early concrete strengths are most efficiently produced by increasing the internal temperature of the concrete while maintaining a high moisture content in the curing environment. Heating reduces the relative humidity of the air surrounding the concrete. Thus, moisture must be added to the heated air to maintain the same relative humidity of the air. If adequate moisture isn't maintained in the curing environment, the concrete won't develop maximum compressive strength, and cracking may occur. Durability of the concrete may also be reduced due to inadequate hydration of the cementitious material.

Three heating methods are commonly used to accelerate curing:

i. Discharging steam or hot air directly into the curing environment puts the heating medium directly in contact with the concrete .
ii. Enclosing steam or hot water in pipes heats the concrete by convection and radiation.
iii. Attaching electrical resistance wires to the forms and covering them with insulation heats the product by heating the forms.

CHAPTER 3

LITERATURE REVIEW

3.1 INTRODUCTION

This chapter presents a state-of-the-art review of literature on how strength, in concrete are affected by high curing temperatures. In concrete structures, high curing temperatures result from a combination of heat produced by the hydration of concrete and the relatively poor heat dissipation of concrete. Although various measures are implemented to limit the maximum temperatures in concrete, a high core temperature of about 95°C has been recorded in concrete structure cast during the summer. While such concrete meets the specification of maintaining a maximum differential temperature of 20°C between the core and surface of the concrete structure, of major concern is what happens to the strength of concrete when subjected to such high curing temperatures. This chapter reviews how heat is generated in concrete from the hydration of cement. Cracking of concrete due to the heat as well as the micro-structure formed under such high temperature curing is studied. The influence of the micro-structure formed under high curing temperatures on the strength of concrete is presented. A final review is presented on how high curing temperatures makes hardened concrete structures susceptible to damage.

3.2 CEMENT HYDRATION

Several authors have identified five different stages of the hydration process(see figure 3.1).The duration and detailed characteristics of these stages mainly depends on the clinker composition, the particle size distribution, the w/c ratio, the curing temperature, and the mineral and chemical admixtures.

Stage 1 : This stage occurs immediately after contact with water. The rapid reactions, which show the high rate of heat generation, result from ions dissolving in water and reacting between C_3A and gypsum. The formation of ettringite slows down the reaction by creating a diffusion barrier around the C_3A. Some semi stable phase of C-S-H is formed. Most of the time, ettringites are included in this phase, which lasts about 15 to 30 minutes.

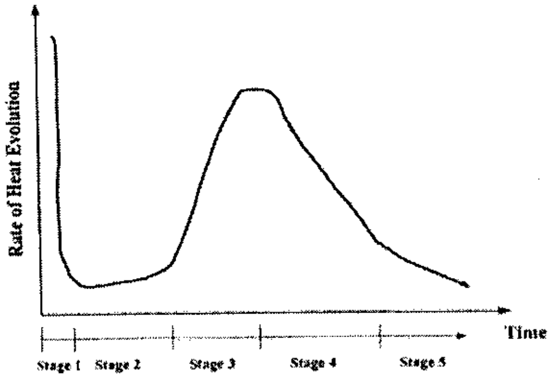


Figure 3.1: Stages of cement hydration

Stage 2: Because the rate of hydration is very small and seems to be stagnant, this phase is known as the dormant period. During this phase, the concentration of ions in the solution gradually increases along with the solution of solid phase. The hydrates made of the main compounds, C_3S and C_2S, are not crystallized yet. This period generally lasts less than 5 hours.

Stage 3: Hydration proceeds actively where the rate of heat generation increases. Induced by the increase of the protection layer permeability and the beginning of C-S-H crystallization, this phase ends the dormant period.

Stage 4: The rate of heat generation gradually slows. In this phase, the thickness of the hydrate layer, which covers unhydrated particles, increases and the surface area of the unhydrated parts decreases. The layer of cement hydrates acts as the diffusion area, which governs the permeability of the water and dissolved ions.

Stage 5: The rate of hydration is remarkably reduced by the thicker layer of hydrates around the particles. Cement hydrates almost completely occupy the space originally filled by the water, making it difficult for hydrates to be precipitated. Stages 4 and 5 are known as the diffusion control phase.

The compounds of Portland cement (see Table 3.1) are non-equilibrium products of high temperature reactions in a high-energy state. When cement is hydrated, the compounds react with water to acquire stable low-energy states, and the process is accompanied by the release of energy in the form of heat. Cement acquires its adhesive property from its reaction with water by forming products, which possess setting, and hardening properties.

Table 3.1 : Major compounds of portland cement

Name of Compound	Oxide Composition	Abbreviation	Mass%
Tricalcium Silicate	$(CaO)_3.SiO_2$	C_3S	45-75
Dicalcium Silicate	$(CaO)_2.SiO_2$	C_2S	7-32
Tricalcium Aluminate	$(CaO)_3.Al_2O_3$	C_3A	0-13
Tetracalcium Aluminoferrite	$(CaO)_4.Al_2O_3Fe_2O_3$	C_4AF	0-18
Gypsum	$CaSO_4$		2-10

The heat generated from the hydration of cement causes a rise in temperature of concrete. If this rise occurred uniformly throughout a given concrete element without any external restraint, the element would expand until the maximum temperature has been reached. The concrete will then cool down with uniform contraction as it loses heat to the ambient atmosphere. This uniform expansion and contraction will result in no thermal stresses within the concrete element. Certain thermal restraints exist in all the of concrete members. These thermal restraints result in external and internal cracking of the concrete. Figure 3.2 shows an example of temperature change,which causes external cracking of large concrete mass. The critical 20°C temperature difference occurs during cooling. In concrete structures, internal restraint occurs from the inability of the heat to dissipate quickly from the core of the member due to the low thermal diffusivity of the concrete.

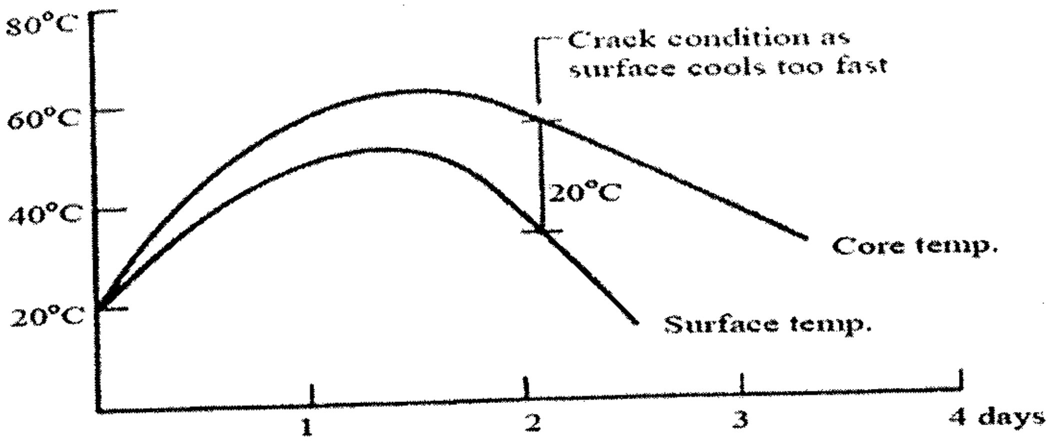


Figure 3.2 : External thermal cracking

Source : Lucy Acquae, Effect of high curing temperatures on the strength, durability and potential of delayed ettringite formation in mass concrete structures[5]

A temperature differential is set up between the core of the concrete and the surface due to the accumulation of the heat from the hydration process. The unequal thermal expansion in the various parts of the concrete member results in stresses, compressive in one part and tensile in the other. Cracking of the surface results when the tensile stresses at the surface of the element due to the expansion of the core exceed the tensile strength of the concrete.The cracking strain of concrete is reached when an internal thermal differential of 20°C is exceeded.

Figure 3.3 shows a pattern of temperature change, which causes internal cracking of a large concrete mass. The critical 20°C temperature is reached during heating but cracks open only when the interior has cooled through a greater temperature range than the exterior.

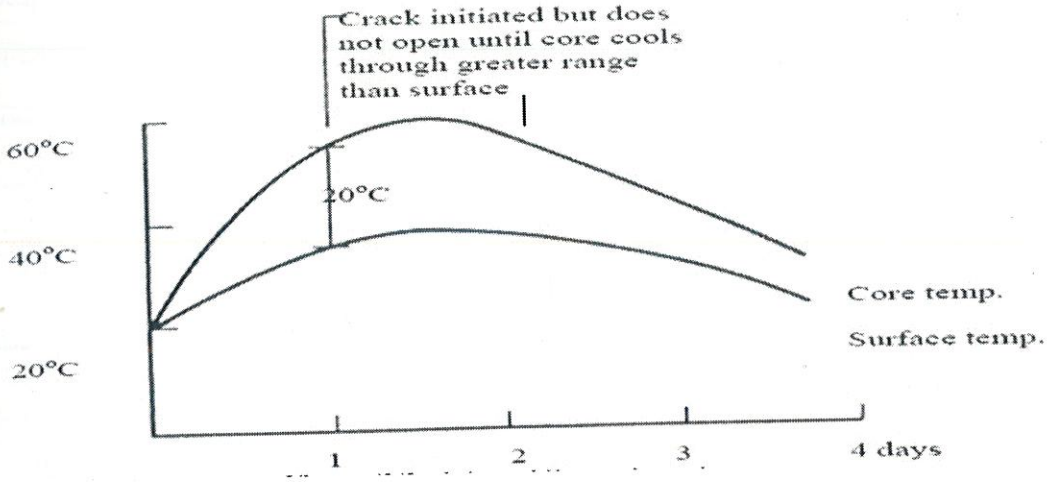


Figure 3.3 : Internal thermal cracking

Source : Lucy Acquae, Effect of high curing temperatures on the strength, durability and potential of delayed ettringite formation in mass concrete structures.[5]

Cracking due to thermal behavior may cause loss of structural integrity and monolithic action or may cause extreme seepage and shorten the service life of the concrete structure. Various measure are undertaken to reduce the temperature rise in large concrete pours. Notable among these measures includes :

i. The prudent selection of a low-heat-generating cement system including pozzolans;
ii. The reduction of the cementitious content;
iii. The careful production control of aggregate gradations and the use of large-size aggregates in efficient mixes with low cement contents;
iv. The pre-cooling of aggregates and mixing water (or the batching of ice in place of mixing water) to make possible a low concrete temperature as placed;
v. The use of air-entraining admixtures and chemical admixtures to improve both the fresh and hardened properties of the concrete;
vi. Dissipating heat from the hardened concrete by circulating cold water through embedded piping;

Despite the application of the above-mentioned measures to control temperature rise in concrete, maximum core temperatures of 95°C have been recorded. Of increasing concern is the effect on the properties of concrete when subjected to such high curing temperatures.

3.3 EFFECT OF CURING TEMPERATURE ON THE MICRO - STRUCTURE OF HYDRATED CEMENT PASTE

The reactions between cement and water is similar to any other chemical reaction, proceeding at a faster rate with increasing temperature. This rapid initial rate of hydration at higher temperatures retards subsequent hydration of the cement producing a non-uniform distribution of the products of hydration within the paste micro-structure.

