EFFECT OF TEMPERATURE ON STRENGTH & STRESS-STRAIN RELATIONSHIP FOR THE HIGHER GRADE OF CONCRETE

A MAJOR PROJECT REPORT

Submitted by

VIVEK KR. SINGH

COLLEGE ROLL NO.: 12/STR/09

DELHI UNIVERSITY ROLL NO.: 9086

in partial fulfilment for the award of the degree

of

MASTER OF ENGINEERING

in

CIVIL ENGINEERING

(STRUCTURAL ENGINEERING)

UNDER THE GUIDANCE OF

Dr. MUNENDRA KUMAR
ASSISTANT PROFESSOR

Mr. S. ANBU KUMAR
ASSISTANT PROFESSOR

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

DELHI COLLEGE OF ENGINEERING

DELHI UNIVERSITY, NEW DELHI

2009-2011

CHAPTER 1

INTRODUCTION

1.1. GENERAL:

In recent years, the construction industry has shown significant interest in the use of high strength concrete (HSC). This is due to the improvements in structural performance, such as high strength and durability that it can provide compared to traditional normal strength concrete (NSC). HSC is being used in many applications such as bridges, offshore structures and infrastructure projects. In recent years, its use has been extended to high rise buildings. Laboratory testing of concrete is usually performed at controlled temperature, normally constant. As the early testing was done in temperate climates, the standardized temperature chosen was generally in the region of 18 to 21° C (64 to 70° F) so that much of the basic information about the properties of both fresh and hardened concrete is based on the behaviour of concrete at these temperatures. In practice, however, concrete is mixed at a wide range of actual range of temperatures and also remains in service at different temperatures. Indeed, the actual range of temperatures has widened considerably with much modern construction taking place in countries which have a hot climate.

In buildings, HSC structural members are designed to satisfy the requirements of serviceability and safety limit states. One of the major safety requirements in building design is the provision of appropriate fire safety measures for structural members. The basis for this requirement can be attributed to the fact that, when other measures for containing the fire fail, structural integrity is the last line of defence.

A series of compressive & tensile strength tests were conducted to examine the strength variation and stress-strain relationships due to rise in temperature on concrete by making various specimens. Compressive & tensile strength tests were conducted at various temperature (27, 100 & 200°C) and for three types of HSC that was (M30, M40, M50) respectively. The two tests were conducted as follows-

Compressive strength of the various strengths of concrete the determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive strength. The cubes are usually 150mm side; the specimens are cast, cured and tested as per standards prescribed for such tests.

The compressive strengths given by different specimens for the same concrete are different .the cylinders and prisms of a ratio of height or length to the lateral dimension of 2 may give strength of about 75 to 85 percent of the cube strength of normal-strength concrete.

The split tensile test is carried out by placing specimen horizontally between the loading surfaces of a compression testing machine and load is applied until failure of the cylinder, along the vertical diameter.

The main advantage of this method is that the same type of specimen and the same testing machine as are used for the compression test can be employed for the test. The splitting test is simple to perform and gives more uniform results than other tension tests. Splitting strength gives about 5 to 12% higher value than the direct tensile strength.

- To assess the structural safety of structures after exposure to high temperature (fire conditions).
- No Indian Standard Code available for structural design of heat resistant structures.
- Provisions for concrete strength at elevated temperatures in current major codes and authoritative guides, are unconstructive when applied to HSC

1.2. OBJECTIVE OF STUDY:

→ Determination of compressive and tensile strength of concrete specimens with increasing temperature for specific time (1 hour).

→ To create relations between rising temperature and strength of concrete.

→ Mix Design Study using IS code 10262 – 2009.

→ Stress-Strain relationship of concrete studied.

1.3. OVERVIEW:

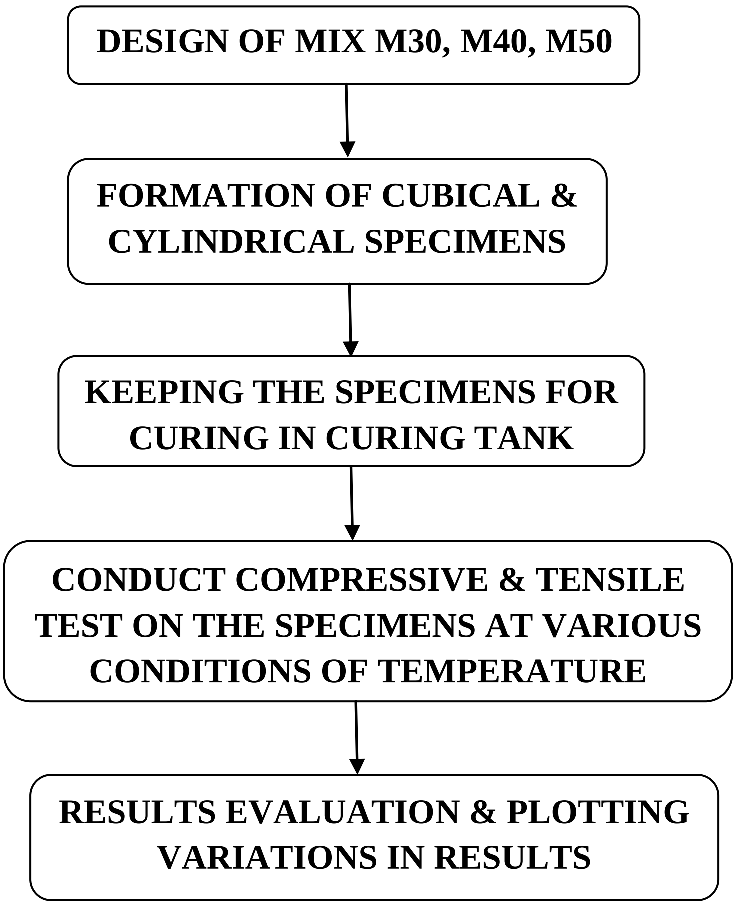


Fig 1.1: Flow chart showing the overview of the Project work

CHAPTER 2

LITERATURE REVIEW

In this chapter, I reviewed the literature on the effect of higher temperature on HSC concrete:

M.A. Youssef, M. Moftah (2007) studied that a general stress–strain relationship for concrete when subjected to fire is needed, as it allows designing concrete structures to specific fire performance criteria and improves the understanding of the behaviour of these structures during fire events. Existing relationships are developed based on fire tests of unconfined concrete specimens. They provide significantly different predictions because of uniqueness of each relationship and the existence of numerous formulations for calculating the governing parameters. In this paper, available formulations for estimating the parameters affecting the behaviour of unconfined and confined concrete are presented. These parameters are concrete compressive strength, concrete tensile strength, concrete compressive strain at peak stress, initial modulus of elasticity of concrete, transient creep strain, thermal strain, and yield stress and bond strength of reinforcing bars. Recommendations for choosing specific formulations are made based on accuracy, generality, and simplicity. Suitable compressive and tensile stress–strain relationships at elevated temperatures that utilize the recommended formulations are proposed based on well-established relationships for confined concrete at ambient temperature. The proposed relationships are compared to existing ones and to the available experimental data. They can capture changes in the mechanical properties of concrete resulting from temperature and confinement and are found to be superior to existing relationships. However, additional tests are needed to further validate and improve the proposed relationships [1].

According to Jin-Keun Kima, Sang Hun Hanb, Young Chul Song (2002), this paper reports the results of curing temperature and aging on the strength and elastic modulus and the Part II paper suggests a prediction model based on these experimental results. Tests of 480 cylinders made of Types I, V, and V cement + fly ash concretes, cured in Isothermal conditions of 10, 23, 35, and 50℃ and tested at the ages of 1, 3, 7, and 28 days are reported. According to the experimental results, concretes subjected to high temperatures at early ages attain higher early-age compressive and splitting tensile strengths but lower later-age compressive and splitting tensile strengths than concretes subjected to normal temperature. Even though the elastic modulus has the same tendency, the variation of elastic modulus with curing temperature is not so obvious as compressive strength. Based on the experimental result, the relationships among compressive strength, elastic modulus, and splitting tensile strength are analyzed, considering the effects of curing temperature, aging, and cement type [2].

Jianzhuang Xiaoa, Gert Konig (2004) has shown in his study ,the effect on concrete at high temperature . Based on the investigation and review of experimental studies in the past 20 years in the People's Republic of China, this paper engages in further discussion and comparative analysis of researches on the mechanical behaviour of concrete both under and after high temperature exposure. The following three aspects are focused on. Firstly, the basic mechanical behaviour of concrete at high temperature including strength, elastic modulus, peak strain and Poisson's ratio. Secondly, the effect of high temperature on the yield strength and elastic modulus of rebar. The high temperature response to the bond behaviour between concrete and rebar. This overview summary the states-of-the-art studies on the mechanical behaviour of concrete at high temperature in China [3].

Long-yuan Li, John Purkiss (2004) studied on Stress–strain constitutive equations of concrete material at elevated temperatures. The paper presents a critical review of the currently available models for the mechanical behaviour of concrete at elevated temperatures. Based on these models and experimental data a stress–strain–temperature model is proposed which incorporates the effect of transient strain implicitly. This model can be easily incorporated into existing commercial finite element analysis software. A numerical example on a wall element heated on two opposite faces indicates that at very early stages of heating transient strain does not play an important part, but that as the exposure time increases the effect of ignoring transient strain progressively increases and produces unconservative estimates of load carrying capacity [4].

According to Leyla Tanaçana, Halit Yasa Ersoy , Ümit Arpacıoglu (2009), effect of elevated temperatures and various cooling regimes on the properties of aerated concrete is investigated. Air cooled materials are tested at room temperature and in hot condition right after the fire. Water quenching effect is determined by testing the material in wet condition right after the quenching and in dry condition at room temperature. Unstressed strength of the material tested hot is relatively higher than air cooled unstressed residual strength up to

600℃. On the other hand, water quenching decreases the percentage of the strength particularly when the material is wet right after the quenching; strength is lost gradually as the temperature rises. As a result, if the quenching effect is disregarded, temperature rise does not have a considerable effect on the strength of the aerated concrete approximately up to 700–800℃. It is able to maintain its volumetric stability as well. However, more care needs to be taken in terms of its use above 800℃ for fire safety [5].

Metin Husem (2005), examined the variation of compressive and flexural strengths of ordinary and high-performance micro-concrete at high temperatures. Compressive and flexural strengths of ordinary and high-performance micro-concrete which were exposed to high temperatures (200, 400, 600, 800 and 1000℃) and cooled differently (in air and water) were obtained. Compressive and flexural strengths of these concrete samples were compared with each other and then compared with the samples which had not been heated. On the other hand, strength loss curves of these concrete samples were compared with the strength loss curves given in the codes. Experimental results indicates concrete strength decreases with increasing temperature, and the decrease in the strength of ordinary concrete is more than that in high-performance concrete.. Strength loss curves obtained from this study agree with strength loss curves given in the Finnish Code [6].

K. Sakra, E. EL-Hakim (2005) observed that temperature plays an important role in the use of concrete for shielding nuclear reactors. In the present work, the effect of different durations (1, 2 and 3 h) of high temperatures (250, 500, 750 and 950 °C) on the physical, mechanical and radiation properties of heavy concrete was studied. The effect of fire fitting systems on concrete properties was investigated. Results showed that ilmenite concrete had the highest density, modulus of elasticity and lowest absorption percent, and it had also higher values of compressive, tensile, bending and bonding strengths than gravel or baryte concrete. Ilmenite concrete showed the highest attenuation of transmitted gamma rays. Firing (heating) exposure time was inversely proportional to mechanical properties of all types of concrete. Ilmenite concrete was more resistant to elevated temperature. Foam or air proved to be better than water as a cooling system in concrete structure exposed to high temperature because water leads to a big damage in concrete properties [7].

V.K.R. Kodur and M.A. Sultan (2003) presented that, the relevant thermal properties of high strength concrete were determined as a function of temperature for use in fire resistance calculations. These properties included the thermal conductivity, specific heat, thermal expansion and mass loss, of plain and steel fibre-reinforced concrete made of siliceous and carbonate aggregate. The thermal properties are presented in equations that express the values of these properties as a function of temperature in the temperature range between 0°C and 1000°C. The effect of temperature on thermal conductivity, thermal expansion, specific heat and mass loss of HSC is discussed. Test data indicate that the type of aggregate has significant influence on the thermal properties of HSC, while the presence of steel fibre-reinforcement has very little influence on the thermal properties of HSC [8].

Ilker Bekir Topcu and Mehmet Ugur Toprak (2004) studied that removal of formwork can be made in a short time by early-strength gain of concrete with heat treatment. The effects of accelerated curing temperature and fine aggregate on early strength as well as the relationships between early strength–28-day strength and strength maturity have been examined. Cube concrete specimens produced with a 10-cm constant slump value, 0.59 w/c ratio, and with two different types of fine aggregate were subjected to three-phase cure processes. These cure processes include a 1-h preheating process after having replaced concrete in the mould, the cure application process, and finally the last waiting period for 2 h that is aimed at minimizing the effects of thermal stresses. Each of the specimen groups was cured at different temperatures for different periods (6 or 18 h). At the end of curing and on the 28th day, cube compressive strengths were determined. Therefore, it was seen that it is possible to estimate 28-day strength beforehand with reasonable accuracy [9].

According to Samir N. Shoukry, Gergis W. William, Brian Downie, Mourad Y. Riad (February 2011), concrete mechanical properties are determined under laboratory conditions of ideal air temperatures between 20 and 22℃ and relative humidity between 40% and 60%. This paper describes the development of concrete mechanical properties when cured under different environmental conditions. Tests to measure modulus of elasticity, compressive strength, and split tensile strength were conducted at varying temperatures and humidity conditions to examine their effects on normal concrete. An environmental chamber was constructed in the laboratory using available materials. The chamber works in conjunction with a freezer to provide chilled air and a heat gun to provide hot air. The heating and cooling functions were controlled via a microcontroller. The moisture content in the concrete specimens was controlled by massing the specimens. The results indicate that concrete strength and modulus of elasticity are inversely related to temperature as well as moisture content in the concrete. Concrete modulus of elasticity was directly related to concrete compressive strength in both temperature and moisture testing. Mathematical formulas were developed for modulus of elasticity, compressive strength, tensile strength, and Poisson's ratio [10].

Fu-Ping Cheng, V. K. R. Kodur & Tien-Chih Wang (2004) investigated that the effects of high temperature on the strength and stress-strain relationship of high strength concrete (HSC). Stress-strain curve tests were conducted at various temperatures (20, 100, 200, 400, 600, and 800°C) for four types of HSC. The variables considered in the experimental study included concrete strength, type of aggregate, and the addition of steel fibers. Results from stress-strain curve tests show that plain HSC exhibits brittle properties below 600°C, and ductility above 600°C. HSC with steel fibers exhibits ductility for temperatures over 400°C. The compressive strength of HSC decreases by about a quarter of its room temperature strength within the range of 100– 400°C. The strength further decreases with the increase of temperature and reaches about a quarter of its initial strength at 800°C. The strain at peak loading increases with temperature, from 0.003 at room temperature to 0.02 at 800°C. Further, the increase in strains for carbonate aggregate HSC is larger than that for siliceous aggregate HSC [11].

CHAPTER 3

THERMAL PROPERTIES

3.1. DEFINITION

Rock and aggregate possesses four thermal properties which are significant in establishing the quality of aggregate for concrete constructions. They are:

1. Coefficient of expansion
2. Specific heat
3. Thermal conductivity
4. Thermal diffusivity

3.2. TYPES OF THERMAL PROPERTIES

3.2.1. Coefficient of Expansion

Out of these, specific heat and conductivity are found to be important only in mass concrete construction where rigorous control of temperature is necessary. When we are dealing with the aggregate in general it will be sufficient at this stage to deal with only the coefficient of expansion of the aggregate, since it interacts with the coefficient of thermal expansion of cement paste in the body of the set-concrete.

An average value of the linear thermal coefficient of expansion of concrete may be taken as $9.9x10^{-6}$ per℃, but the range may be from about $5.8x10^{-6}$ per℃ to $14x10^{-6}$per℃ depending upon the type and quantities of the aggregates, the mix proportions and other factors. The range of coefficient of thermal expansion for hydrated cement paste may vary from $10.8x10^{-6}$ per℃ to $16.2x10^{-6}$ per℃. Similarly, for mortar it may range from $7.9x10^{-6}$ per℃ to $12.6x10^{-6}$ per℃.

The linear thermal coefficient of expansion of common rocks ranges from about $0.9x10^{-6}$ per℃ to $16x10^{-6}$ per℃. From the above it could be seen that while there is thermal compatibility between aggregate and concrete or aggregate and paste at higher range, there exists thermal incompatibility between aggregate and concrete or aggregate and paste at the lower range. This thermal incompatibility between the aggregate and concrete at the lower range cause severe stress which has got damaging effect on the durability and integrity of concrete structures. The study of coefficient of thermal expansion of aggregate is also important, in dealing with the fire resistance of concrete [13].

Table 3.1: **For Coefficient of Thermal Expansion of Concrete at High Temperature [13]**

Curing condition	Water/ Cement Ratio	Cement content kg/m^3	Aggregate	Linear coefficient of thermal expansion at the age of			
				28 days		90 days	
				Below 260℃ 10^{-6}per℃	Above 430℃ 10^{-6}per℃	Below 260℃ 10^{-6}per℃	Above 430℃ 10^{-6}per℃
Moist	0.4 0.6 0.8	435 310 245	Calcareous Gravel	7.6 12.8 11.0	20.3 20.5 21.1	6.5 8.4 16.7	11.2 22.5 32.8
Air 50% relative humidity	0.4 0.6 0.8	435 310 245	Calcareous Gravel	7.7 7.7 9.6	18.9 21.1 20.7	12.2 8.8 11.7	20.7 20.2 21.6
Moist air	0.68 0.68	355 355	Expanded Shale	6.1 4.7	7.5 9.7	- 5.0	- 8.8

3.2.2. Specific Heat

Specific heat, which represents heat capacity of concrete, increases with an increase in temperature and with a decrease in the density of the concrete. It is defined as the quantity of heat required to raise the temperature of a unit mass of a material by one degree centigrade. The common range of values for concrete is between 840 and 1170 j/kg per℃ [13].

3.2.3. Thermal Conductivity

This measures the ability of material to conduct heat. Thermal conductivity is measured in joules per second per square metre of area of body when the temperature is measured deference is 1℃ per metre thickness of the body. The conductivity of concrete depends on type of aggregate, moisture content, density and temperature of concrete [13].

Table 3.2: For typical values of Thermal Conductivity of Concrete made with different Aggregates [13]

Type of aggregate	Wet density of concrete Kg/m^3	Conductivity $j/m^2S\,^\circ C/m$
Quartzite	2440	3.5
Dolomite	2500	3.3
Limestone	2450	3.2
Sandstone	2400	2.9
Granite	2420	2.6
Basalt	2520	2.0
Baryte	3040	2.0
Expanded shale	1590	0.8

3.2.4. Thermal Diffusivity

Diffusivity represents the rate at which temperature changes within a mass can take place, and is thus an index of the facility with which concrete can undergo temperature changes. Diffusivity, δ, is simply related to the conductivity K by the equation:

$$\delta = \frac{K}{c\rho}$$

where c is the specific heat and ρ is the density of concrete. The range of typical values of diffusivity of ordinary concrete is between 0.002 and 0.006 m^2/h, depending on the type of aggregate used [13].

CHAPTER 4

TEMPERATURE EFFECT ON CONCRETE

4.1. HOT WEATHERING CONCRETE

Special problem are faced in making, placing and compacting concrete in hot weather and cold weather. In India most of areas are in tropical regions and some areas in extremely cold weather regions. It is difficult to define what hot weather condition is. However, just for convenience it is regarded that the concrete placed at an atmospheric temperature above 40℃ is considered as hot weather concreting. At this temperature certain special problems are usually encountered. They are:-

(a) Rapid rate of hydration of cement, quick setting and early stiffening.

(b) Rapid evaporation of mixing water.

(c) Greater plastic shrinkage.

(d) Less time for finishing.

(e) Reduced relative humidity.

(f) Absorption of water from the concrete by the subgrade and formwork.

(g) Difficulty in continuous and uninterrupted curing.

(h) Difficulty in incorporation of air entrainment.

4.1.1. Rapid rate of hydration:-

At high ambient temperature the setting time of the cement is reduced considerably. It must be remembered that setting time pertains to a temperature range of 27± 2℃. At a higher temperature, naturally setting time will be reduced with the result that early stiffening takes place which makes the concrete lose the workability. This is also pointed out that the quality of gel and gel structure formed at higher temperature in the early period of hydration is of poor quality. Concrete placed in hot weather no doubt develops high early strength, but it will suffer certain loss of long term strength [13].

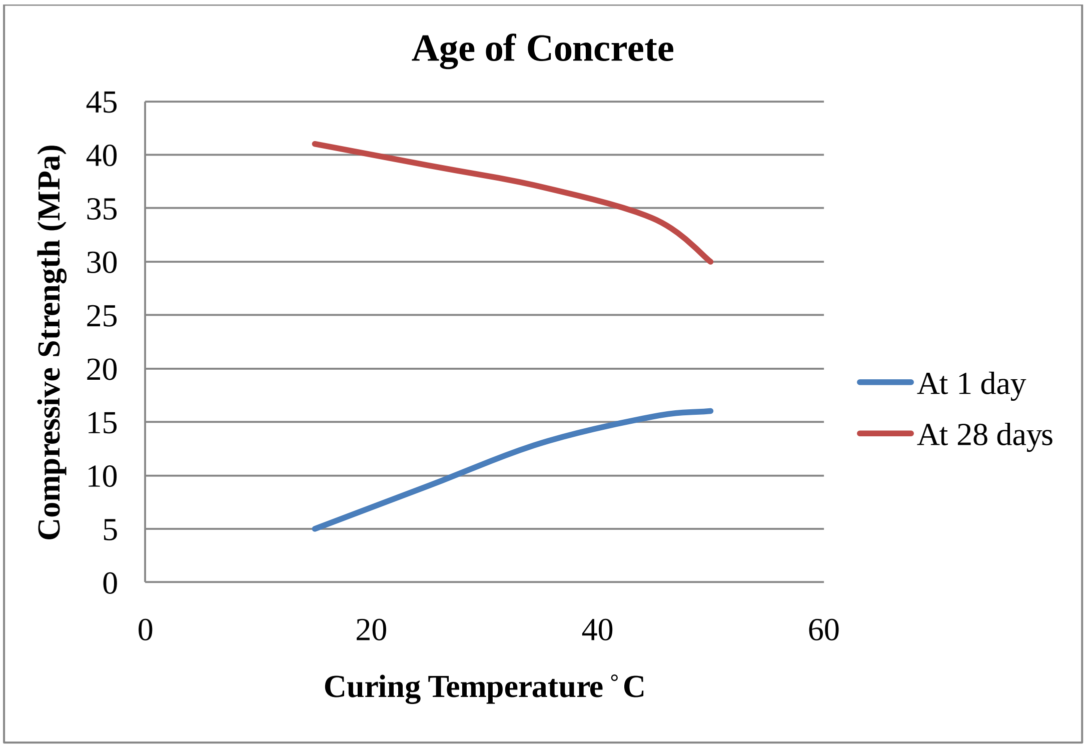


Figure 4.1: Effect of curing temperatures on 1-day and 28-day Compressive strength of concrete [13]

4.1.2. Rapid evaporation of mixing water:-

Hot weather condition is normally associated with relatively lower relative humidity. On account of this, the water mixed with the concrete to give the required workability will be lost. The concrete turns to be unworkable with the result, inordinate amount of compacting effort is required to compact concrete fully. If this is not forthcoming, large voids will remain in the concrete, which are responsible for all the ills in concrete [13].

4.1.3. Greater plastic shrinkage:-

The rate of evaporation of water from the surface of the concrete will be faster than the rate of movement of water from the interior to the surface. As a result, a moisture gradient will be set up which results in surface cracks known as plastic shrinkage cracks [13].

4.1.4. Finishing time:-

In hot weather, finishing must be done as early as possible after placing. In certain cases if early finishing is not possible due to faster stiffening and quicker evaporation of water, the quality of finishing will be of poor standard [13].

4.1.5. Absorption of water by sub grade:-

In hot weather regions the sub grade is normally dry and absorptive. The sub grade or surface of formwork is required to be wetted before placing the concrete. If this not done carefully with proper considerations, the water in the concrete may be lost by absorption by the surface in contact with concrete making the contact zone poorer in quality [13].

4.1.6. Curing:-

In hot weather comparatively early curing becomes necessary, particularly where 53 grade cement is used. Hot weather requires a continuous effort for curing. If there is any lapse, the concrete surface dries up fast and interrupts the continuous hydration. Once the interruption takes place, the subsequence wetting does not fully contribute to the development of full strength. No doubt, continuous curing in hot weather entails greater cost of water and labour [13].

4.1.7. Air-entrained:-

Air-entrained concrete is rarely used in hot weather conditions. However, if used from consideration of better workability, greater proportion of air-entraining agents are required to compensate for the loss of air-entrainment due to higher temperature [13].

4.2. INFLUNCE OF EARLY TEMPERATURE ON STRENGTH OF CONCRETE

We have seen that a rise in the curing temperature speeds up the chemical reactions of hydration and thus affects beneficially early strength of concrete without any ill-effects on the later strength. Higher temperature during and following the initial contact between cement and water reduces the length of the dormant period so that the overall structure of the hydrated cement paste becomes established very early.

Although, a higher temperature during placing and setting increases the very early strength, it may adversely affect the strength from about 7 days onwards. The explanation is that a 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.

This explanation of adverse effects of a high early temperature on later strength has extended by Verbeck and Helmuth who suggest that the rapid initial rate of hydration at higher temperatures retards the subsequent hydration and produced a non-uniform distribution of the products of hydration within the paste. The reason for this is that, at the high initial rate of hydration, there is insufficient time available for the diffusion of the products of hydration away from the cement particle and for a uniform precipitation in the interstitial space (as is the case at lower temperatures). As a result, high concentration of the products of hydration and adversely affects the long-term strength [12].

Figure 4.2 shows Price data on the effect of the temperature during the first two hours after mixing on the development of strength of concrete with a water/cement ratio of 0.53. The range of temperatures investigated was 4 to 46℃ and, beyond the age of two hours, all specimens were cured at 21℃.

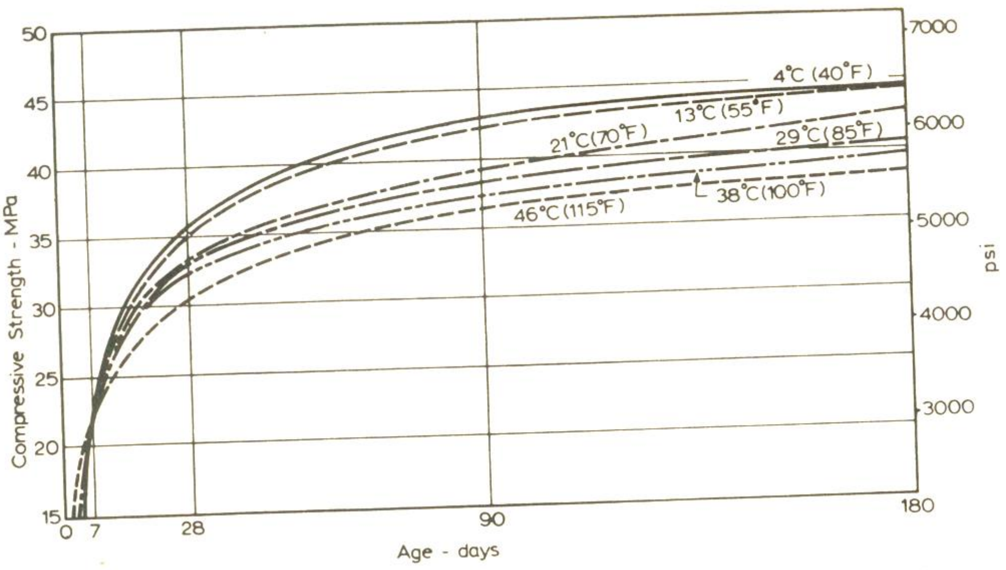


Figure 4.2: Effect of temperature during the first two hours after casting on the development of strength (all specimens sealed and after the age of 2 hours cured at 21℃ [12]

Some field tests have confirmed the influence of temperature at the time of placing on strength: typically, for an increase of 5℃ there is a decrease in strength of 1.9 MPa.