At high temperatures, there is insufficient time available for the diffusion of the products of hydration away from the cement particles due to the low solubility and diffusivity of the products of hydration. This results in a non-uniform precipitation of the products of hydration within the hardened cement paste. Although a rough approximation, the rate and quantity of heat generation is a function of the following cement parameters:

i. Cement chemical composition
ii. Cement fineness and particle size distribution
iii. Water/cement ratio
iv. Reaction temperature

The results of a calorimetric study on the early hydration of cement had indicated that a heat evolution peak occurs at about 8 to 10 hours after the initialization of the hydration process at normal temperatures. During this period, the cement undergoes very rapid reactions with 20 percent of the cement hydrating over a 2 or 4-hour period. Products of cement hydration have low solubility and diffusivity and at high curing temperatures, the rapid hydration does give sufficient time for the products of hydration to diffuse within the voids. This results in a high concentration of hydration products in a zone immediately surrounding the cement particle. This forms a relatively impermeable rim around the cement particle, which subsequently retards any subsequent hydration. This situation does not occur in normal temperature curing where there is adequate time for the hydration products to diffuse and precipitate relatively uniformly throughout the interstitial space among the cement particles. The coarse pore structure in the interstitial space from the high temperature has a detrimental effect on the strength of Concrete. In the structure of the hydrated cement paste subjected to high temperatures in its early life,it was found that curing at 60°C resulted in a much higher volume of pores larger than 150nm in diameter compared with curing at 27°C. Elevated temperatures results in a non-uniformly distributed hydration products and coarse, interconnected pores. Since strength resides in the solid parts of a material, the presence of voids as a consequence of high curing temperature are detrimental to the strength of the concrete. These large pores make the concrete susceptible to deterioration from harmful substances, which are easily transported through the concrete structure.

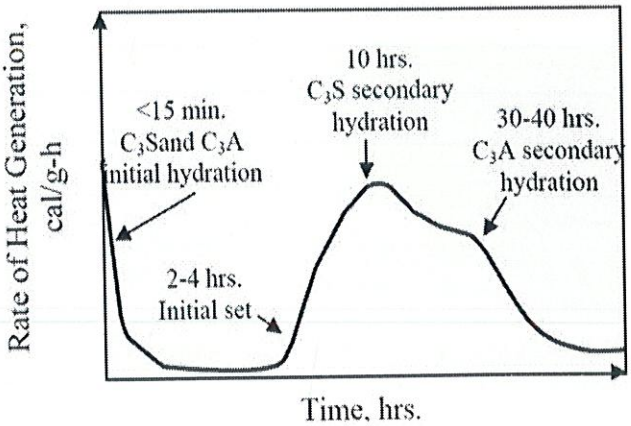
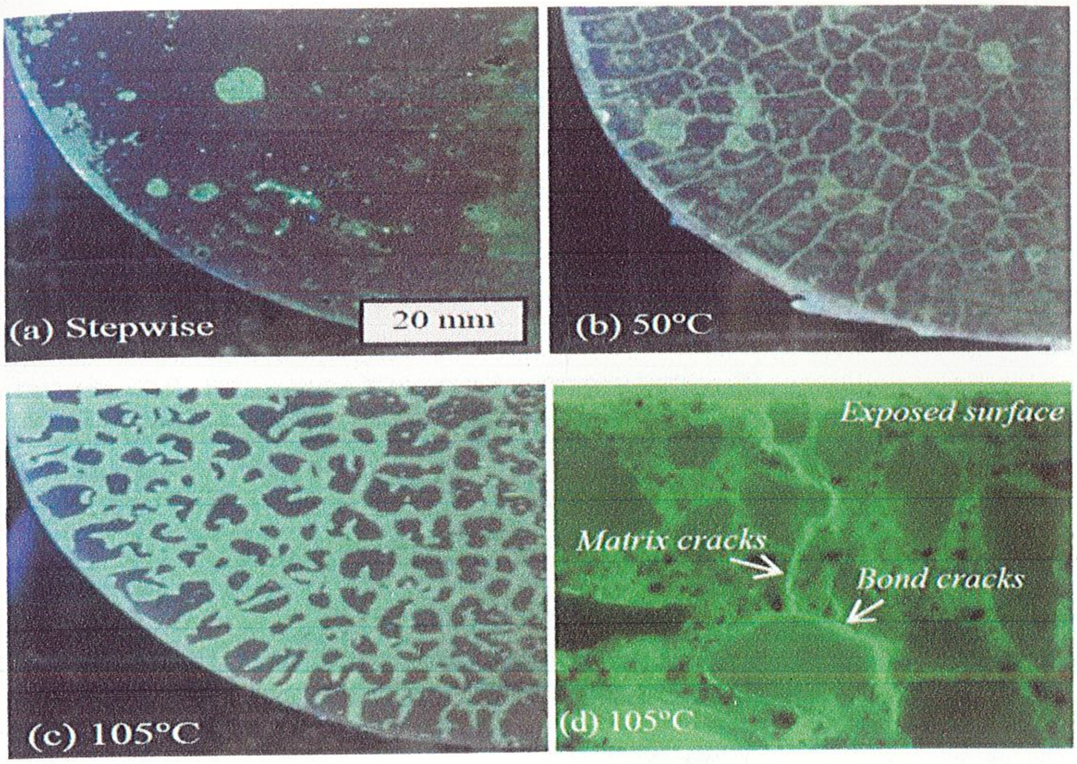


Figure 3.4 : Typical rate of heat evolution



Picture 3.1 : Micro-cracking on the exposed surface of pastes (a-c) and interior of concrete (d) induced by drying.

Source: Z.Wu, M.J.Mac, H.S.Wong, N.R.Buenfeld,Characterisation of microcracks and their influence on transport properties of cementitious materials[4]

3.4 EFFECT OF CURING TEMPERATURE ON THE CONCRETE STRENGTH DEVELOPMENT

The strength of concrete is its ability to resist stress without failure. Strength of concrete is commonly considered its most valuable property. Strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hydrated cement paste. A rise in curing temperature speeds up the hydration process so that the structure of the hydrated cement paste is established early. Although a higher temperature during placing and setting increases the very early strength, it may adversely affect the strength. This is because the rapid initial hydration appears to form products of a poorer physical structure, probably more porous, so that a proportion of the pores will always remain unfilled. Since the voids do not contribute to the strength of concrete, a low temperature with slow hydration will result in a uniform distribution of hydration products within the interstitial space and high strengths at latter ages.

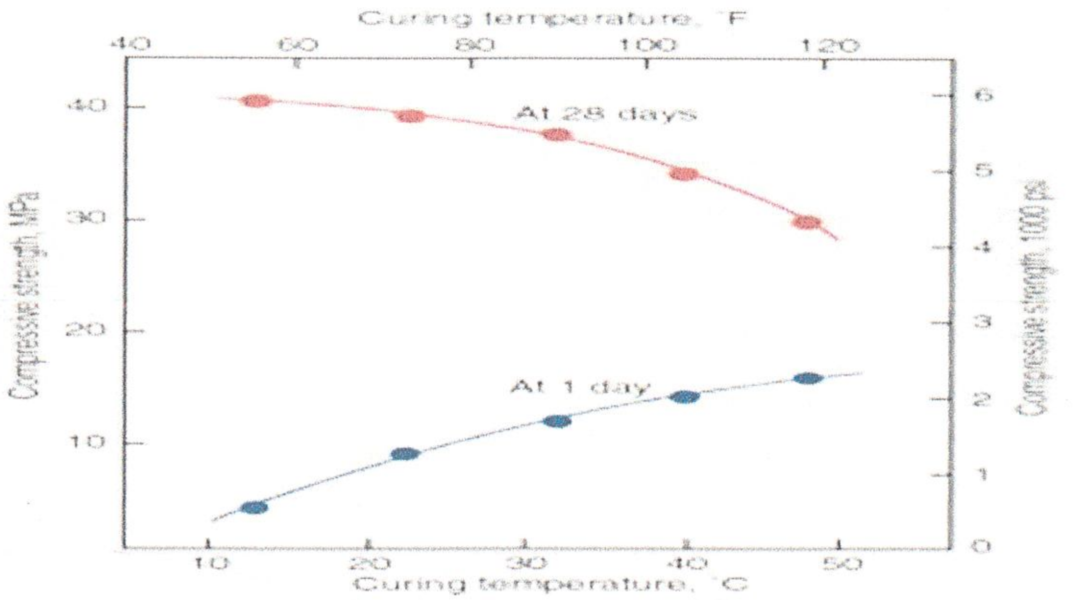


Figure 3.5 : Effect of curing temperature on concrete strength development

Source : Lucy Acquae, Effect of high curing temperatures on the strength, durability and potential of delayed ettringite formation in mass concrete structures.[5]

A fast hydration of cement from high curing temperatures will result in a high early strength due to more hydration products being formed. At later ages however, the retardation in hydration as a result of a dense shell around the hydrating cement grains will result in a more porous structure and reduced strengths as shown in Figure 3.5.

3.5 PREVIOUS STUDIES

Table 3.2 shows some of the important researches and studies carried out for understanding the current subject.

Table 3.2 : Previous studies

S. No.	Author	Study	Inference
1	Usman Ghani, Faisal Shabbir, Kamran Muzaffar Khan	Effect of temperature on different properties of concrete	The high temperature during curing causes an increase in initial compression strength of concrete. The same trend was observed for 3 and 7 days. However an adverse effect on compressive strength was observed due to rising temperature at the age of 28 days.
2	Z.Wu, M.J.Mac, H.S.Wong, N.R.Buenfeld	Characterisation of microcracks and their influence on transport properties of cementitious materials	Microcracks propagation with increase in temperature.
3	A.M. Mustafa Al , H. Kamarudina, M. BinHussainb, I.Khairul Nizarc, Y. Zarinaa, A.R. Rafizaa	The effect of curing temperature on physical and chemical properties of geopolymers	Based on the data from this study, it can be concluded that the optimum curing temperature is 60°C.When cured at high temperature, the samples do not had enough moisture in order to develop better strength.

S. No.	Author	Study	Summary
4	Ali H. Hameed	The effect of curing condition on compressive strength in high strength concrete	The curing temperature increases, the compressive strength increases
5	Lucy Acquae	Effect of high curing temperatures on the strength, durability and potential of delayed ettringite formation in mass concrete structures.	Mentioned Above in the theory
6	Kjellsen, Detwiler (1990)	Dense Shell of Hydration Products	Support the concept that a dense shell of hydration products surrounding the cement grains is formed at higher curing temperatures.
7	Zhi Ge	Predicting temperature and strength development of the field concrete	Gives model for concrete strength prediction
8	M. Monjurul Hasan & Ahsanul Kabir	Prediction of compressive strength of concrete from early age test result	Equation proposed by ACI committee
9	T.R. Neelakantan, S. Ramasundaram, R. Shanmugavel & R. Vinoth	Prediction of 28-day compressive strength of concrete from early strength and accelerated curing parameters	Regression models developed for conduction curing

3.5.1 Some Other Studies

Previous studies indicated that concrete exhibits change in its compressive strength and its modulus of elasticity as environmental conditions change .Lawson et al. indicated that the concrete loses 50 percent of its compressive strength for every 100 °C rise in temperature up to about 200 °C, after which the strength starts to drop significantly. This is also confirmed by the results reported by Phan and Carino who also found that concrete would permanently lose strength if exposed to repeated extreme temperatures.This was attributed to the formation of shrinkage cracks when concrete is exposed to cool damp conditions then exposed to hot dry conditions. Another reason was that the porosity allows moisture to slowly infiltrate the concrete specimen. The water vapor expands faster than it can escape the sample, which creates vapor pressure inside the specimen. When this pressure becomes greater than strength of the concrete sample, the sample will start to crack internally, which may not be visible from the outside of the specimen and the entire specimen may not break for an extended period. This is because as cracks form the moisture is allowed to escape. This in turn puts more pressure on the outer shell of the specimen, which will eventually fail.Carette and Malhotra investigated the effects of sustained high heat on cured concrete properties. The results indicated that concrete strength is continually lost during the period of exposure to high temperature; however most of the strength loss occurs during the first thirty days of exposure. At higher temperatures, the concrete strength is lost faster than at lower temperatures .Lee et al. showed that compressive strength, split tensile strength of concrete, Young's modulus and Poisson's ratio increase as temperature decreases.