The test described so far was all made in the laboratory or under known conditions, but the behaviour on site in a hot climate may not be the same. Here, there are some additional factors acting: ambient humidity, direct radiation of the sun, wind velocity, and method of curing [12].

4.2.1. Steam Curing at Atmospheric Pressure:

An increase in the curing temperature of concrete increases its rate of development of strength can be speeded up by curing concrete in steam. When steam is at atmospheric pressure, i.e. the temperature is below 100℃, the process can be regarded as a special case of moist curing in which the vapour-saturated atmosphere ensures a supply of water. High-pressure steam curing (autoclaving) is an entirely different. Figure-4.3 shows typical values of strength of concrete made with modified cement and a water/cement ratio of 0.55; steam curing was applied immediately after casting [12].

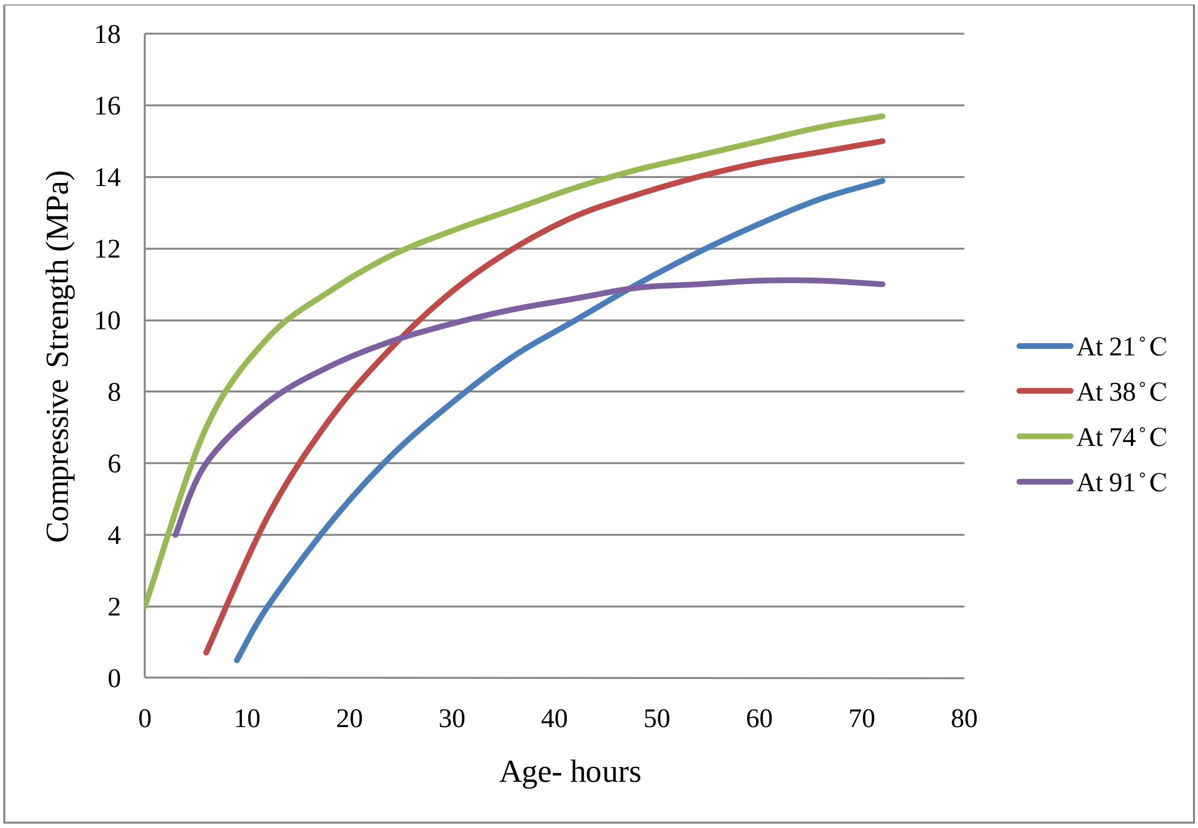


Figure 4.3: Typical values of strength of concrete made with modified cement and a water/cement ratio of 0.55; steam curing was applied immediately after casting [12].

4.2.2. High-Pressure Steam curing (autoclaving):

This process is quite different from curing in steam at atmospheric pressure, both in the method of execution and in the nature of the resulting concrete. It is worth emphasizing that a longer period of curing at a lower temperature leads to a higher optimum strength than when high temperature is applied for a shorter time. For any one period of curing, there is a temperature which leads to an optimum strength [12].

CHAPTER 5

CONCRETE MIX DESIGN

5.1. INTRODUCTION:

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The purpose of designing as can be seen from the above definitions is two-fold. The first objective is to achieve the stipulated minimum strength and durability. The second object is to make the concrete in the most economical manner.

Cost-wise all concrete depend primarily on two factors: namely cost of material and cost of labour. Labour cost, by way of formwork, batching, mixing, transporting and curing is nearly same for good concrete and bad concrete. Therefore attention is mainly directed to the cost of materials. Since the cost of cement is many times greater than the cost of other ingredients, attention is mainly directed to the use of as little cement as possible consistent with strength and durability.

Variables in Proportioning

With the given materials, the four variable factors to be considered in connection with specifying a concrete mix are:

(a) Water-Cement ratio
(b) Cement content or cement-aggregate ratio
(c) Gradation of the aggregates
(d) Consistency

In general all four of these inter-related variables cannot be chosen or manipulated arbitrarily. Usually two or three factors are specified and the others are adjusted to give minimum workability and economy. Water/cement ratio expresses the dilution of the paste-cement content varies the amount of paste. Gradation of aggregate is controlled by varying the amount of given fine and coarse aggregate. Consistency is established by practical requirements of placing. In brief, the effort in proportioning is to use a minimum amount of paste that will lubricate the mass while fresh and after hardening will bind the aggregate particles together and fill the space between them. Any excess of paste involves greater cost, greater drying shrinkage, and greater susceptibility to percolation of water and there and therefore attack by aggressive water and weather attack by aggressive water and weathering action. This is achieved by minimising the voids by good gradation.

5.2. TYPES OF MIXES:

5.2.1. Nominal Mixes

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

5.2.2. Standard mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

5.2.3. Designed Mixes

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm^2. No control testing is necessary reliance being placed on the masses of the ingredients.

5.3. INDIAN STANDARD RECOMMENDED METHOD OF CONCRETE MIX DESIGN (IS 10262 – 2009):

The Bureau of Indian Standards recommends a set of procedure for design of concrete mix mainly based on the work done in national laboratories. The mix design procedures are covered in IS 10262 – 2009. The methods given can be applied for both medium strength and high strength concrete [17].

5.3.1. Target mean strength for mix design:

The target mean compressive ($\tilde{f}_{ck}$) strength at 28 days is given by:

$$\tilde{f}_{ck} = f_{ck} + tS$$

Where f_{ck} = characteristic compressive strength at 28 days.

S = standard deviation.

t = a statistical value depending on expected proportion of results (risk factor).

The value of the standard deviation has to be worked out from the trials conducted in the laboratory or field. According to IS: 456-2000 and IS: 1343–1980, the characteristic strength is defined as that value below which not more than 5 percent results are expected to fall, in which case the above equation reduces to –

$$[\ \tilde{f}_{ck} = f_{ck} + 1.65S\ ]$$

Table 5.1: **For Assumed Standard Deviation as per IS 456 – 2000 [17]**

Grade of Concrete	Assumed Standard Deviation N/mm^2
M10 M15	3.5
M20 M25	4.0
M30 M35 M40 M45 M50	5.0

5.3.2. Selection of Water Content

The water content of concrete is influenced by a number of factors, such as aggregate size, shape & texture, workability, water-cement ratio, cement and other supplementary cementitious material type and content, chemical admixtures and environmental conditions. An increase in aggregates size, a reduction in water-cement ratio and slump, and use of rounded aggregate and water reducing admixtures will reduce the water demand.

The quantity of maximum mixing water per unit volume of concrete may be determined from Table. The water content in Table is for angular coarse aggregate and 25 to 50mm slump range. The water estimate in Table-5.2 can be reduced by approximately 10kg for sub-angular aggregates, 20 kg for gravel with some crushed particles and 25kg for rounded gravel to produce same workability. For the desired workability(other than 25 to

50mm slump range), the required water content may be established by trial or an increase by about 3 percent for every additional 25mm slump or alternatively by use of chemical admixtures conforming to IS 9103. Water reducing admixtures or super plasticizing admixtures usually decrease water content by 5 to 10 percent and 20 percent and above respectively at appropriate dosages [17].

Table 5.2: for Maximum Water Content per cubic metre of Concrete for Nominal Maximum size of Aggregate [17]

Sl. No.	Nominal Maximum size of Aggregate (mm)	Maximum Water Content (kg)
i)	10	208
ii)	20	186
iii)	40	165

Note- These quantities of mixing water are for use in computing cementitious material contents for trial batches.

5.3.3. Estimation of Entrapped Air

The air content is estimated from Table-5.3 for the normal maximum size of aggregate used.

Table 5.3: For Approximate Entrapped Air Content [17]

Sl. No.	Maximum Size of Aggregate (mm)	Entrapped Air, as % of Volume of Concrete
i)	10	3.0
ii)	20	2.0
iii)	40	1.0

5.3.4. Estimation of Coarse Aggregate Proportion

Aggregates of essentially the same nominal maximum size, type and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate per unit volume of total aggregate is used. Approximate values for this aggregate volume are given in Table-5.4 for a water-cement ratio of 0.5, which may be suitably adjusted for other water-cement ratios. It can be seen that for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and grading zone of the aggregate. Differences in the amount of mortar required for workability with different aggregates, due to differences in particle shape and grading, are compensated for automatically by differences in rodded void cement.

Table 5.4: for Volume of Coarse Aggregate per unit Volume of Total Aggregate for Different Zones of Fine Aggregate [17]

Sl. No.	Nominal Maximum Size of Aggregate (mm)	Volume of Coarse Aggregate per unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
		Zone IV	Zone III	Zone II	Zone I
i)	10	0.50	0.48	0.46	0.44
ii)	20	0.66	0.64	0.64	0.60
iii)	40	0.75	0.73	0.71	0.69

5.3.5. Estimation of Fine Aggregate Proportion

These quantities are determined by finding out the absolute volume of cementitious material, water and the chemical admixture; by dividing their mass by their respective specific gravity, multiplying by 1/1000 and subtracting the result of their summation from unit volume. The values so obtained are divided into Coarse and Fine aggregate fractions by volume in accordance with coarse aggregate proportion already determined above. The coarse and fine aggregate contents are then determined by multiplying with their respective specific gravities and multiplying by 1000 [17].

Procedure:-

1.) Determine the mean target strength f_t from the specified characteristic compressive strength at 28-day f_{ck} and the level of quality control.

$f_t = f_{ck} + 1.65\ S$

where S is the standard deviation obtained from the Table 5.1 of approximate contents given after the design mix.

2.) Obtain the water cement ratio for the desired mean target using the empirical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ratio. The water cement ratio so chosen is checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.

3.) Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.

4.) Select the water content, for the required workability and maximum size of aggregates (for aggregates in saturated surface dry condition) from table.

5.) Determine the percentage of fine aggregate in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.

6.) Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.

7.) Calculate the cement content from the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability, and greater of the two values is adopted.

8.) From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relations:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p}\frac{f_a}{S_{fa}}\right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p}\frac{C_a}{S_{ca}}\right] \times \frac{1}{1000}$$

where

V = absolute volume of concrete

= gross volume ($1m^3$) minus the volume of entrapped air

S_c = specific gravity of cement

W = Mass of water per cubic metre of concrete, kg

C = mass of cement per cubic metre of concrete, kg

p = ratio of fine aggregate to total aggregate by absolute volume

f_a, C_a = total masses of fine and coarse aggregates, per cubic metre of concrete kg and

S_{fa}, S_{ca} = specific gravities of saturated surface dry fine and coarse aggregates, respectively.

9.) Determine the concrete mix proportions for the first trial mix.

10.) Prepare the concrete using the calculated proportions and cast three cubes of 150 mm size and test them wet after 28-days moist curing and check for the strength.

11.) Prepare trial mixes with suitable adjustments till the final mix proportions are arrived a

5.3.6. Sieve Analysis of Fine Aggregate:

Sieve analysis is conducted on the sand used in experiments and result is drawn that the sand is in Zone-II

Table 5.5: Observation Sheet for Sieve Analysis

S.NO	IS Sieve	Particle size D(mm)	Mass retained (g)	% retained	Cumulative % retained	Cumulative % finer(N)
1.	4.75 mm	4.75 mm	92.3	9.23	9.23	90.77
2.	2.36 mm	2.36 mm	156.4	15.64	24.87	75.13
3.	1.18 mm	1.18 mm	200.1	20.01	44.88	55.12
4.	600 µ	0.600 mm	224.9	22.49	69.37	30.63
5.	300 µ	0.300 mm	214.7	21.47	90.84	9.16
6.	150 µ	0.150 mm	74.8	7.48	98.32	1.68
7.	75 µ	0.075 mm	10.8	1.08	99.40	0.60

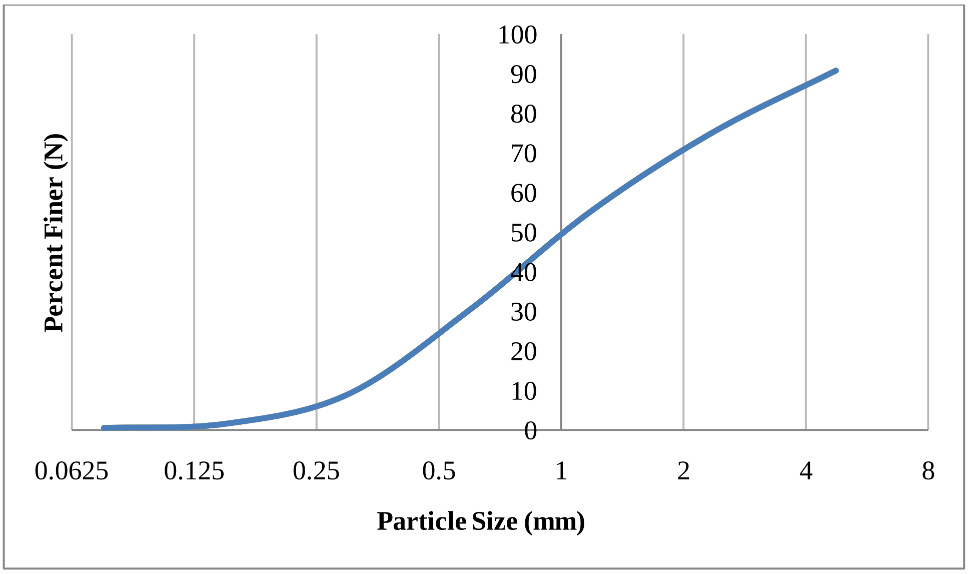


Fig. 5.1: Grading curves for fine aggregate

5.4. PARAMETERS FOR MIX DESIGN M30:

Table 5.6: Mix Design M30 details

M30 CONCRETE MIX DESIGN		
As per IS 10262-2009		
A-1	**Stipulation for proportioning**	
1	**Grade Designation**	**M30**
2	Type of Cement	OPC 43 grade confirming to IS-12269-2009
3	Maximum Nominal Aggregate Size	20 mm
4	Minimum Cement Content	310 kg/m^3
5	Maximum Water Cement Ratio	0.45
6	Workability	50-75 mm (Slump)
7	Exposure Condition	Normal
8	Degree of Supervision	Good
9	Type of Aggregate	Crushed Angular Aggregate
10	Maximum Cement Content	540 kg/m^3
11	Chemical Admixture Type	Super plasticiser Confirming to IS-9103

A-2	**Test Data for Materials**	
1	Cement Used	OPC 43 grade
2	Sp. Gravity of Cement	3.15
3	Sp. Gravity of Water	1.00
4	Chemical Admixture	FORSAC super plasticizer
5	Sp. Gravity of 20 mm Aggregate	2.74
6	Sp. Gravity of 10 mm Aggregate	2.74
7	Sp. Gravity of Sand	2.605
8	Free (Surface) Moisture of 20 mm Aggregate	nil

9	Free (Surface) Moisture of 10 mm Aggregate	nil
10	Free (Surface) Moisture of Sand	nil
11	Sp. Gravity of Combined Coarse Aggregates	2.882
12	Sieve Analysis of Fine Aggregates	Separate Analysis Done
13	Sieve Analysis of Individual Coarse Aggregates	Separate Analysis Done

A-3	**Target Strength for Mix Proportioning**	
1	Target Mean Strength	38.5N/mm^2
2	Characteristic Strength @ 28 days	30N/mm^2
A-4	**Selection of Water Cement Ratio**	
1	Maximum Water Cement Ratio	0.45
2	Adopted Water Cement Ratio	0.42
A-5	**Selection of Water Content**	
1	Maximum Water content (10262-table-2)	186 Lit.
2	Estimated Water content for 50-100 mm Slump	160 Lit.
3	Super plasticiser used	1 % by wt. of cement
A-6	**Calculation of Cement Content**	
1	Water Cement Ratio	0.42
2	Cement Content (160/0.42)	380 kg/m^3
A-7	**Proportion of Volume of Coarse Aggregate & Fine Aggregate Content**	
1	Vol. of C.A. as per table 3 of IS 10262	62.00%
2	Adopted Vol. of Coarse Aggregate	62.00%
	Adopted Vol. of Fine Aggregate (1-0.62) = 38.00%	

A-8	**Mix Calculations**	
1	Volume of Concrete in m^3	1.00
2	Volume of Cement in m^3 (Mass of Cement) / (Sp. Gravity of Cement)x1000	0.12
3	Volume of Water in m^3 (Mass of Water) / (Sp. Gravity of Water)x1000	0.16
4	Volume of Admixture @ 0.5% in m^3 (Mass of Admixture)/(Sp. Gravity of Admixture)x1000	0.00160
5	Volume of All in Aggregate in m^3 Sr. no. 1 – (Sr. no. 2+3+4)	0.718
6	Volume of Coarse Aggregate in m^3 Sr. no. 5 x 0.62	0.445
7	Volume of Fine Aggregate in m^3 Sr. no. 5 x 0.38	0.273

A-9	**Mix Proportions for One Cum of Concrete**	
1	Mass of Cement in kg/m^3	**380**
2	Mass of Water in kg/m^3	**160**
3	Mass of Fine Aggregate in kg/m^3	**711**
4	Mass of Coarse Aggregate in kg/m^3	1283
	Mass of 20 mm in kg/m^3	**924**
	Mass of 10 mm in kg/m^3	**359**
5	Mass of Admixture in kg/m^3	**3.8**
6	Water Cement Ratio	0.42

5.5. TEST PROCEDURE:

In this study, uniaxial compressive and tensile tests were conducted on ordinary concrete samples (for each concrete 10 samples) were performed using Universal Testing Machine (UTM) and Compression Testing Machine (CTM). In determining the effects of high temperature on the compressive and flexural strength on ordinary concrete, a flexural test was done on the prismatic samples with dimensions 150X150X300 mm. Compressive tests were done on the samples with dimensions 150X150X150 mm and 150X150X300 mm. For each concrete, 3 samples were used at each test temperature. The tests were performed at three different temperatures (27, 100 and 200℃) in order to have practical measurements. Eighteen of these samples were kept at 27℃ and the other 42 samples were put in the oven. They were removed 1 h after the desired temperature was reached. Forty two samples were cooled in water and the other 18 were cooled in air (at room temperature) until they were at 27℃. The flexural and compressive tests were performed on the cooled samples and 18 others which were kept at 27℃.

CHAPTER 6

RESULTS AND DISSCUSION

6. RESULTS:

Various cubical and cylindrical specimens are tested at different temperature for specific period to evaluate the compressive & tensile strength and stress-strain relationship.

Compressive strength tests are done on the concrete samples. Three samples were used for each series of experiments. The average compressive strengths are given in appendix A & B.
In this study, concrete with an average compressive strength of 34MPa have been produced using the composition ratios in Table 5.6.
The samples of concrete produced for the examination of the behaviour of exposed to high temperature are placed into an oven with a heating capacity of 100 & 200℃. The rate of 28 days after their production, experimental samples were kept in the oven until the temperature is 100 and 200℃ respectively. Then, they were taken out of the oven and they were left to cool in water till they reached 27℃. Cooled in water, samples were first exposed to flexural and then to compressive experimentation on broken pieces. The flexural and compressive test was carried out on 3 samples for each series was performed. The compressive and flexural strengths obtained in this way are given in appendix A & B. The variations with temperature of flexural strength on concrete is given below, and
The flexural strength of concrete cooled in water after being exposed to the effect of different temperature is also lower than that of reference samples: 9.8 % for 100℃, 24.6% for 400℃.
The compressive strength of concrete cooled in water is also less than that of reference samples: 8.2% for 100℃, 20% for 200℃. In the test results it is seen that compressive strength of concrete under the effect of high temperature and cooled in water has a decreasing trend when the temperature increases. Strength loss curves obtained from this study for the concrete have the same trend but different changing ratio. In the present study, it is seen that the strength of concrete exposed to high temperature and cooled in water decreases 200℃ (as shown below). According to the results obtained from the tests, when the temperature is increased from 27 to 200℃, compressive strength loss of concrete is 20% for the specimens which were cooled in water.

6.1. STRENGTH CALCULATIONS ON CUBICAL SPECIMENS AFTER 28 DAYS CURING:

Cubical specimen casted

Placing of Specimens in Curing Tank after casting them

COMPRESSIVE STRENGTH:

Compressive strength of the various strengths of concrete the determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive strength. The cubes are usually 150mm side; the specimens are cast, cured and tested as per standards prescribed for such tests. In this study, three batches were tested for compressive strength test. Each batch consists of three specimens each tested at 27, 100 and 200

Compressive test conducted using CTM

Variation of compressive strength of cube of M30 mix

For detailed values refer to Appendix-A

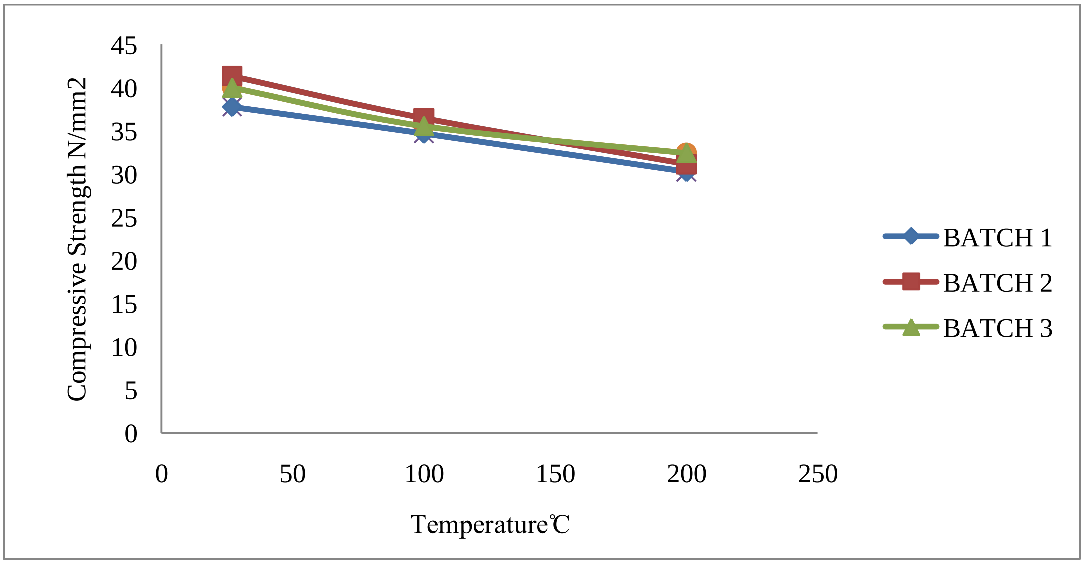


Fig. 6.1: Variation of compressive strength of cube of M30 mix

Variation of compressive strength of cube of M40 mix

For detailed values refer to Appendix-A

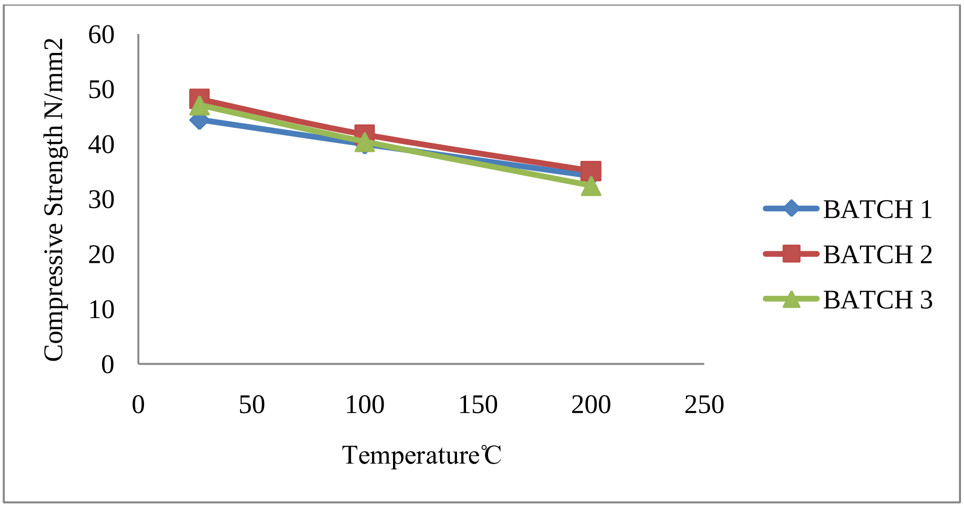
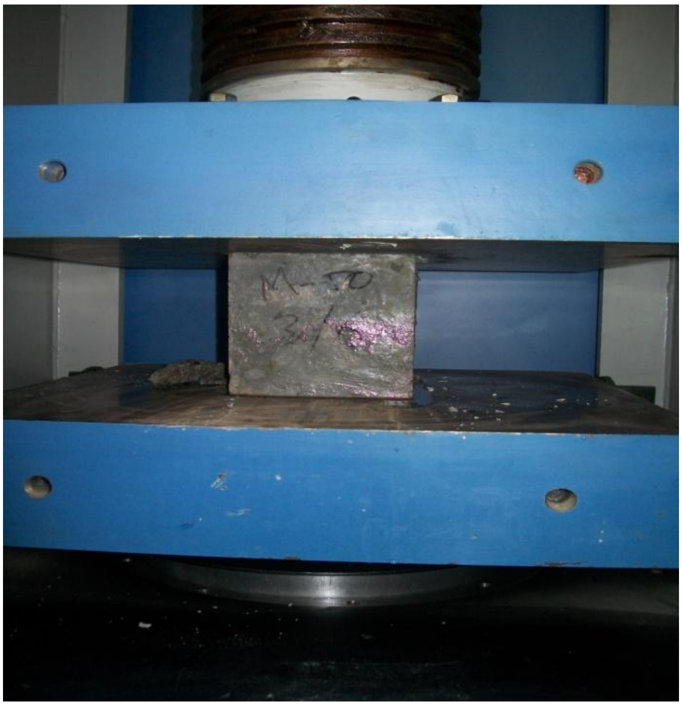