A study by Tarkhan (2000) specified a maximum curing temperature of 160°F. A maximum differential temperature of 35°F was specified with mass concrete specifications. 65% of all respondents believed that there is a need for further research into the effects of high curing temperature on concrete properties.

Reasons cited to limit the maximum curing temperature of mass concrete elements included:

i. Avoid reduction of later age strength,
ii. Minimize swelling and shrinkage cracking,
iii. Increase the durability of the concrete and
iv. Decrease the formation of delayed ettringite (DEF) in the hardened concrete and its subsequent damage.

3.7 INFERENCE DRAWN FROM THE LITERATURE REVIEW

Following inference can be drawn from above studies :

i. In concrete structures, high curing temperatures result from a combination of heat produced by the hydration of concrete and the relatively poor heat dissipation of concrete.
ii. Internal restraint occurs from the inability of the heat to dissipate quickly from the core of the member due to the low thermal diffusivity of the concrete.
iii. The cracking strain of concrete is reached when an internal thermal differential of 20°C is exceeded.
iv. Curing temperature has significant effect on the concrete strength development.
v. Curing temperature also significantly effect the micro- structure of the hydrated cement paste.

From the inference drawn from the literature review the base of all of the objectives of this project can be concluded as:

Curing temperature has significant effect on the concrete strength development. Hence, evaluating the effect of elevated curing temperature on concrete compressive strength and propensity of compressive strength of different grades.

CHAPTER 4

PREREQUISITES & PRE -TEST WORK

4.1 INTRODUCTION

Before starting the project work, a proper assessment of different technical and non-technical aspects and tasks associated with that project should be done to identify various needs, requirements and different problems that can originate as the work proceeds. On the bases of this assessment a baseline must be formed. This baseline includes every small thing that will be use in the project. In my case, it includes :

i. Cement,

ii. Sand,

iii. Coarse aggregates,

iv. Mixture proportioning,

v. Size of the test specimen etc.

4.2 EXPERIMENTAL PROGRAMME

The concrete structures laboratory at JUIT, Waknaghta was used to conduct the various experiments. Also, a baseline is needed to establish an experimental design to conduct testing and observations for future development and research. All the baseline concrete material used in this study is shown in table 4.1.

Table 4.1: Experimental baseline

S.No.	Baseline Elements	Type
1	Cement	PPC
2	Sand (Fine aggregates)	Zone2
3	Coarse Aggregates	20mm-4.75mm size

4.2.1 Pozzolanic Portland Cement

PPC cement is used for this whole experimental study. The physical test results on PPC are as follows:

Table 4.2: Physical test results on PPC

S.No.	Physical Test	Apparatus	Result
1	Normal Consistency	Vicat apparatus	35%
2	Initial Setting Time	Vicat apparatus	30 min.
3	Final Setting Time	Vicat apparatus	10 hrs.
4	Specific Gravity	Specific gravity bottle	3.15

Source : Results of laboratory tests performed on available cement by JUIT students

4.2.2 Mixture Proportioning

The mixture proportioning was done according the Indian Standard Recommended Method IS 10262- 1982 to create concrete of different grades .

Table 4.3: Mixture proportioning

S.No	Mix ID	WATER	CEMENT	SAND	COARSE AGGREGATES
1	M15	0.55	1	2	4
2	M20	0.50	1	1.5	3
3	M25	0.45	1	1	2

4.3 FLOW CHART OF LABORATORY WORK

Following diagram shows the flow chart of the lab work.

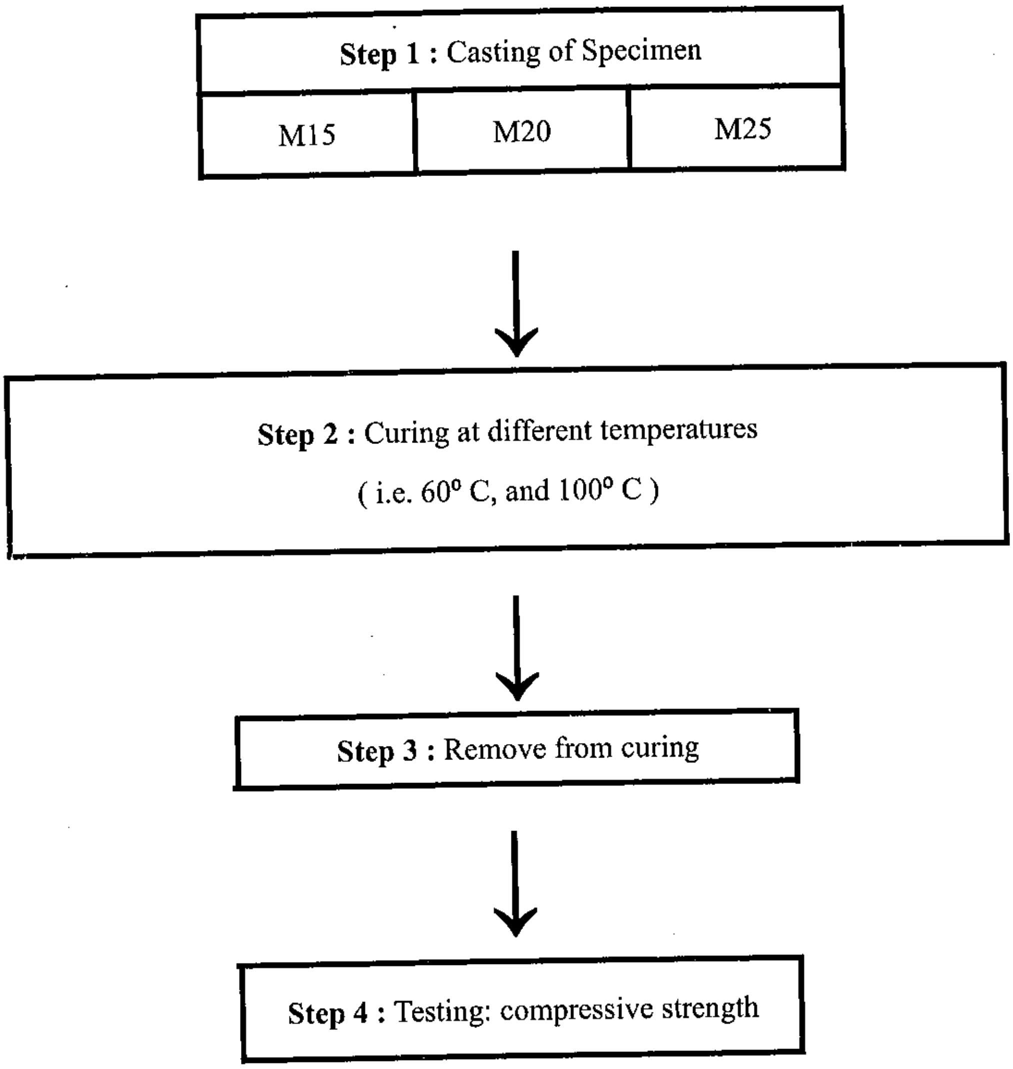


Figure 4.1 : Flow chart of the lab work

CHAPTER 5

EXPERIMENTAL SETUP

5.1 INTRODUCTION

Testing plays an important role in controlling the quality of cement concrete work. Systematic testing of the raw materials, the fresh concrete and the hardened concrete is an inseparable part of any quality control programme for concrete which helps to achieve higher efficiency of the materials used and greater assurance of the performance of the concrete in regard to both strength and durability. The test methods used should be simple, direct and convenient to apply.

In this project tests for compressive strength of concrete are performed conforming to :

IS 516 (1959): Method of Tests for Strength of Concrete

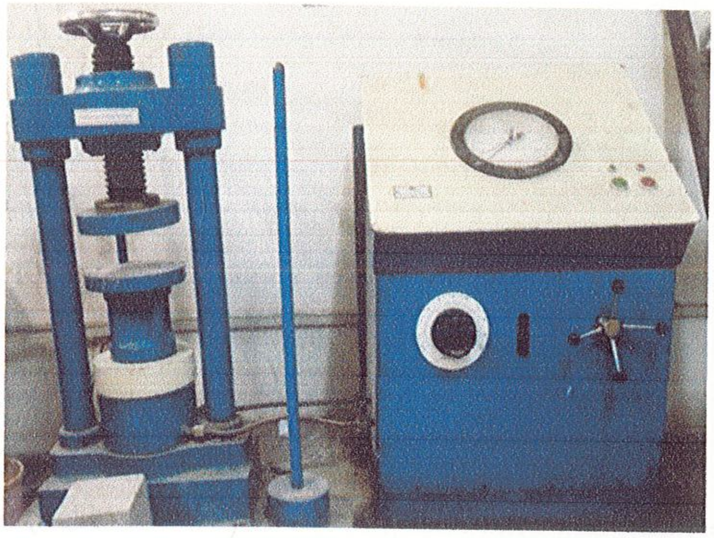
5.2 TEST FOR THE COMPRESSIVE STRENGTH OF CONCRETE

This part of project deals with the procedure for determining the compressive strength of concrete specimens.

5.2.1 Apparatus

A. Compression Testing Machine (CTM):

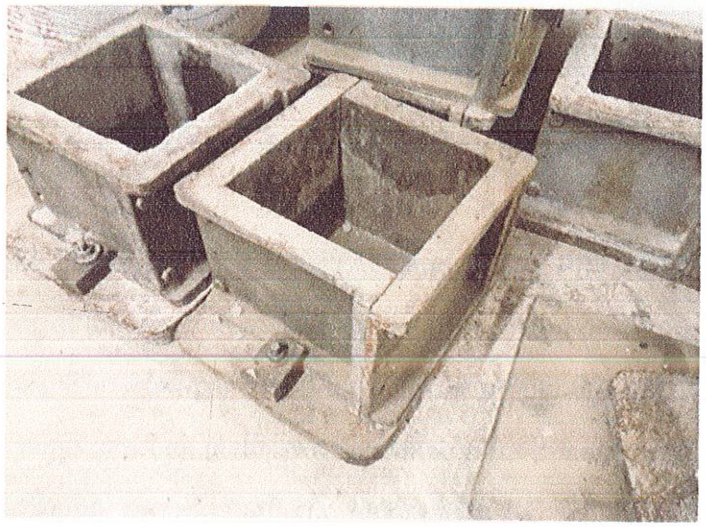
The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the specified rate.The permissible error shall benot greater than ± 2 percent of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied. The bearing surface of the platens. when new, shall not depart from a plane by more than 0·01 mm at any point, and they shall be maintained with a permissible variation limit of 0·02 mm. The movable portion of the spherically seated compression platen shall be held on the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.



Picture 5.1 : CTM

B. Molds Used

150 mm cubes which are prepared according to BS 1881:Part 108:1983 and tested according to BS 1881:Part 116:1983.