Fig. 6.2: Variation of compressive strength of cube of M40 mix

Variation of compressive strength of cube of M50 mix



Compressive Test conducted using UTM

For detailed values refer to Appendix-A

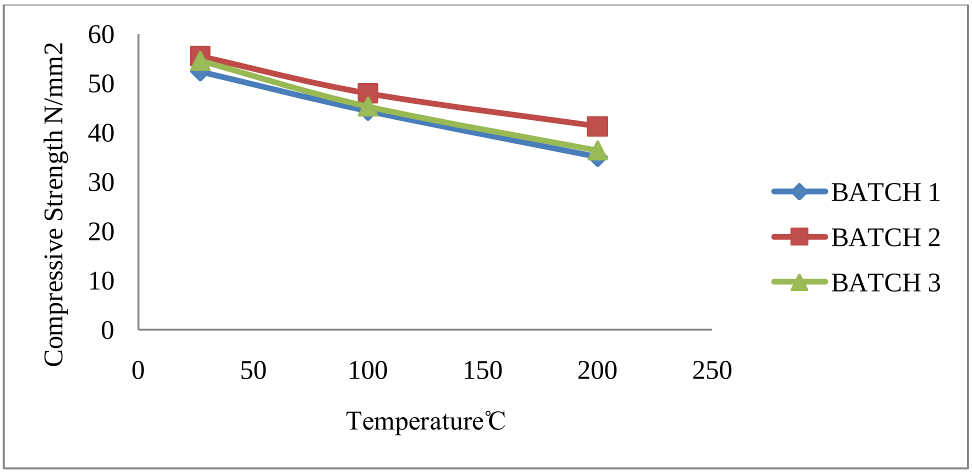


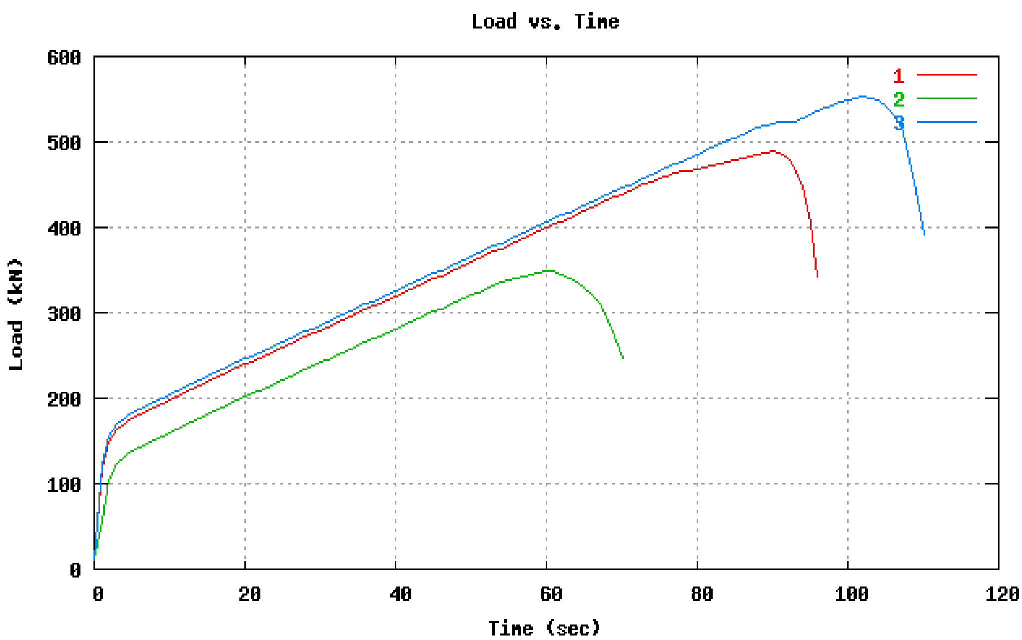
Fig.6.3: Variation of compressive strength of cube of M50 mix

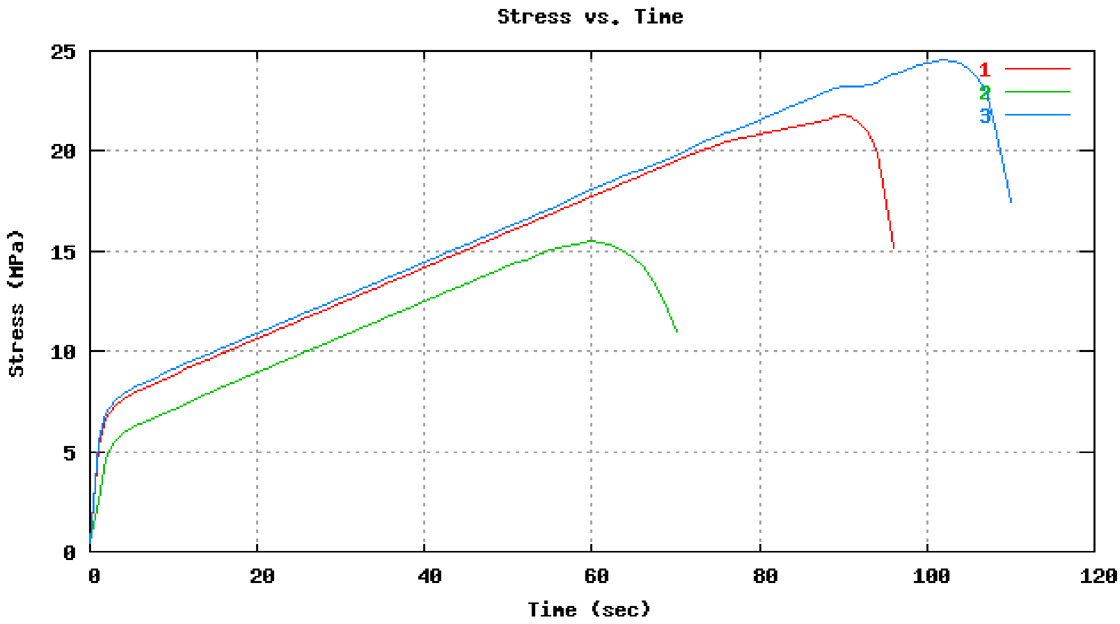
Variation of compressive strength of cube of M30 mix at temperature (27, 100 & 200℃)

3 – Represents test conducted at 27℃

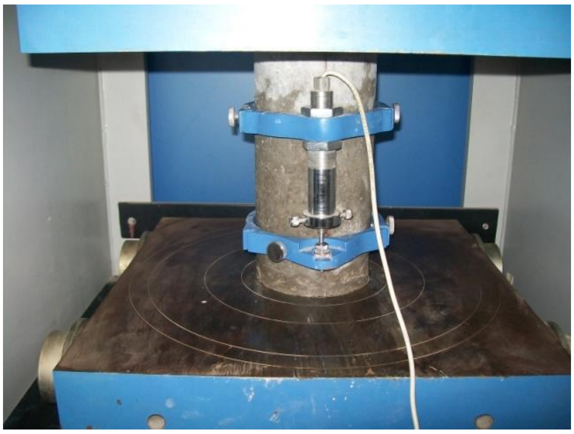
1 – Represents test conducted at 100℃

2 – Represents test conducted at 200℃





6.2. STRENGTH CALCULATIONS ON CYLINDRICAL SPECIMENS AFTER 28 DAYS CURING:



Cubical specimens casted and tested

Variation of tensile strength of M30 mix

SPLIT TENSILE STRENGTH TEST:

The test is carried out by placing specimen horizontally between the loading surfaces of a compression testing machine and load is applied until failure of the cylinder, along the vertical diameter.

Behaviour of concrete shown after tensile test conducted

For detailed values refer to Appendix-B

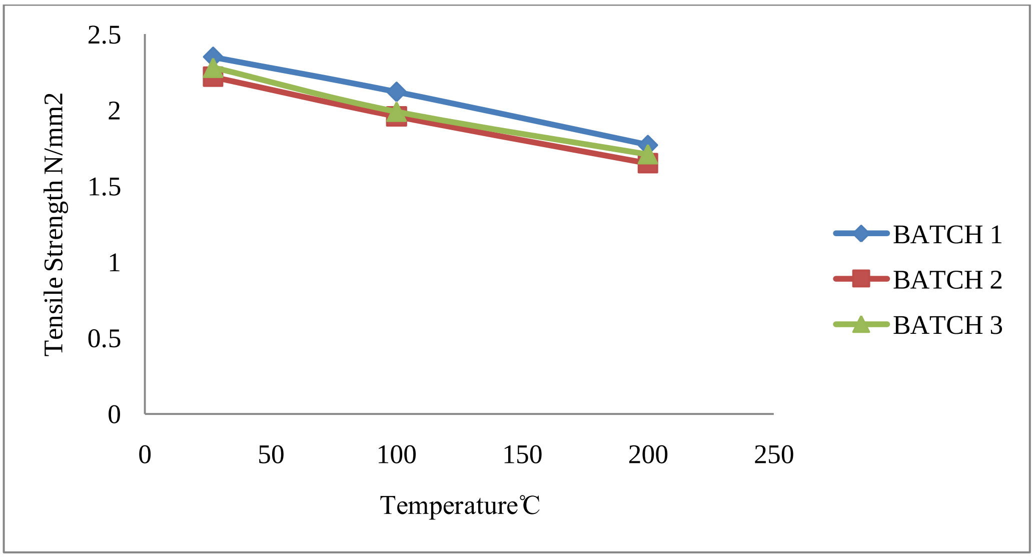


Fig. 6.4: Variation of tensile strength of cylinder of M30 mix

COMPRESSIVE STRENGTH:

Compressive strength of the various strengths of concrete the determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive strength.