Picture 5.2 : Molds used

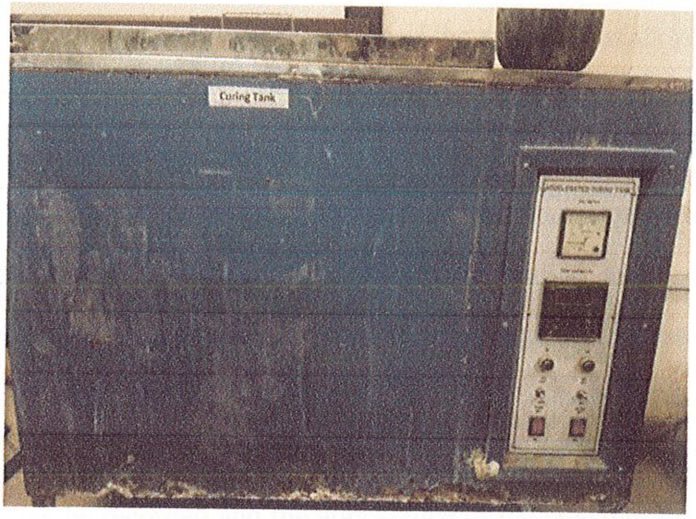
C. Accelerated Curing Tank

Any accelerated curing tank capable of producing and maintaining the required temperatures for the curing of the concrete specimens can be used.

General Descriptions & Specifications :

Accelerated Curing Tank having capacity to accommodate 6/12/18 Concrete Cubes of 150mm size with a facility for accelerated curing by boiling water method up to temperature range : 100 /- 2 deg.C as per IS standard IS : 9013. Also it has capacity for curing by warm water method at temperature 55 /- 2 deg.C

Tank consists of a rectangular double walled metal cabinet, inside lined with stainless steel, outer powder coated. Easily replaceable high Wattage heaters are mounted in side the chamber. A slow speed stirrer is provided to circulate water inside the chamber to maintain the uniform temperature of water. A strong stainless steel perforated platform is provided for keeping the cubes and also have a lid with lifting handle to cover the chamber.



Picture 5.3 : Accelerated curing tank

The temperature is indicated and controlled by a DIGITAL auto tuning PID Temp. Controller with soak timer to control the duration of heating and then to shut down the system without manual attendance. The front panel will have power supply indicating lamp, control action indication lamp and one main switch. Suitable for operation on 220 V, 50 Hz single phase, AC supply or 440 V 50 Hz, three phase AC supply, for bigger size of curing tank.

5.2.2 Procedure:

Specimens stored in water shall be tested immediately on removal from the water and while they are still in the wet condition. Surface water and grit shall be wiped off the specimens and any projecting fins removed. Specimens when received dry shall be kept in water for 24 hours before they are taken for testing. The dimensions of the specimens to the nearest 0.2 mm and their weight shall be noted before testing.

A. Placing the specimen in the testing machine:

The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression platens. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is not to the top and bottom.The axis of the specimen shall be carefully aligned with the center of thrust of the spherically seated platen.No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.As the spherically seated block is brought to bear on the specimen. the movable portion shall be rotated gently by hand so that uniform seating may be obtained. The load shall be applied without shock and Increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.

B. Calculations

The measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area calculated from the mean dimensions of the section and shall be expressed to the nearest kg per sq cm.

5.3 TEST METHODOLOGY

This part of project deals with the sequence of activities carried out for the tests for determining the compressive strength of concrete specimens.

5.3.1 Activities And Their Sequence

Following steps were followed in the given sequence for the test-1 i.e. Compression test on concrete specimens cured at the temperature of 60° C & 100° C.

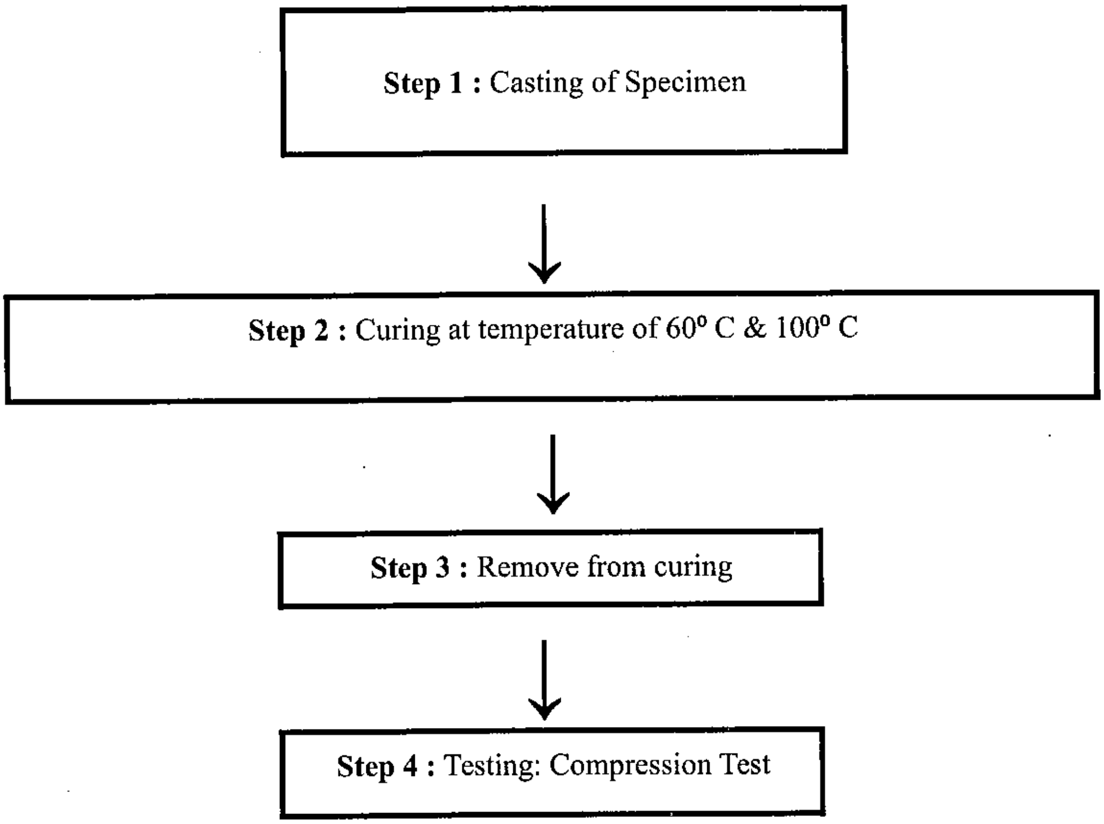


Figure 5.1 : Work sequence

CHAPTER 6

EXPERIMENTAL WORK

6.1 INTRODUCTION

This chapter covers all the part of the project related with the lab work and testings. Starting with the casting of cubes, to their curing in curing tank and ending with the compression test performed on these cubical concrete specimens.

6.2 CASTING OF THE CONCRETE SPECIMENS

A total of 27 cubical concrete specimen were made (i.e. 9 for each of three grades of concrete used namely M15 , M20 and M25) for the first test . Casting was carried out on 3 days. On day 1, nine M15 concrete cubes were made. Day 2 was all about casting nine M20 concrete cubes. Nine M25 cubes were made on day 3. Mix proportion opted for the first test in this project are shown in the table below.

Table 6.1: Mixture proportioning for test 1

S.No	Mix ID	WATER	CEMENT	SAND	COARSE AGGREGATES
1	M15	0.55	1	2	4
2	M20	0.50	1	1.5	3
3	M25	0.45	1	1	2

A total of 12 cubical concrete specimen were made (i.e. 6 for M25 grade of concrete and 6 sample specimen to validate the mix design of M40 and M50) for the second test. Mix proportion opted for the second test in this project are shown in the table 6.2.

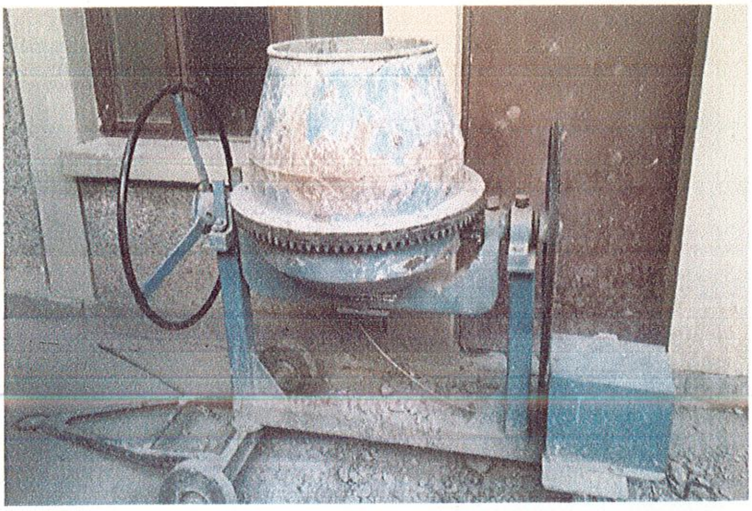
Table 6.2: Mixture proportioning for test 2

Mix ID	SUPER-PLASTICIZER	WATER	CEMENT	SAND	COARSE AGGREGATES
M25	–	0.45	1	1	2
M40	21gm/kg of cement	0.40	1	1.8	3.6
M50	21 gm/kg of cement	0.35	1	1.45	3.15

6.2.1 Mixing

Considering approximately 10 kilograms of concrete for each cube, calculations were performed and individual weights of different materials required for each grade were found.Each material was weighed according to the weights found above for the different grade of concrete on various days .

A concrete mixer was used to make the mix. Before using the mixer for the making of the desired mix grade, a lean mix of cement and sand in the ratio 1: 6 with water was made and rotated in the mixer. This was done in order to avoid adhesion of aggregates to the mixer and maintaining proper water cement ratio for the desired mix. Sand, coarse aggregates and cement were dry mixed first and then the measured amount of



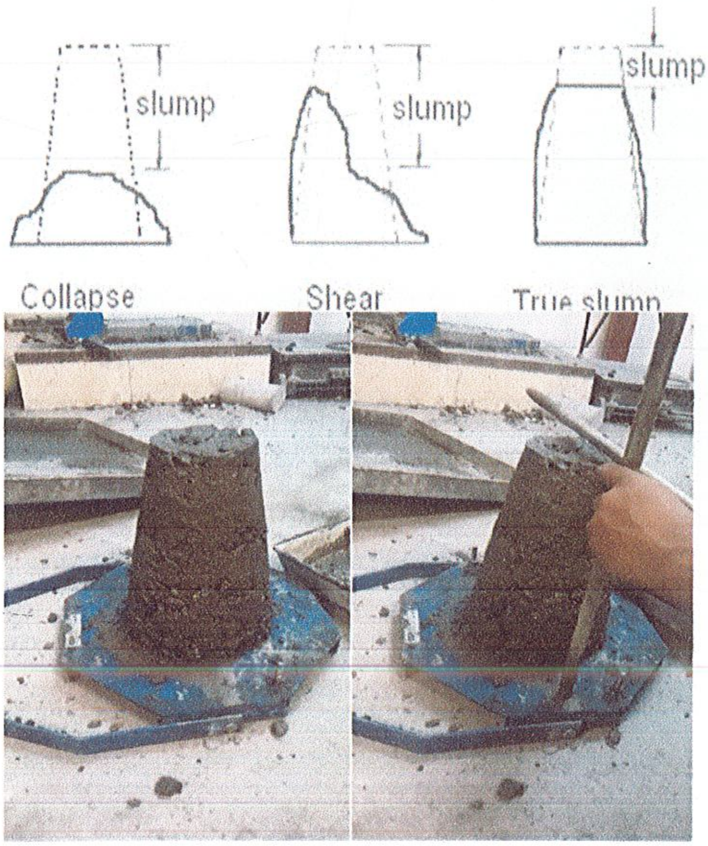
Picture 6.1 : Portable concrete mixer

water was added to them and mix was generated.