Fixing of LVDT on cylindrical specimen

Variation of compressive strength of M30 mix

For detailed values refer to Appendix-B

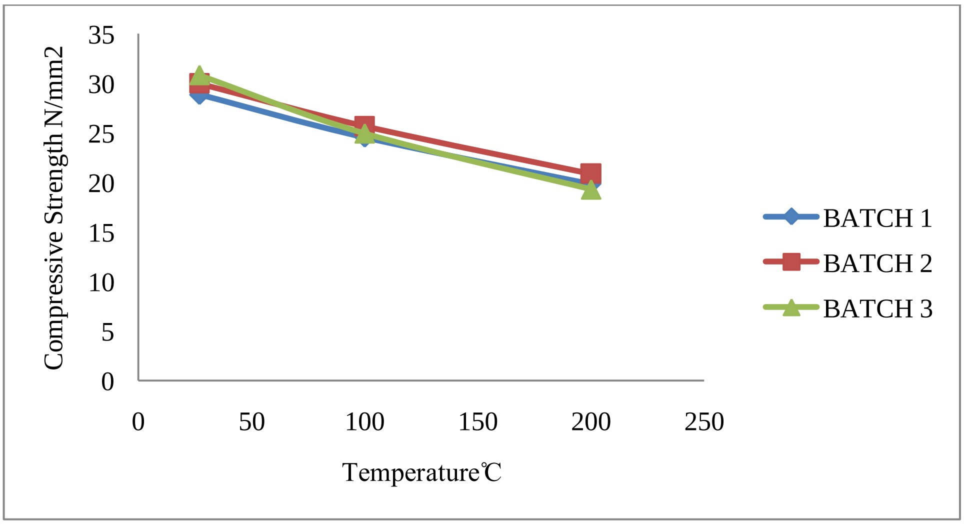


Fig. 6.5: Variation of compressive strength of cylinder of M30 mix

Variation of compressive strength of M40 mix

For detailed values refer to Appendix-B

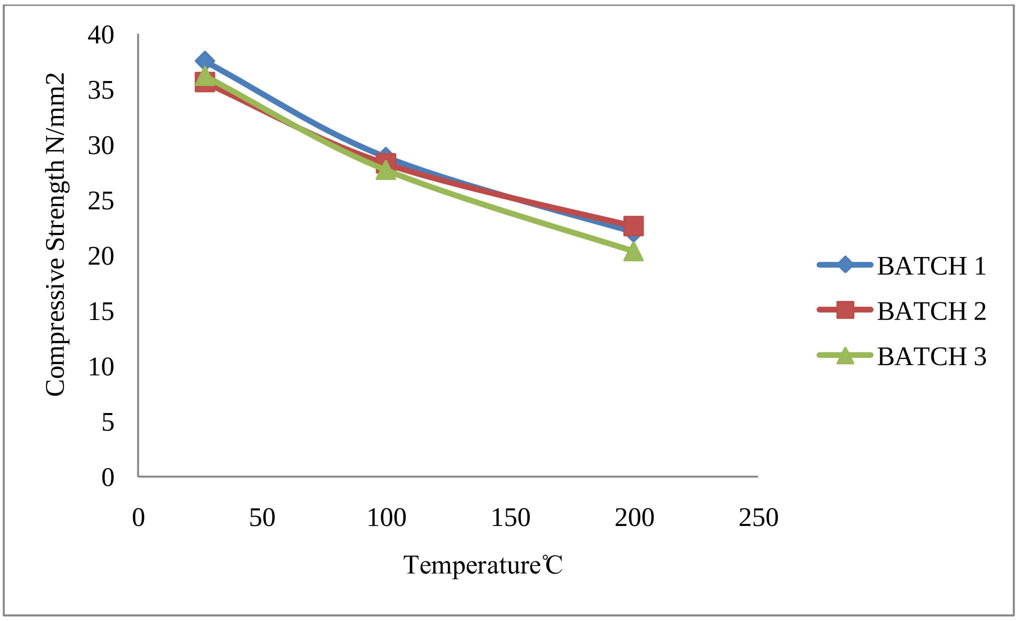


Fig. 6.6: Variation of compressive strength of cylinder of M40 mix

6.3. STRESS-STRAIN RELATIONSHIP:

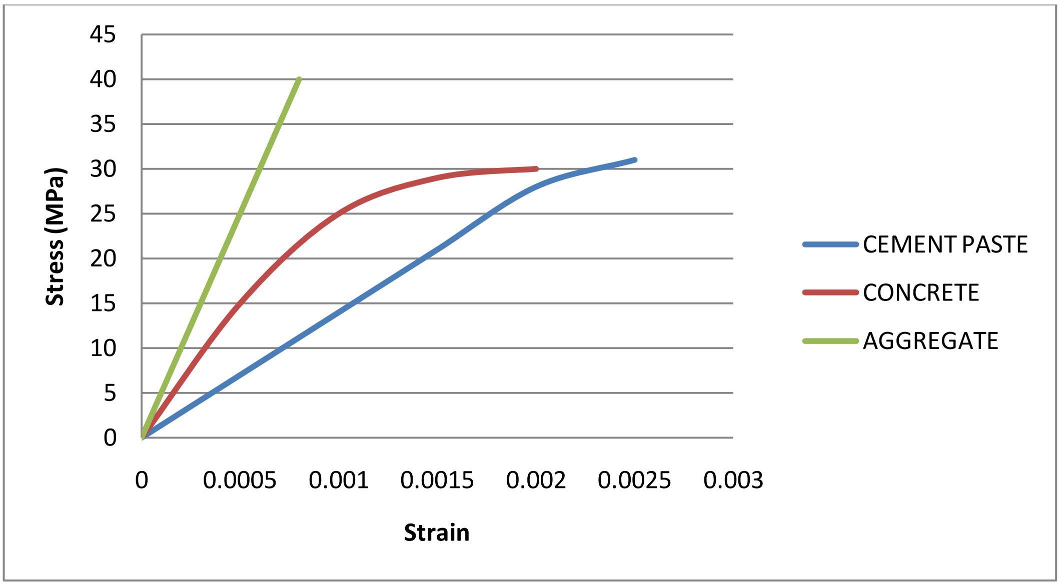
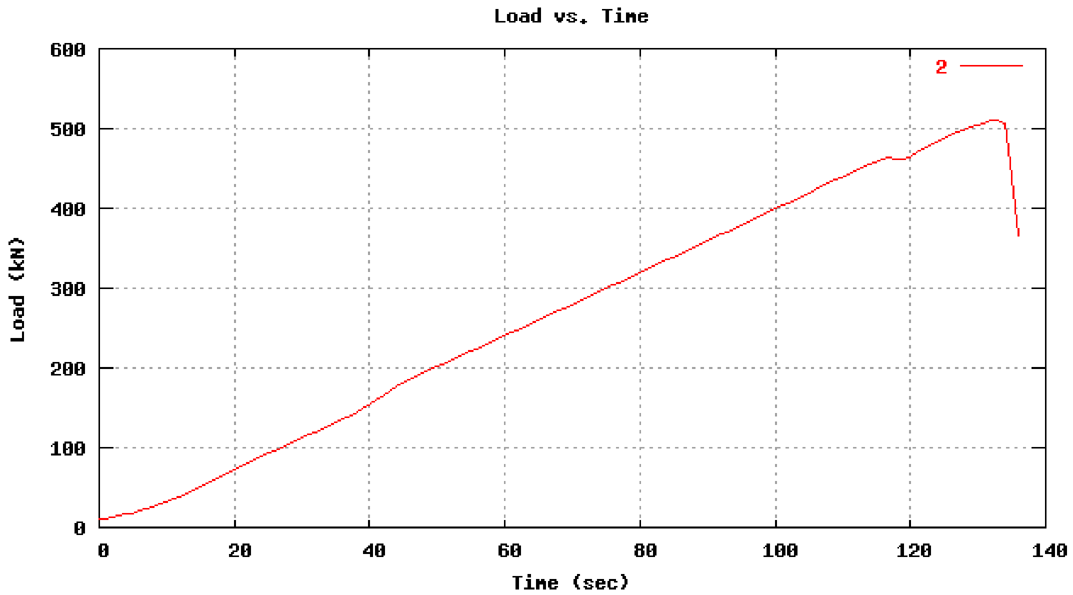


Fig. 6.7: Stress-strain relationship of cement paste, concrete & aggregate [13]

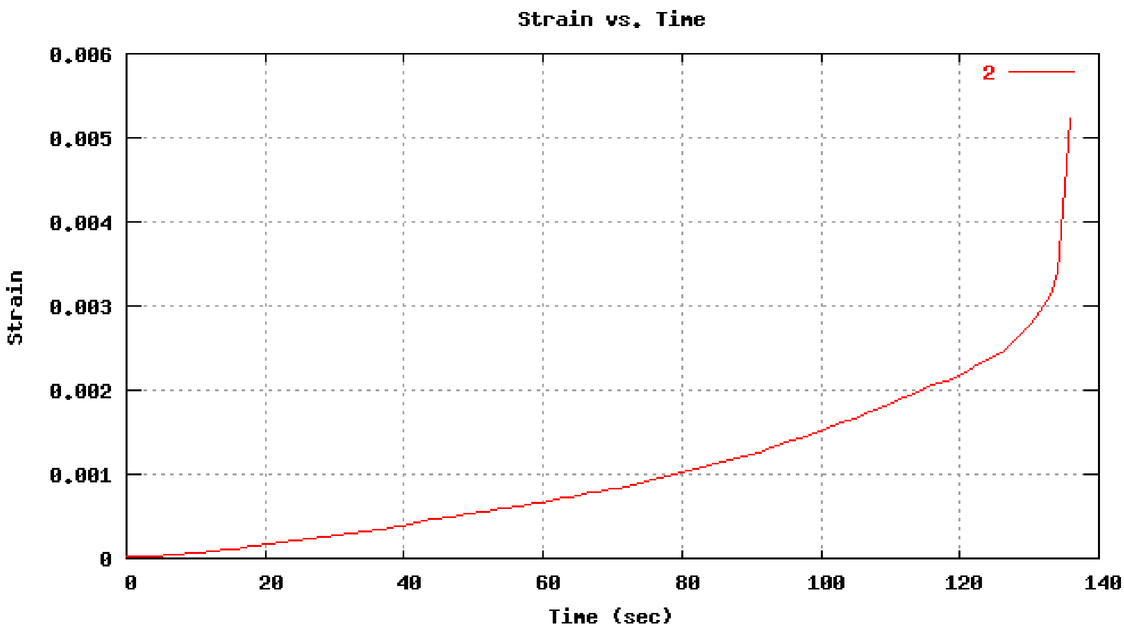
FOR M30 MIX:

Test conduct at room temperature (27℃)

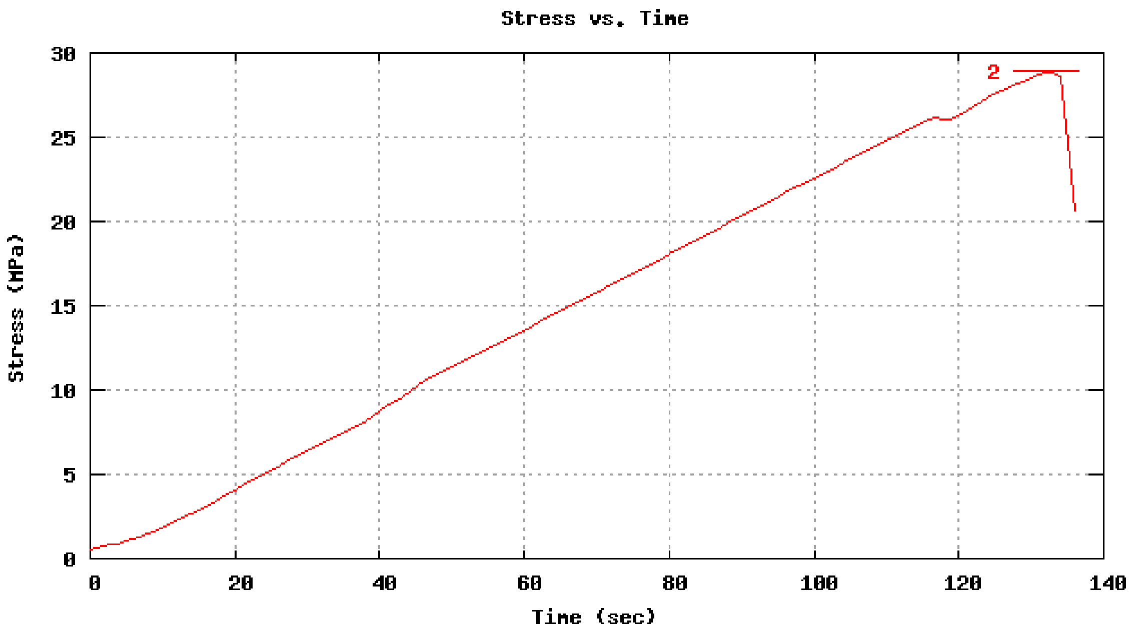
For detailed values refer to Appendix-C



Load vs Time plot conducted at 27℃



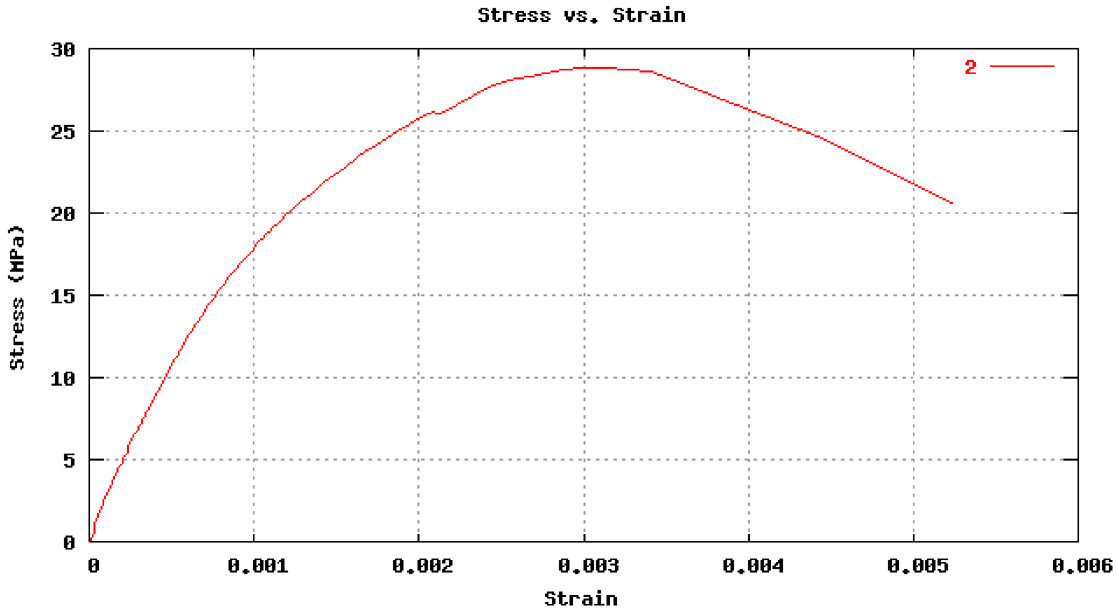
Strain vs Time plot conducted at 27℃



Stress vs Time plot conducted at 27℃

Stress-strain relationship of M30 mix tested on 27℃

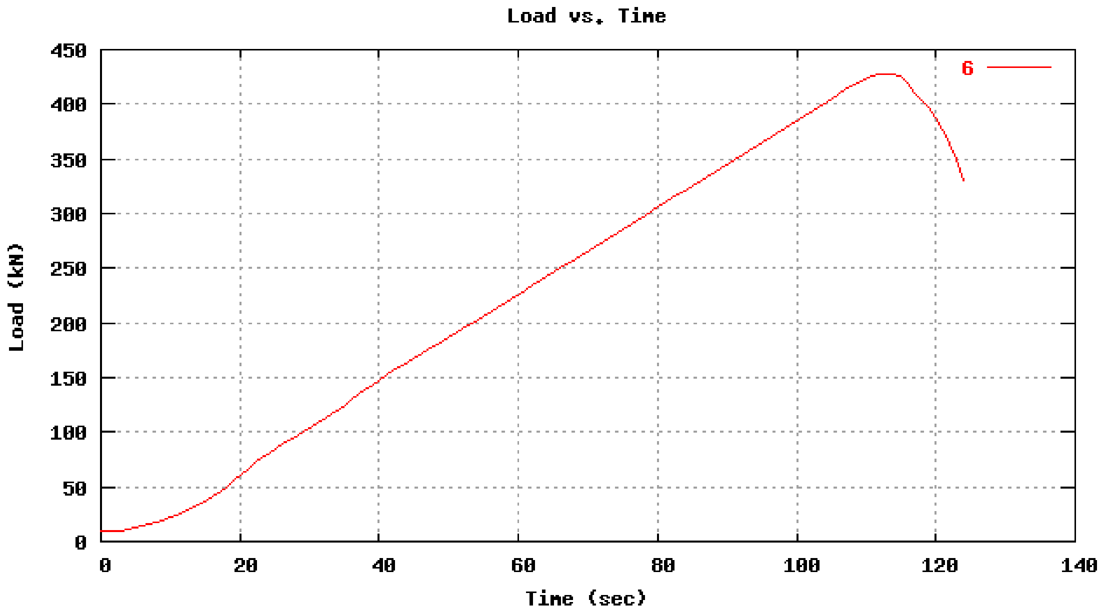
For detailed values refer to Appendix-C



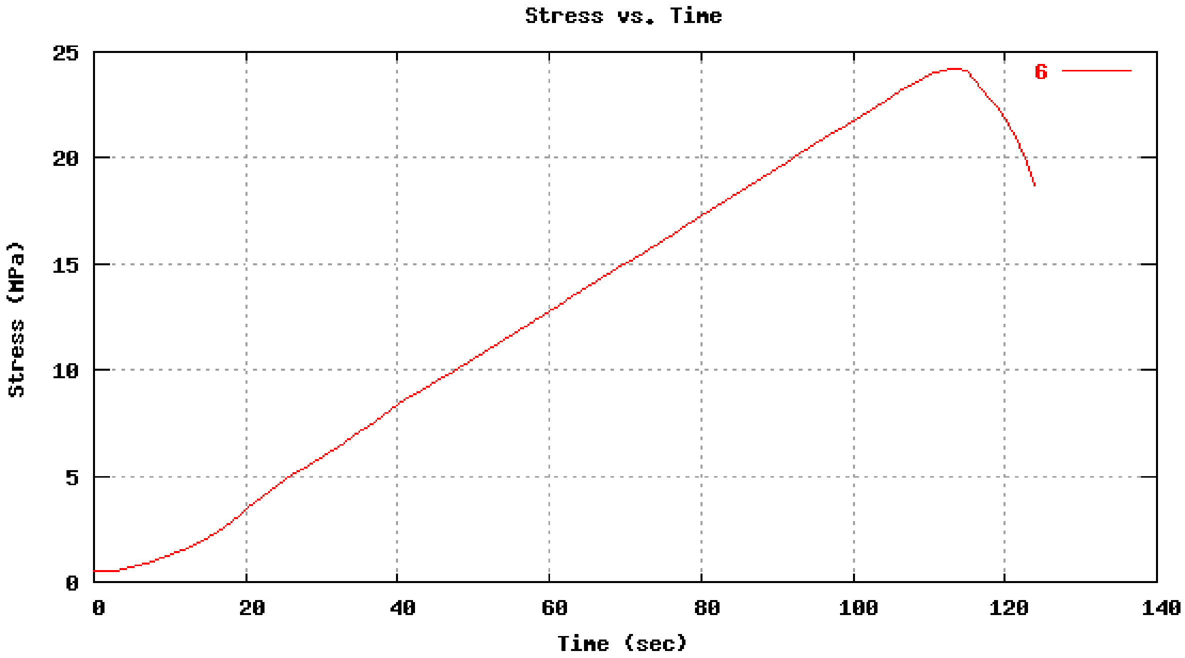
Stress vs Strain plot conducted at 27℃

Test conduct at room temperature (100℃)