6.2.2 The Slump Test

Mix was first tested for the slump value using slump cone test. The slump test is a means of assessing the consistency of fresh concrete. It is used, indirectly, as a means of checking that the correct amount of water has been added to the mix. The mold for the slump test is a frustum of a cone, 300 mm of height. The base is 200 mm (8in) in diameter and it has a smaller opening at the top of 100 mm (4 in).The steel slump cone is placed on a solid, impermeable, level base and filled with the fresh concrete in three equal layers. Each layer is rodded 25 times to ensure compaction. The third layer is finished off level with the top of the cone.

The cone is carefully lifted up, leaving a heap of concrete that settles or 'slumps' slightly. When the cone is removed, the slump may take one of three forms namely Collapse Slump, Shear Slump and True Slump. In a true slump the concrete simply subsides, keeping more or less to shape. In a shear slump the top portion of the concrete shears off and slips sideways. In a collapse slump the concrete collapses completely.

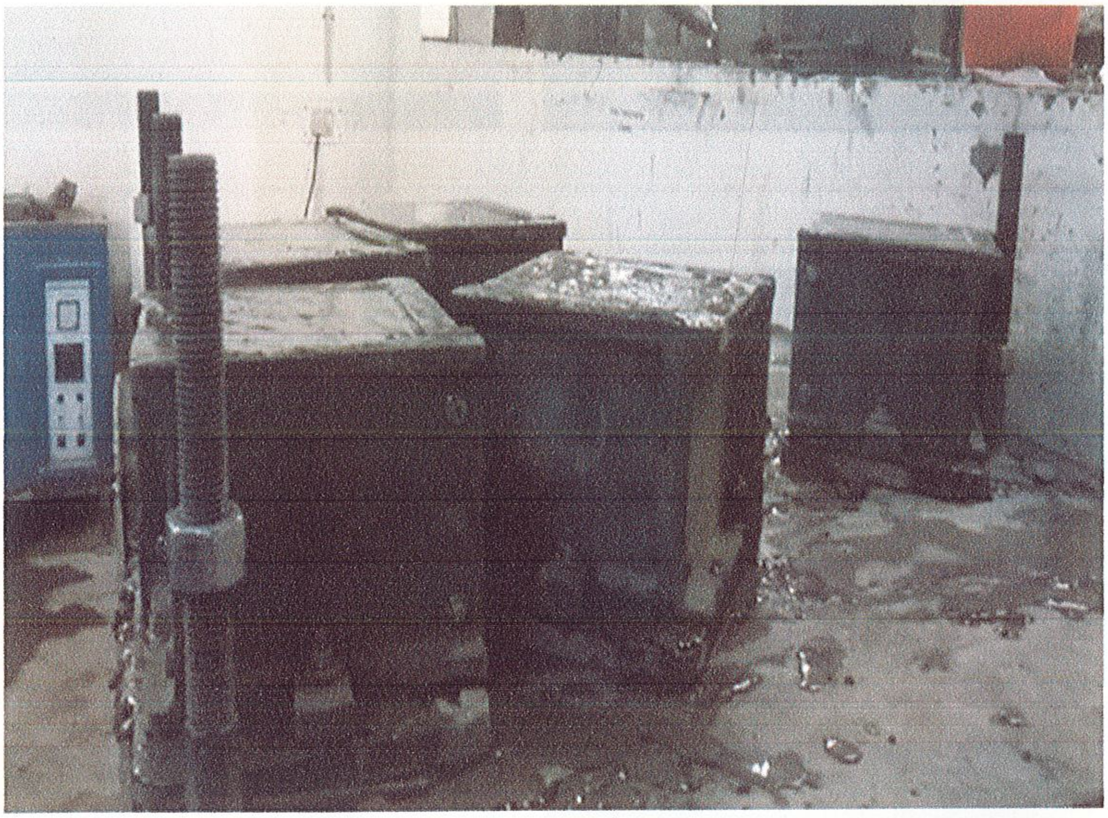


Picture 6.3 : Slump test

Only a true slump is of any use in the test. In our case true slump was found which is perfectly alright .

6.2.3 Compaction

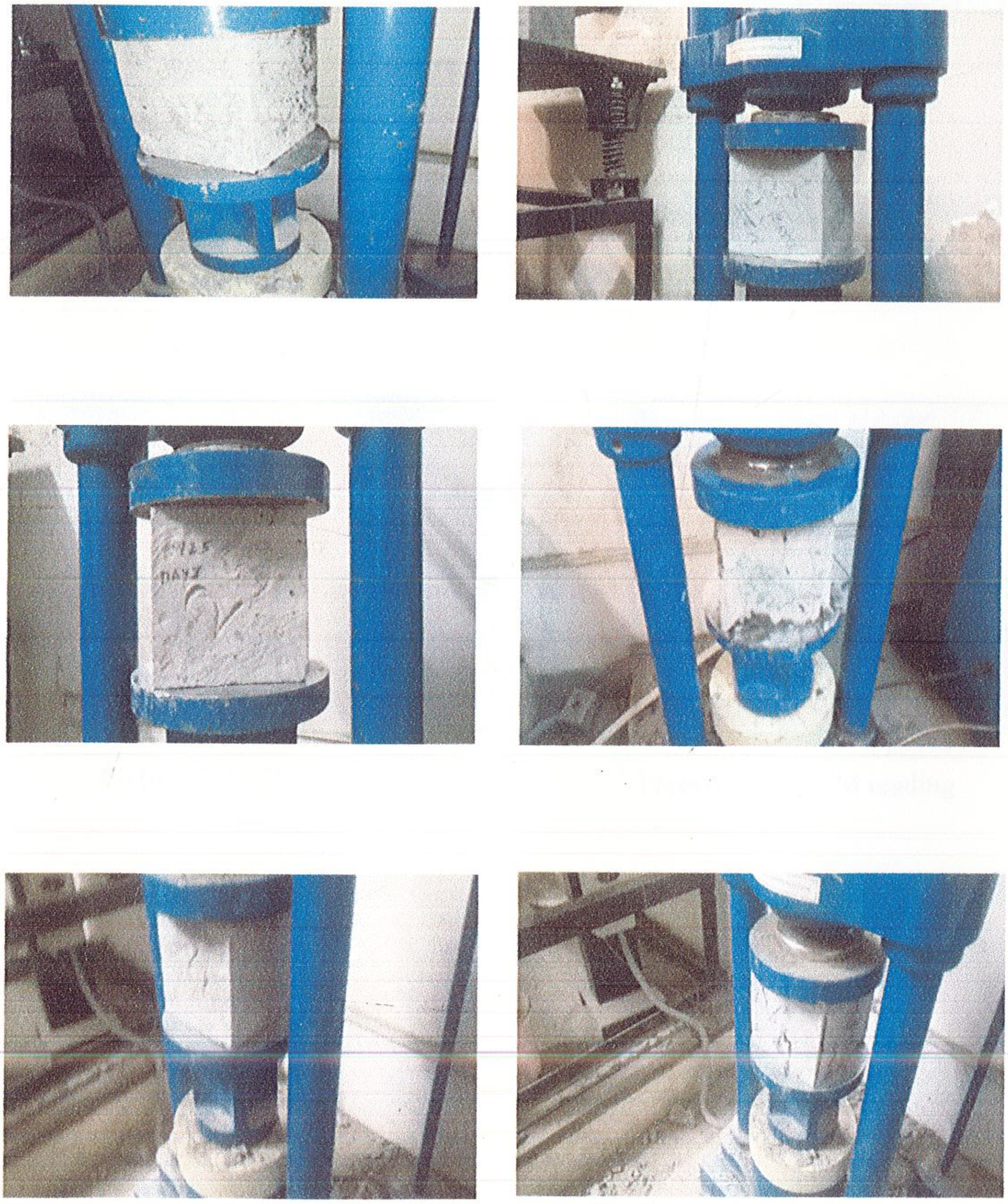
Mix was filled in the properly assembled and oiled molds. A mechanical vibrator was used for the compaction of the concrete in the molds. Concrete was compacted properly in the molds. One day after, these molds were de-molded and the cubical concrete specimens were placed in the curing tank.



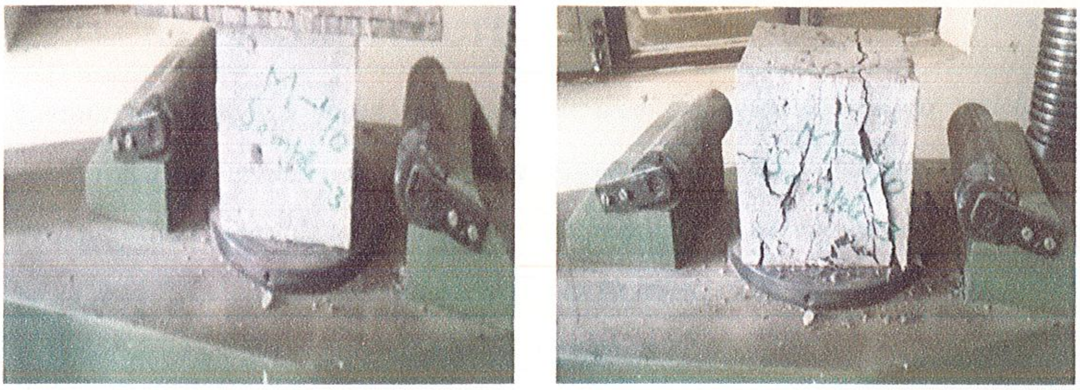
Picture 6.4 : Compaction using vibrators

6.3 COMPRESSION TESTING

Cubes were taken out of the curing tank on the end of their respective days of curing age and were surface dried for 5 minutes. After that a series of compression tests were performed on these accelerated cured concrete specimens on Compression testing machine (CTM).



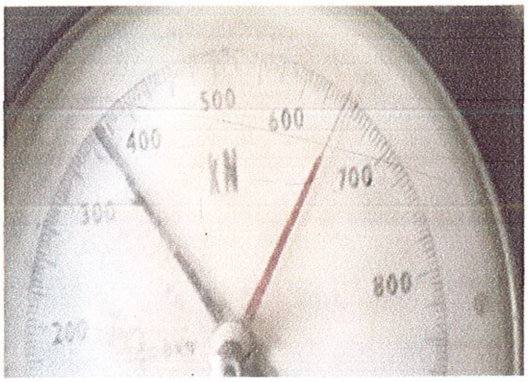
Picture 6.5 : CTM testing



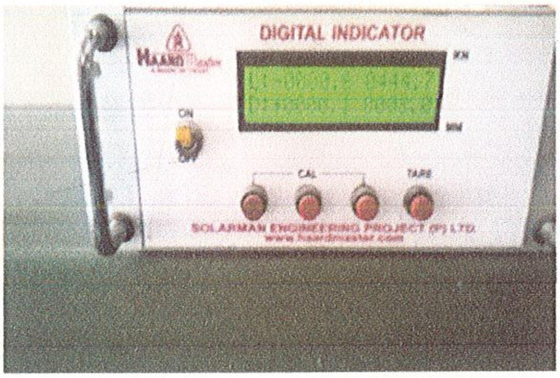
Picture 6.6 : UTM testing

6.4 DATA COLLECTION

Readings were taken for these tests, at the point of sample failure.



Picture 6.7: CTM reading



Picture 6.8 : UTM reading

6.5 TECHNICAL OBSTRUCTION

Certain problem was faced in the accelerated curing tank, due to which the accelerated curing tank was not working properly. Due to this a full curing period of 28 days was not feasible to attain for the specimens which were to be tested at the end of 28 days. Hence, the concrete specimens to be tested at 28 days curing age for the first test were not tested for compressive strength.

Thermostat / Thermo-regulator of the accelerated curing tank was out of work during the period of second part of the project, due to which the accelerated curing tank was not able to attain and maintain the required temperature. Hence project objectives were to be changed to the study of methods for later age concrete compressive strength prediction.

CHAPTER 7

LAB TEST RESULTS

7.1 INTRODUCTION

This chapter presents the data collected from the experimental program described in Chapter 6. The effect of curing temperature on compressive strength three different grades of concrete characteristics was evaluated.

7.2 DATA COLLECTED

The data collected or the readings taken from the CTM for test on various concrete specimen can be shown in the tabular form as below.

Table 7.1 : CTM readings test 1

Test ID	Mix ID	Temperature °C	Compressive Testing Machine Reading (kN)						
			7 days			14 days			28 days
	M15	60 ° C	645	650	650	650	650	650	
	M20	60 ° C	670	665	670	670	675	670	–
1	M25	60 ° C	685	690	685	690	695	695	

Table 7.2 : CTM readings test 2

Mix ID	Temperature °C	Compressive Testing Machine Reading (kN)					
		1 day		2 days		3 days	
M25	100 ° C	460	480	545	550	605	615

7.3 TEST RESULTS

Compressive strength of various test samples is found by dividing the readings from CTM by the area of the concrete specimen. The calculated results are tabulated as below.

Table 7.3 : Calculated Compressive Strength in Mpa for test 1

Test ID	Mix ID	Temperature °C	Compressive Strength (MPa) at						
			7 days			14 days			28 days
1	M15	60 ° C	28.67	28.89	28.89	28.89	28.89	28.89	—
	M20	60 ° C	29.78	29.56	29.78	29.78	30.00	29.78	
	M25	60 ° C	30.44	30.67	30.44	30.67	30.89	30.67	

Table 7.4 : Calculated Compressive Strength in Mpa for test 2

Mix ID	Temperature °C	Compressive Strength (MPa) at					
		1 day		2 days		3 days	
M25	100 ° C	20.44	21.33	24.22	24.44	26.89	27.33

7.3 .1 Average compressive strength

Average compressive strength of these concrete specimen at the specific curing age when accelerated cured is calculated by the formula

$$A = \frac{1}{n} * \sum_{i=1}^{n} Xi \qquad \text{(equation 7.1)}$$

and these values are presented in the tabular form for better understanding and are shown in the table below.

Table 7.5 : Average compressive strength for test 1

Test ID	Mix ID	Temperature	Average Compressive Strength (MPa) at		
			7 days	14 days	28 days
1	M15	60 °C	28.82	28.89	—
	M20	60 °C	29.71	29.85	
	M25	60 °C	30.52	30.74	

Table 7.6 : Average compressive strength for test 2

Mix ID	Temperature °C	Average Compressive Strength (MPa) at		
		1 day	2 days	3 days
M25	100 °C	20.89	24.33	27.11

CHAPTER 8

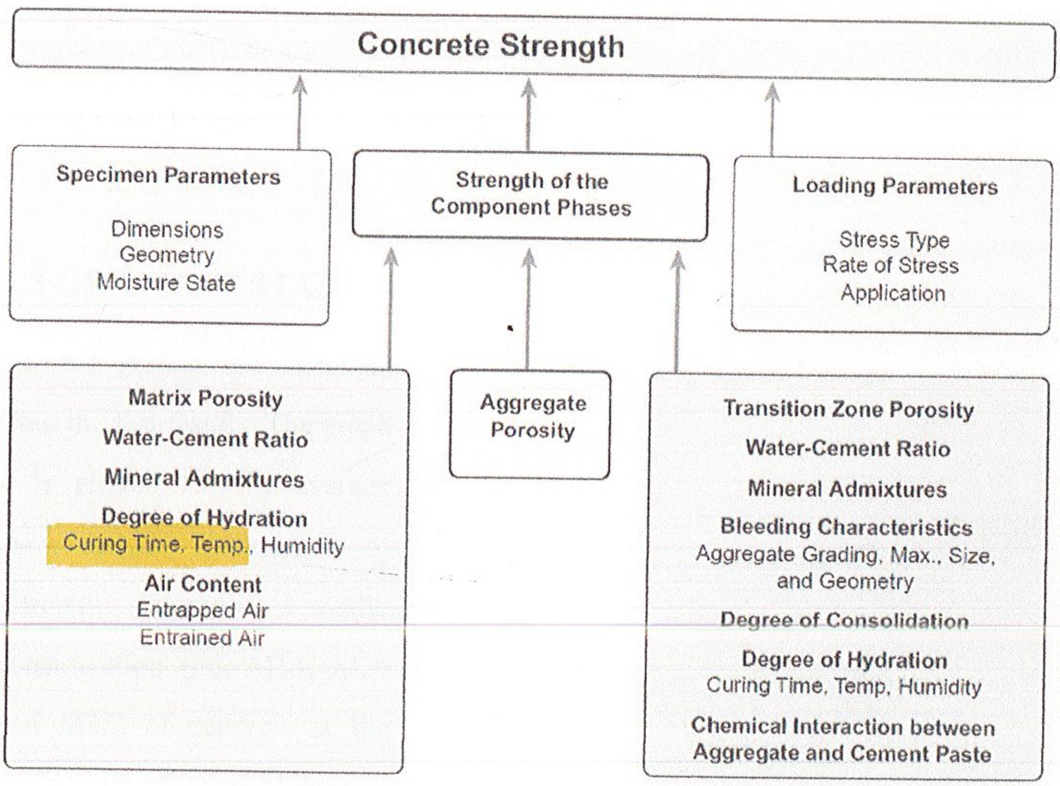
GRAPHICAL REPRESENTATION

8.1 INTRODUCTION

In this chapter firstly various factors affecting the concrete compressive strength are mentioned and then the study parameters are discussed. Various graphs are plotted for these study parameters and analysis performed on the results derived from the lab tests are shown.

8.2 STUDY PARAMETERS

Various factors contributing to concrete strength can be shown as:



Picture 8.1 : Factors contributing to concrete strength

In this project , compressive strengths of three mixes (M 15, M 20 and M 25) of concrete are studied as a function of curing temperature and curing age.

i.e.

Compressive strength = f(curing temperature, curing age)

The curing temperature is varied along three values 60° C, and 100° C and the curing age is also varied.

Concrete compressive strength when studied as function of curing age then variations in its magnitude is practically determined in lab through testing various specimen of different grades under consideration at different curing age as specified in the project, cured at constant temperatures (i.e. 60° C or 100° C).

Concrete compressive strength when studied as function of curing temperature then variations in its magnitude is practically determined in lab through testing various specimen of different grades under consideration at same curing age cured at different temperatures as specified for the project.

8.3 GRAPHS OBTAINED

Various graphs are obtained from the test results. The graph 1 is plotted for the average compressive strength of different grades under consideration (i.e. M15, M20 and M25) of concrete at the curing ages of 7 and 14 days.

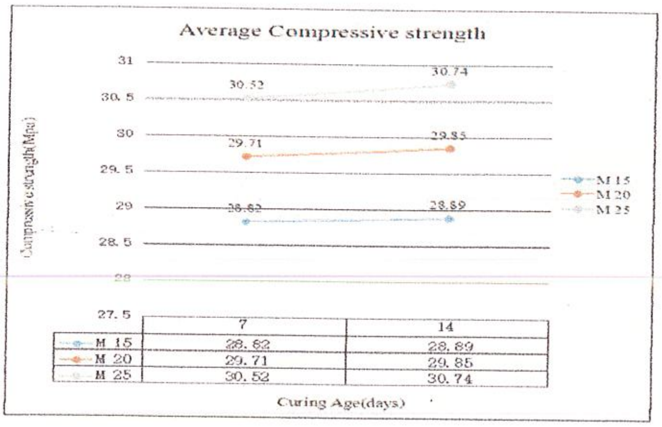


Figure 8.1 : Average compressive strength for M15, M20 and M25 cured at 60°C

The graph 2 shows the three different set of values obtained from the tests for the M15 grade of concrete when cured at the temperature of 60° C for the curing ages of 7 and 14 days.

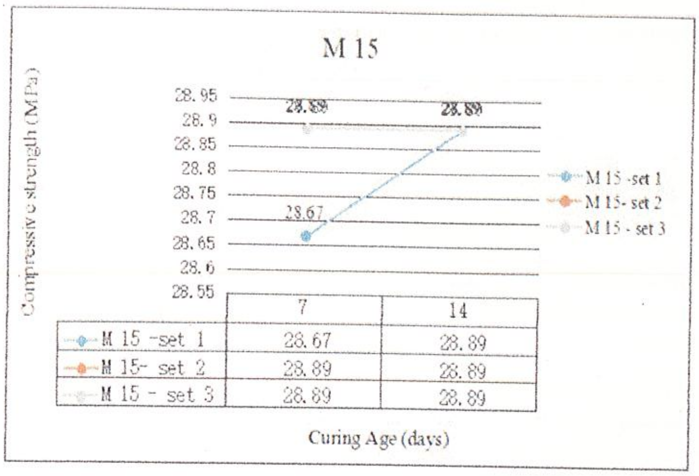


Figure 8.2 : M15 compressive strength variations when cured at 60°C

The graph 3 shows the three different set of values obtained from the tests for the M20 grade of concrete when cured at the temperature of 60° C for the curing ages of 7 and 28 days.

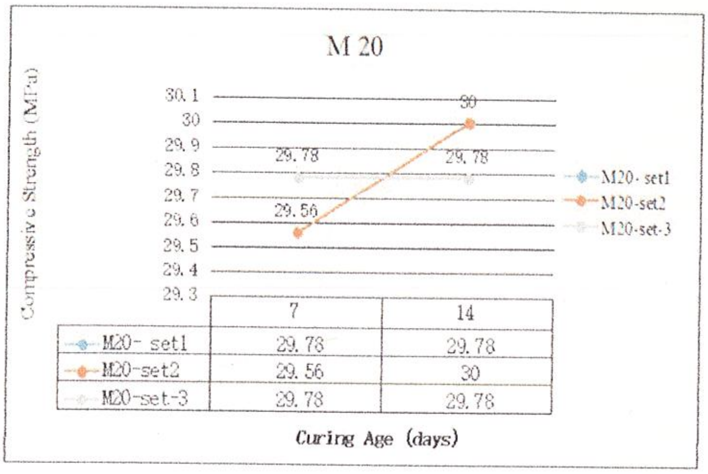


Figure 8.3 : M20 compressive strength variations when cured at 60°C

The graph 4 shows the three different set of values obtained from the tests for the M25 grade of concrete when cured at the temperature of 60° C for the curing ages of 7 and 28 days.

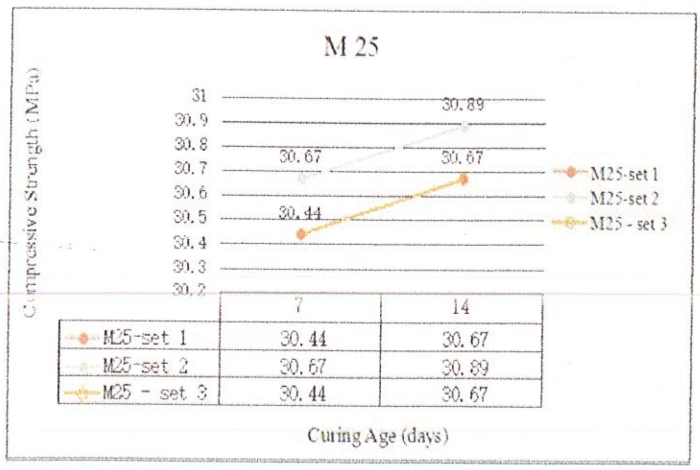


Figure 8.4 : M25 compressive strength variations when cured at 60°C

Now, these sets or set of values for compressive strength of different grades concrete are plotted on same graph and comparision was made.