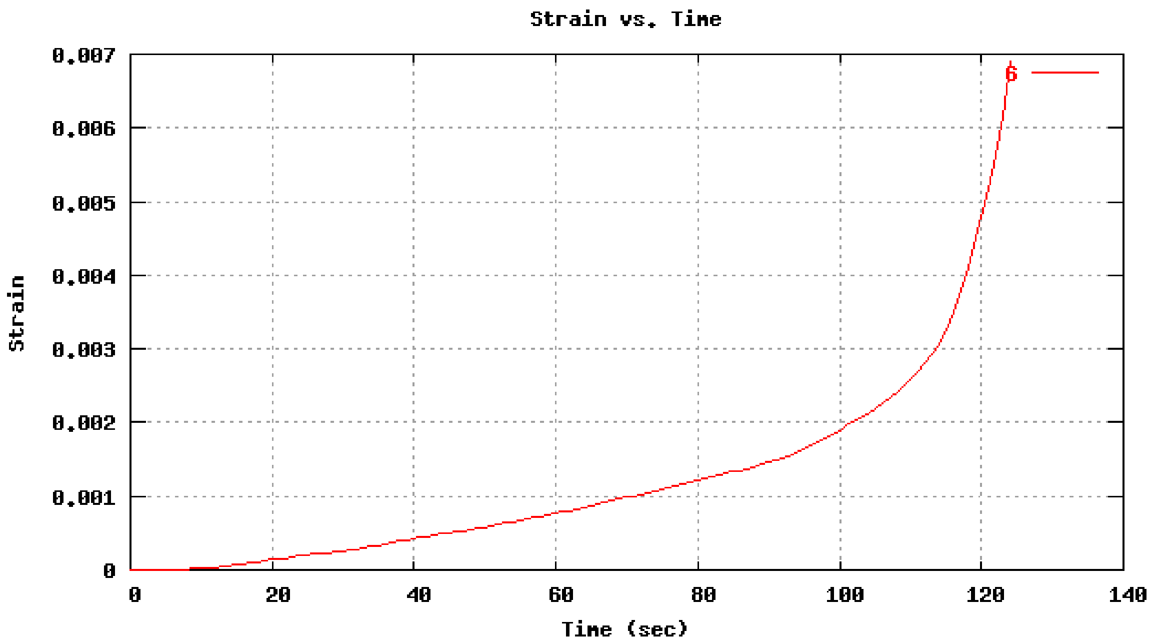
For detailed values refer to Appendix-C



Load vs Time plot conducted at 27℃



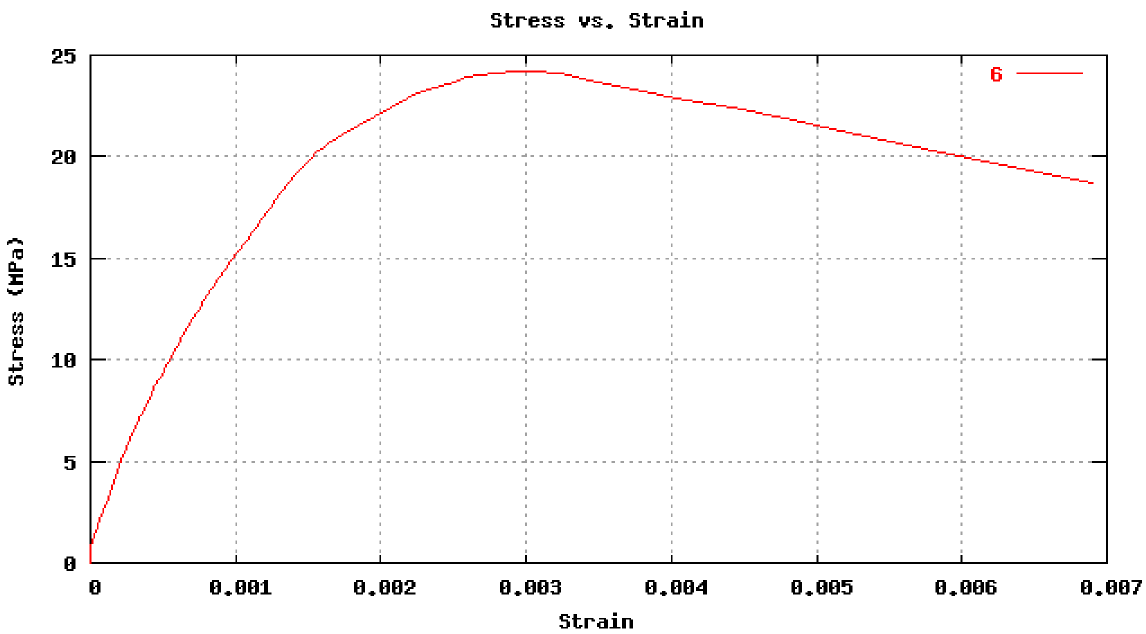
Stress vs Time plot conducted at 27℃



Strain vs Time plot conducted at 27℃

Stress-strain relationship of M30 mix tested on 100℃

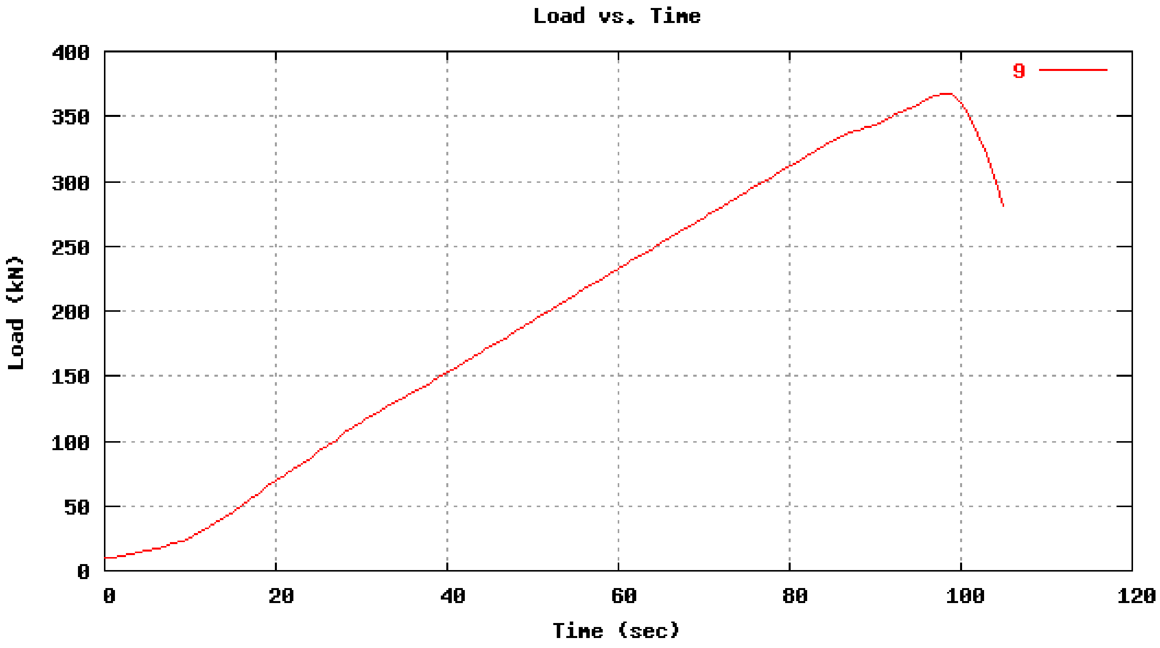
For detailed values refer to Appendix-C



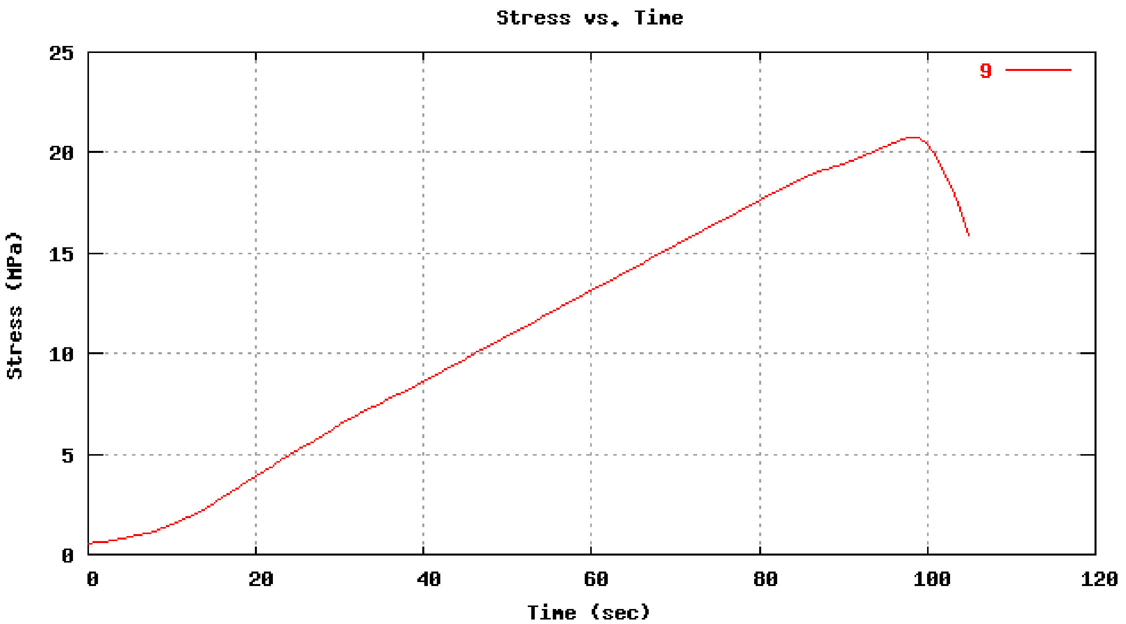
Stress vs Strain plot conducted at 27℃

Test conduct at room temperature (200℃)