The graph 5 compares the first set of values obtained from the tests for all three grade of concrete when cured at the temperature of 60° C for the curing ages of 7 and 28 days.

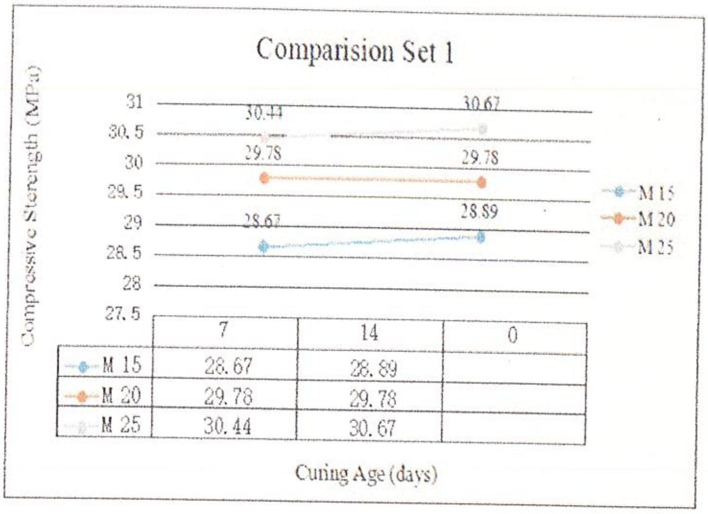


Figure 8.5 : Set-1 compressive strength variations when cured at 60°C

The graph 6 compares the second set of values obtained from the tests for all three grade of concrete when cured at the temperature of 60° C for the curing ages of 7 and 28 days.

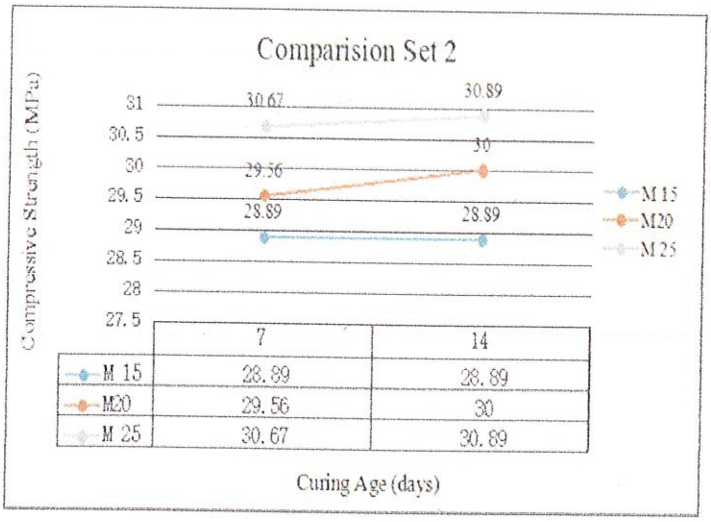


Figure 8.6 : Set-2 compressive strength variations when cured at 60°C

The graph 7 compares the third set of values obtained from the tests for all three grade of concrete when cured at the temperature of 60° C for the curing ages of 7 and 28 days.

This ends the graphical representation of the results obtained from the test one of this project. Below are the graphs obtained from the result derived from the test two of this project.

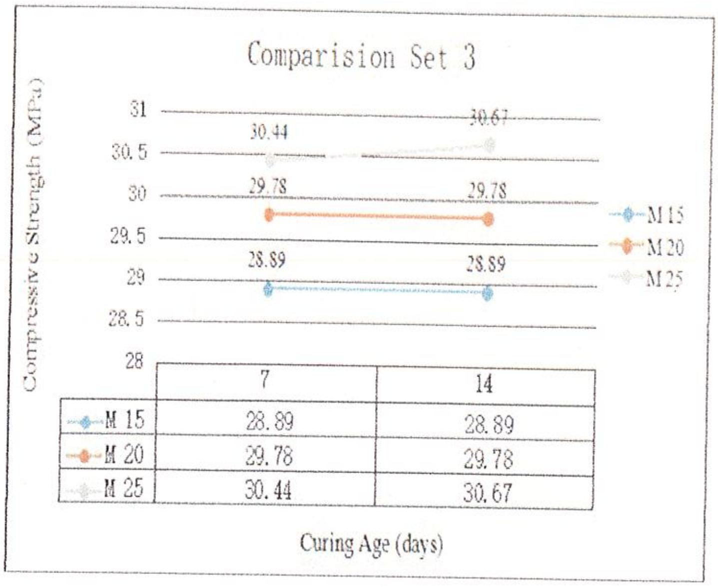


Figure 8.7 : Set-3 compressive strength variations when cured at 60°C

The graph 8 is plotted for the average compressive strength of M25 grade of concrete at the curing ages of 1, 2 and 3days.

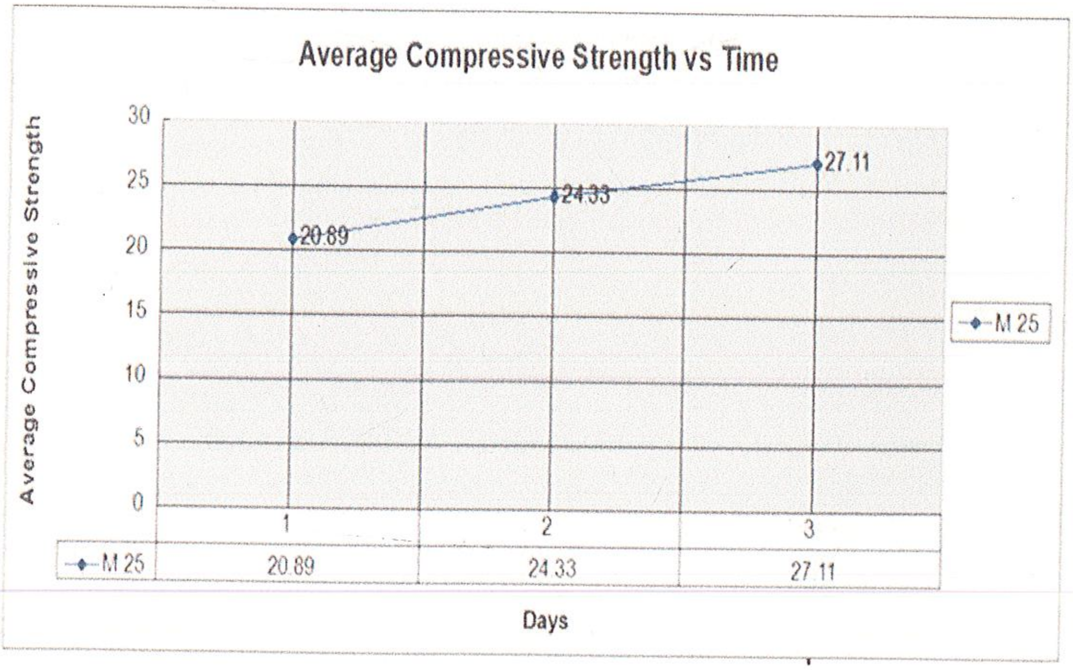


Figure 8.8 : Average compressive strength for M25 when cured at 100°C

The graph 9 shows the two different set of values obtained from the tests for the M25 grade of concrete when cured at the temperature of 100° C for the curing ages of 1, 2 and 3days.

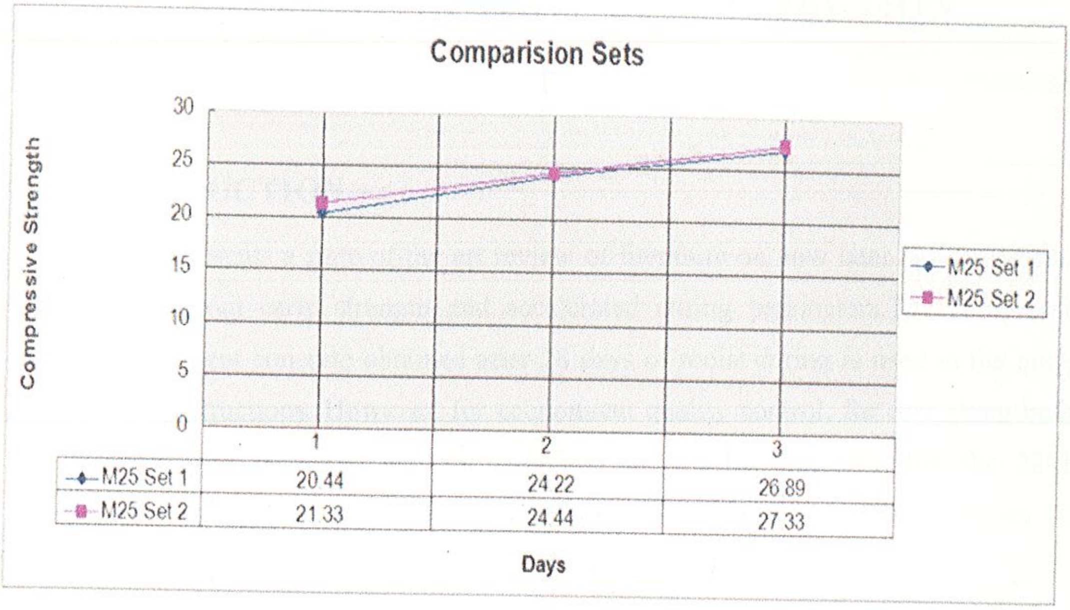


Figure 8.9 : M25 compressive strength variations when cured at 100°C

CHAPTER 9

THEORIES FOR STRENGTH PREDICTION

9.1 INTRODUCTION

This chapter presents a state-of-the-art review of literature on how later age strength can be predicted from early strength and accelerated curing parameters.The compressive strength of cement concrete obtained after 28 days of moist curing is used in the quality control of constructions. However, for economical quality control, for reworking before the concrete gets hardened and for reducing the waiting time, finding the 28-day compressive strength at an earlier time with a reasonable accuracy is necessary. The compressive strength of a concrete can be estimated in lesser time.

9.2 PRIDCTION OF STRENGTH

This can be done by either one of the following methods:

(a) using ACI committee's established regression relationship between some of these characteristics and 28-day strength;

(b)using maturity concept;

(c) finding the early (3 or 7 or 14 day) strength and then finding 28-day strength using the previously established regression relationship between the early strength and 28-day strength;

(d) finding the strength at an early age with accelerated curing then finding 28-day strength using the previously established regression relationship between the early strength with accelerated curing and 28-day strength.

The first method requires very less time while the accuracy is poor. The second method is theoretical and requires much data and references and is much complex. The third method is time consuming while the accuracy is best. Hence, there exist a trade-off between time and accuracy and difficulty to perform. The fourth method is preferred as the time required is less and better accuracy is expected as the concrete is hardened considerably by accelerated curing and it is not that much complex to apply.

9.2.1 ACI Committee's Proposed Model[7]

Proposed by ACI committee (ACI 209-71) for predicting compressive strength at any time.

$$(f'_c)_t = \frac{t}{a+bt}(f'_c)_{28d} \qquad \text{(equation 9.1)}$$

Here a and b are constants, $(f'_c)_{28d}$ = 28-day strength and t is time.

9.2.2 Using Concrete Maturity Concept[6]

As discussed earlier, the cement hydration process depends on the curing temperature and on time. Concrete hydration is the key for other properties. For a given mixture, concrete strength is a function of the time and thermal history. The concept of maturity is introduced to account for the effect of temperature and time on cement hydration and also the development of concrete mechanical properties.