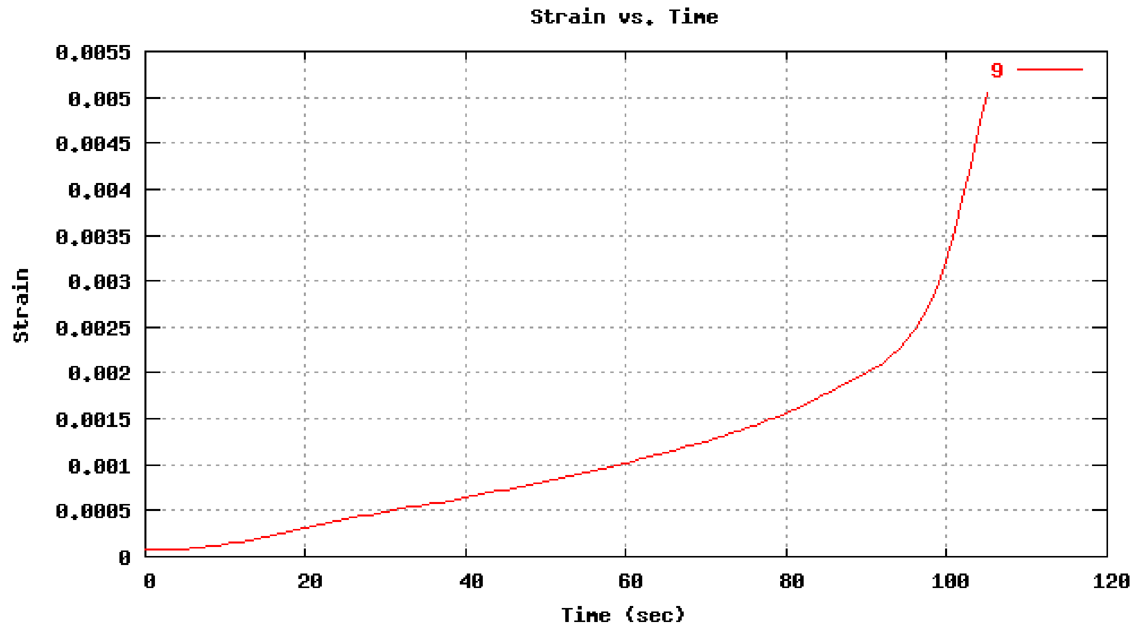
For detailed values refer to Appendix-C



Load vs Time plot conducted at 27℃



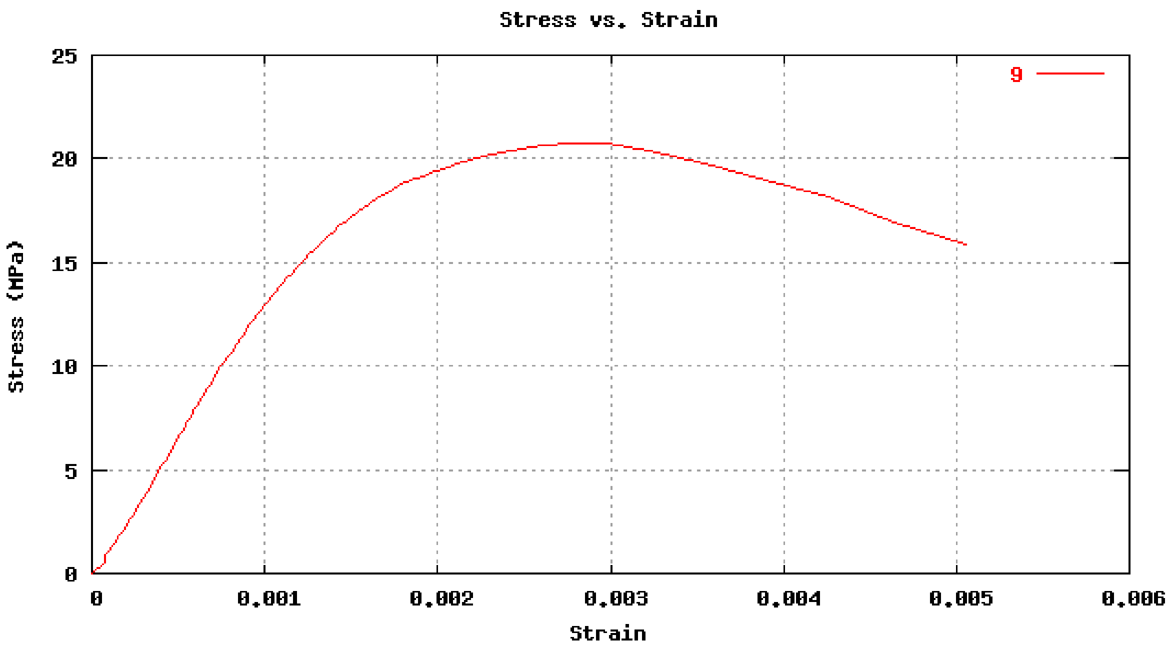
Stress vs Time plot conducted at 27℃



Strain vs Time plot conducted at 27℃

Stress-strain relationship of M30 mix tested on 200℃

For detailed values refer to Appendix-C



Stress vs Strain plot conducted at 27℃

Combined variation of stress vs. strain at 27℃, 100℃ & 200℃

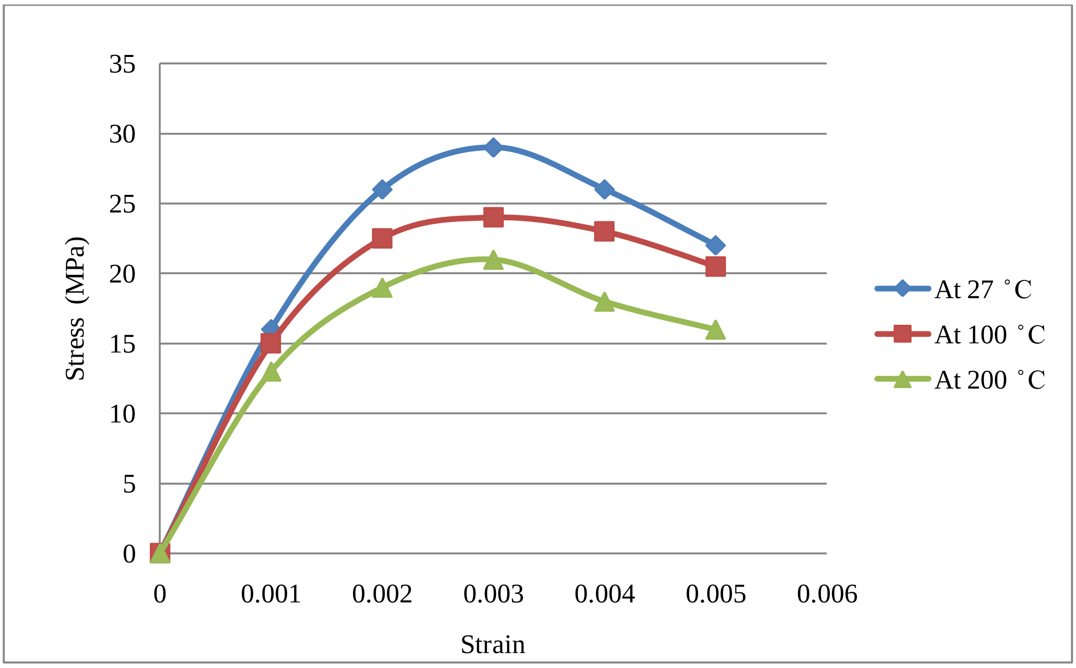


Fig. 6.8 Combined Stress-strain relationship of M30 mix tested on 27℃, 100℃ & 200℃

CHAPTER 7

CONCLUSION

In this chapter, the following conclusions are drawn:

The behaviour of concrete in fire is not well defined at present, and further research is required. The response of concrete materials to heating is fundamentally complex; for example, degradation in the physical properties of concrete varies strongly depending on the details of the concrete mix, including the moisture content, and relevant environmental parameters, such as the maximum fire temperature and fire duration. Systematic studies are required on the effects of different heating conditions on concrete.

Therefore, it can be conclude that

1. Concrete exposed to temperature ranging from 27 ℃ to 200℃, tensile and compressive strength decreases with the increase of temperature. Such decrease is greater in those cooled in water with respect to those cooled in air.

2. The effect of increase in temperature on the strength of concrete is not much upto a temperature of about 200℃.

3. The tensile strength of ordinary concrete cooled in water decreases on rise in temperature upto 200℃.

4. Stress-strain relationship of concrete at increasing temperatures varies but the pattern is similar.

5. The concrete may completely lose its strength as the temperature varies, this is caused due to different thermal properties of aggregate and cement.

CHAPTER 8

SCOPE FOR FUTURE WORK

At present, the concrete has been subjected to some predefined temperature conditions but in real fire conditions the temperatures can go out of control and hence concrete can be subjected to different fire situations, for more realistic observations.

An open hearth (furnace) can be constructed for the purpose of heating concrete specimens and subjecting them to fire lit by using different materials like gasoline, wood, etc. Temperatures of fire can be monitored up to 1degree centigrade using thermo couple or bimetallic strip; in order to facilitate the study of behaviour at elevated temperatures in an efficient way.

REFRENCES

[1] M.A. Youssef, M. Moftah "**General stress–strain relationship for concrete at elevated temperatures**" Engineering Structures 29 (2007) 2618–2634

[2] Jin-Keun Kima, Sang Hun Hanb, Young Chul Song "**Effect of temperature and aging on the mechanical properties of concrete Part I. Experimental results**" Cement and Concrete Research 32 (2002) 1087–1094

[3] Jianzhuang Xiaoa, Gert Konig "**Study on concrete at high temperature in China—an overview**" Fire Safety Journal 39 (2004) 89–103

[4] Long-yuan Li, John Purkiss "**Stress–strain constitutive equations of concrete material at elevated temperatures**" Fire Safety Journal 40 (2005) 669–686

[5] Leyla Tanaçana, Halit Yasa Ersoy , Ümit Arpacıoglu "**Effect of high temperature and cooling conditions on aerated concrete properties**" Construction and Building Materials 23 (2009) 1240–1248.

[6] Metin Husem, "**The effects of high temperature on compressive and flexural strengths of ordinary and high-performance concrete**" Fire Safety Journal 41 (2006) 155–163

[7] K. Sakr & E. EL-Hakimb "**Effect of high temperature or fire on heavy weight concrete properties**" Cement and Concrete Research 35 (2005) 590–596

[8] V.K.R. Kodur and M.A. Sultan "**Effect of temperature on thermal properties of high strength concrete**" Journal of Materials in Civil Engineering © ASCE / March/April 2003

[9] Ilker Bekir Topcu, Mehmet Ugur Toprak "**Fine aggregate and curing temperature effect on concrete maturity**" Cement and Concrete Research 35 (2005) 758– 762

[10] Samir N. Shoukry, Gergis W. William, Brian Downie, Mourad Y. Riad "**Effect of moisture and temperature on the mechanical properties of concrete**" February 2011

[11] Fu-Ping Cheng; V. K. R. Kodur and Tien-Chih Wang "**Stress-Strain Curves for High Strength Concrete at Elevated Temperatures**" (2004)

[12] Neville A.M. and Brooks J. J. Addition Wesley Longman Limited, concrete technology. Reprinted 1997.

[13] Shetty M. S. S. Chand and company limited, New Delhi. Concrete technology fifth revision 2008.

[14] Gambhir M. L. TATA Mc Graw Hill Publishing Company limited New Delhi Concrete technology. Eight reprint 2007.

[15] **BUREAU OF INDIOAN STANDARDS IS 383:1970:** Specifications of coarse and fine aggregates from natural sources for concrete (second revision).

[16] **BUREAU OF INDIAN STANDARDS IS 456 – 2000:** Code of practice for plain and reinforced concrete (fourth revision).

[17] **BUREAU OF INDIAN STANDARDS IS 12269-:2009:** Specification for 43 grade ordinary Portland cement.

[18] **BUREAU OF INDIAN STANDARDS IS 9013: 1978:** Methods of making, curing and determining compressive strength of cured concrete test specimen.

[19] **BUREAU OF INDIAN STANDARDS IS 9103: 1999:** Specification for admixtures for concrete (first revision).

[20] Aitcin , P. C. (1988) , high performance concrete , E $ FN Spoon , London , p 199.

APPENDIX-A

TEST ON CUBICAL SPECIMENS

A-1 Results of 28 days Compressive Strength of M30 mix:

Table A1: Observation sheet of Compressive Strength of M30 mix

Temperature (℃)	Stress (N/mm^2)		
	Batch 1	Batch 2	Batch 3
27	37.77	41.33	40.0
100	34.67	36.44	35.55
200	30.22	31.11	32.44

A-2 Results of 28 days Compressive Strength of M40 mix:

Table A2: Observation sheet of Compressive Strength of M40 mix

Temperature (℃)	Stress (N/mm^2)		
	Batch 1	Batch 2	Batch 3
27	44.44	48.22	47.11
100	40.00	41.77	40.44
200	34.21	35.14	32.44

A-3 Results of 28 days Compressive Strength of M50 mix:

Table A3: Observation sheet of Compressive Strength of M50 mix

Temperature (℃)	Stress (N/mm^2)		
	Batch 1	Batch 2	Batch 3
27	52.44	55.55	54.60
100	44.44	48.00	45.33
200	35.11	41.33	36.44

APPENDIX-B

TEST ON CYLINDRICAL SPECIMENS

B- Results of 28 days Tensile Strength of M30 mix:

Table B1: Observation sheet of Tensile Strength of M30 mix

Temperature (℃)	Stress (N/mm^2)		
	Batch 1	Batch 2	Batch 3
27	2.35	2.22	2.28
100	2.12	1.96	1.99
200	1.77	1.65	1.71

B-2 Results of 28 days Compressive Strength of M30 mix:

Table B2: Observation sheet of Compressive Strength of M30 mix

Temperature (℃)	Stress (N/mm^2)		
	Batch 1	Batch 2	Batch 3
27	28.86	29.99	30.84
100	24.55	25.69	24.95
200	19.86	20.88	19.29

B-3 Results of 28 days Compressive Strength of M40 mix:

Table B3: Observation sheet of Compressive Strength of M40 mix

Temperature (℃)	Stress (N/mm^2)		
	Batch 1	Batch 2	Batch 3
27	37.54	35.65	36.21
100	28.86	28.29	27.72
200	22.06	22.63	20.37

APPENDIX –C

STRESS-STRAIN RELATIONSHIP DATA

Sample	:	2
Shape	:	cylinder
Pace rate	:	4 KN/sec
Maximum load achieved	:	512 KN
Maximum stress achieved	:	28.93 MPa
Maximum strain achieved	:	0.003
System configuration	:	CTM+LVDT

Table C1: Observation Table for Test conduct at 27℃

Time (sec)	Load (KN)	Stress (MPa)	Compression (mm)	Strain
0	10.0	0.57	0.01	0.0000
10	31.9	1.80	0.02	0.0001
20	72.2	4.08	0.05	0.0002
30	112.7	6.37	0.08	0.0003
40	153.8	8.69	0.12	0.0004
50	201.2	11.37	0.16	0.0005
60	239.8	13.55	0.20	0.0007
70	279.9	15.79	0.25	0.0008
80	319.2	18.04	0.30	0.0010
90	359.2	20.30	0.37	0.0012
100	399.30	22.56	0.46	0.0015
110	439.1	24.81	0.55	0.0018
120	464.8	26.27	0.65	0.0022
130	504.6	28.52	0.83	0.0028
133	510.9	28.87	0.90	0.0030
134	506.0	28.59	1.02	0.0034
135	437.4	24.72	1.32	0.0044

Sample : 6
Shape : cylinder
Pace rate : 4 KN/sec
Maximum load achieved : 428.8 KN
Maximum stress achieved : 24.23 MPa
Maximum strain achieved : 0.028
System configuration : CTM+LVDT

Table C2: Observation Table for Test conduct at 100℃

Time (sec)	Load (KN)	Stress (MPa)	Compression (mm)	Strain
0	10.0	0.57	0.00	0.0000
10	22.1	1.25	0.01	0.0000
20	60.6	3.42	0.04	0.0001
30	104.1	5.88	0.08	0.0003
40	147.3	8.32	0.13	0.0004
50	186.2	10.52	0.17	0.0006
60	225.7	12.75	0.23	0.0008
70	265.4	15.00	0.29	0.0010
80	305.6	17.27	0.36	0.0012
90	344.9	19.49	0.44	0.0015
100	384.8	21.75	0.57	0.0019
110	422.9	23.90	0.78	0.0026
114	428.3	24.20	0.90	0.0028
117	410.5	23.20	1.14	0.0038
120	387.6	21.90	1.44	0.0048
124	330.8	18.69	2.07	0.0069

Sample : 9

Shape : cylinder

Pace rate : 4 KN/sec

Maximum load achieved : 369.2 KN

Maximum stress achieved : 20.86 MPa

Maximum strain achieved : 0.027

System configuration : CTM+LVDT

Table C3: Observation Table for Test conduct at 200℃

Time (sec)	Load (KN)	Stress (MPa)	Compression (mm)	Strain
0	10.0	0.57	0.02	0.0001
10	26.0	1.47	0.04	0.0001
20	69.3	3.92	0.09	0.0003
30	114.7	6.48	0.15	0.0005
40	152.7	8.63	0.19	0.0006
50	192.6	10.88	0.25	0.0008
60	232.6	13.14	0.31	0.0010
70	272.2	15.38	0.38	0.0013
80	311.7	17.61	0.47	0.0016
90	343.9	19.43	0.60	0.0020
98	369.2	20.86	0.81	0.0027
102	336.0	18.99	1.17	0.0039
105	281.0	15.88	1.52	0.0051