The concept of concrete maturity was developed in the late 1940s and early 1950s. Saul (1951) pointed out that "Concrete of the same mix at the same maturity has approximately the same strength whatever combination of temperature and time to make up that maturity." This is known as the "maturity rule." The maturity function can be expressed as follows:

$$M = \sum_{0}^{t}(T - T_0)\Delta t \qquad \text{(equation 9.2)}$$

Where

M = Maturity at time t (It is also called the temperature-time factor.)

T = Average temperature of the concrete during time interval Δt

To = Datum temperature

This equation has become known as the Nurse-Saul function. A value of -10°C (14°F) has been recommended for the datum temperature in this equation. When a concrete sample was cured under the datum temperature, the cement hydration and strength gain stopped. The datum temperature could be different for different cement and also could be affected by the addition of other substances.

Later the concept of equivalent age was introduced. Equivalent age represents the time at a specified temperature that is required to produce maturity equal to the maturity achieved by a curing period at temperatures different from the specified temperature, which is normally 20°C. They modified the Nurse-Saul maturity function as follows:

$$M = \int_0^t K(T)dt = \int_0^{t_{eq}} K(T_{ref})dt = K(T_{ref})t_{eq}$$

$$t_{eq} = \int_0^t \frac{K(T)}{K(T_{ref})}dt = \int_0^t f(T)dt \qquad \text{(equation 9.3)}$$

Where,

K(T) = Rate constant at temperature T,

$K(T_{ref})$ = Rate constant at the isothermal reference temperature T_{ref}

T_{ref} = Reference temperature, normally 20°C

t_{eq} = Equivalent age

f(T) = Age conversion factor at temperature T

Several expressions have been proposed for the rate constant K(T). Generally, Arrhenius law is used for quantifying the effect of temperature on the early rate of cement hydration.

The expression obtained from this law for the rate constant is given as:

$$K(T) = A\exp(-\frac{E}{RT}) \qquad \text{(equation 9.4)}$$

Where,

A = Constant of proportionality

E = Activation energy (J/mol)

R = Universal gas constant, 8.314 J/(mol K)

T = Absolute reaction temperature (°K)

Based on the Arrhenius law, the equivalent age t_{eq} could be expressed as follows:

$$t_{eq} = \int_0^t \frac{K(T)}{K(T_{ref})} dt = \int_0^t \frac{A\exp(-\frac{E}{R(273+T)})}{A\exp(-\frac{E}{R(273+T_{ref})})} dt$$

$$= \int_0^t \exp(-\frac{E}{R}(\frac{1}{273+T} - \frac{1}{273+T_{ref}}))dt \qquad \text{(equation 9.5)}$$

Above Equation indicates that the age conversion factor f(T) is a non-linear function. The exact value of the age conversion factor at different temperatures depends on the value of E. Proposed values for the activation energy for OPC based on strength tests are given by following relations[6]:

For T > 20°C

E = 33,500 J/mol

For T < 20°C

E = 33,500 + 1,470 (20-T) J/mol

Figure below shows the calculated age conversion factors at different temperatures, using the different activation energy levels of 30, 45, and 60 KJ/mol and the activation energy proposed by above equations. The reference temperature is 20°C. At the reference temperature, all of the values are equal to one regardless of the activation energy. At the highest temperature, the age conversion factor becomes more non-linear with high activation energy. At the lowest temperature, all of the values are smaller than one. The higher the activation energy, the higher the age conversion factor is. Therefore, it is important to select the right activation energy to predict the equivalent age of the specific concrete mixture.

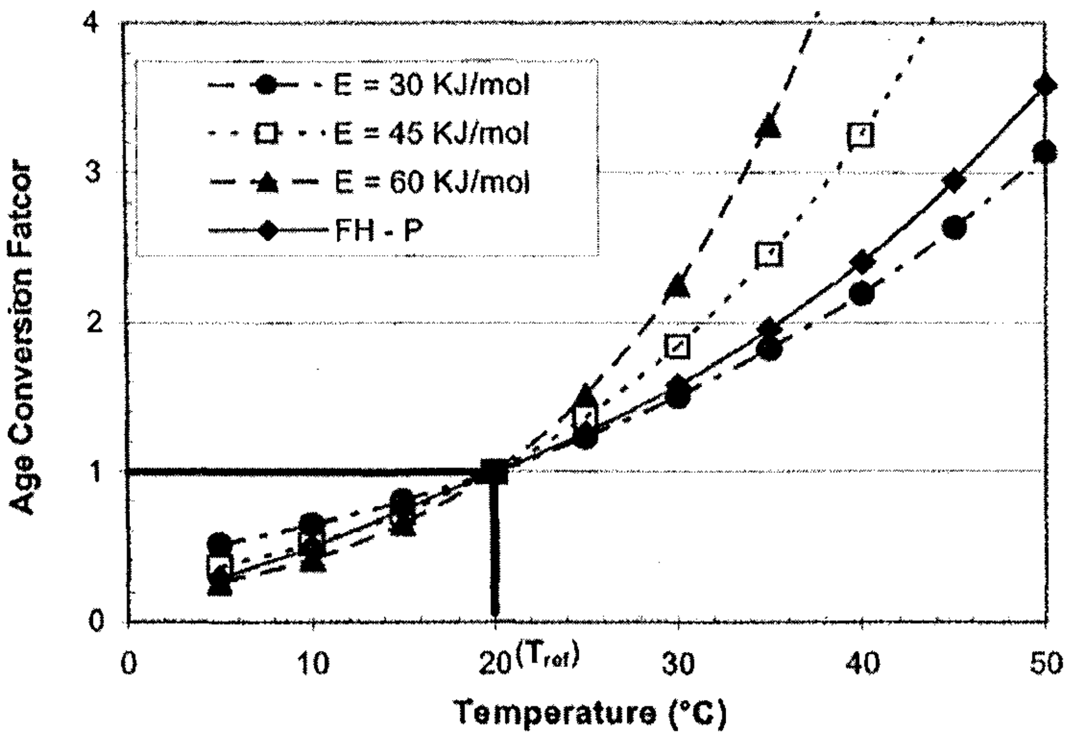


Figure 9.1: Effect of activation energy on the age conversion factor[6]

Now, for the same maturity specimen behaviour can be compared with reference values and compressive strength can be estimated.

9.2.3 From Early Age Strength

Very first step to this approach is to understand the strength gaining pattern of the concrete with age. For this reason strength verses day curve must be plotted for every single set. It was observed that every curve follows a typical pattern. MATLAB curve fitting tool or any other tool with similar function can be used to plot these data and also for the analysis purposes. From the plotted data the best fit curve for each set is drawn. Second step of the study was to determine a general equation of these curves being plotted.

9.2.4 Using Accelerated Curing Parameters[8]

Some of the basic terms used in this methods are:

i. **Delay period (*D*)** is time duration from the casting of a cube to the time subjecting it to the thermal curing. During the delay period, the cube must be kept in moist condition at room temperature which varies diurnally between the range of 25°C and 35°C.

ii. **Thermal curing duration (*T*)** is the time duration during which the cube is subjected to higher temperature above the ambient temperature either by conduction process or by radiation process. In the case of conduction curing, the temperature was maintained in the curing tank through a thermostat attached immersion heater element which had an accuracy of ± 2°C in the range of the temperatures used in the study. In the radiation curing, in place of temperature, the Wattage (*W*) was used as a parameter.

iii. **Early strength (*Se*)** is the strength obtained after undergoing the curing for some time as this is the strength at much earlier than 28 days.

iv. **Discrete temperatures (*t*)** are the different temperature at which the cocrete is cured.

Regression methods and techniques are used to find equations like:

Linear multiple regression equation[8]

$$S_{28} = -0.3974D - 0.1023T - 1.0655t + 1.4697S_e + 27.0110 \quad \text{(equation 9.6)}$$

)

Exponential multiple regression equation[8]

$$S_{28} = 26.8731 * 0.9864^{D} * 0.9965^{T} * 0.9641^{t} * 1.0517^{Se} \quad \text{(equation 9.7)}$$

These equations can be used to determine or predict concrete compressive strength.

CHAPTER- 10

FINDINGS AND CONCLUSION

10.1 INTRODUCTION

This chapter presents various findings and the conclusion drawn from analysis of various results of lab tests and analysis of behaviour and trends of graphs based on those results.

10.2 FINDINGS

From the limited study carried out under this project till now, following points can be concluded :

1. In figure 8.1 it can be seen that, when concrete M15, M20 and M25 are cured at temperature 60° C for 7 and 14 days, then rate of gain of strength for each grade between this duration is almost same. Also there is not much difference in 7th and 14th days average compressive strength for each grade. This implies that strength and strength gain rate has almost approached saturation.

2. Figure 8.2 shows that there is not much difference in 7th and 14th day compressive strength for each set of M15 grade of concrete, which justifies above derived results for average compressive strength. Also, as the results are pretty much same for each set with negligible difference, it can be conclude that quality control was good during the project.

3. Figure 8.3 and figure 8.4 gives the similar trend as explained for figure 8.2 and above stated conclusion can again be derived from these graphs.

4. Figure 8.5 represents the 7th and 14th day compressive strength variation for 1st set of M15, M20 and M25 grades of concrete when concrete M15, M20 and M25 are cured at temperature 60° C for 7 and 14 days. From this it can be concluded that rate of gain of strength for each grade between this duration under given conditions is almost same. Also there is not much difference in 7th and 14th days average compressive strength for each grade. This implies that strength and strength gain rate has almost approached saturation.

5. Figure 8.6 and Figure 8.7 represents the 7th and 14th day compressive strength variation for 2nd and 3rd set of M15, M20 and M25 grades of concrete when concrete M15, M20 and M25 are cured at temperature 60° C for 7 and 14 days. Above statements in point 4 can again be conclude from these figures.

6. Figure 8.8 shows the 1 day, 2 days and 3 days average compressive strength of M 25 grade of concrete when cured at 100° C. Graph shows that majority of strength is gained in the first day of curing. Rate of gain of strength gets highly reduced for second day and again this rate of gain of strength gets reduced for the 3rd day of curing but not by that much difference. So, it can be conclude that most of the gain of strength takes place on ist day of curing and thereafter rate of gain of strength decreases continuously as the saturation in strength gain is approached.

7. Figure 8.9 shows the 1 day, 2 days and 3 days compressive strength of 1st and 2nd set M 25 grade of concrete when cured at 100° C. Graph shows that majority of strength is gained in the first day of curing for both sets. Rate of gain of strength gets highly reduced for second day and again this rate of gain of strength gets reduced for the 3rd day of curing but not by that much difference. Also, nearly same strengths are achieved for respective parameters which represents the similar quality control for each set.

CHAPTER-11

FUTURE WORK

11.1 INTRODUCTION

This chapter defines the work that can be done in the future for further studies.

11.2 FUTURE WORK

The short comings of this project can be rectified and project can be restarted with following goals in order to complete project objectives :

1. Compression test on M15, M20 and M25 concrete mixes cured at 80 ^{o}C at age of 1,2,3,7, 14 and 28 days.

2. Compression test on M15, M20 and M25 concrete mixes cured at 100 ^{o}C at age of 1,2,3,7, 14 and 28 days.

3. Compression test on M40 and M50 concrete mixes cured at 60^{o}C, 80^{o}C and 100 ^{o}C at age of 1,2,3,7, 14 and 28 days.

4. Data can be collected , analyzed and results will be drawn.

5. Results can be plotted on graphs for better understanding of variations and trends in variations.

6. Optimum duration and optimum temperature can be found.

7. Mathematical and graphical model development.

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