1 INTRODUCTION

1.1 General

Concrete generally classified as Normal Strength Concrete (NSC), High Strength Concrete (HSC) and Ultra High Strength Concrete (UHSC). Indian Standard Recommended above 35 MPa is HSC. In the international forum, the high strength concrete is classified having strength above 40MPa. More recently, the threshold rose to 50 to 60 MPa. In the world scenario, however, in the last 15 years, concrete of high strength entered the field of construction, in particularly construction of high- rise building. The strength of concrete depends upon the various factors, such as W/C ratio, ratio of cement to aggregate, grading, surface texture, shape, strength and stiffness of aggregate particles, curing, maxing , temperature and time.

The concrete develops strength with continued hydration. The rate of gain of strength is faster to start with and the rate gets reduced with age. It is customary to assume the 28 days strength as the full strength of concrete. It is not only the time but also the temperature during the early period of hydration that influences the rate of gain of strength of concrete. The strength development of concrete depends on both time and temperature it can be said that strength is a function of summation of product of time and temperature. This summation is called maturity of concrete. The maturity method is a technique to account for the combined effects of time and temperature on the strength development of concrete. The method provides a relatively simple approach for making reliable estimates of in- place strength during construction.

Maturity concepts have been developed around 50 years earlier, but it wasn't recognized until a string of fatal construction failures took place in the 1970's. Engineers and researchers began to refine maturity concepts for use in routine construction thereafter. In the spring of 1973, a multi- story apartment building under construction in US, Virginia collapsed when forms were removed in four days of curing and the reason was found as insufficient concrete strength. In the spring of 1978, fifty-one workers were killed when a cooling tower under construction in Willow Island. Once again the concrete collapsed because the concrete was not strong enough to support additional construction loads. At the time, there was no readily available procedure to estimate the in-place strength of concrete. These failures sparked an interest in the maturity method and early-age concrete temperatures, especially when researchers noticed that these failures occurred when the in place concrete was cured at much lower temperature (7 to 10^{o}C or 45 to 50^{o}F) then the laboratory strength specimens. The need for a procedure to make reliable estimates of in-place strength was realized with the approval of ASTM C 1074 in 1987, the first specification applying the maturity method. [ASTM, 1987]

Figure 1: 13 Stories Apartment Building At Sundhara, Kathmandu (Under construction)

Figure 2: 18 stories Apartment Building at Dhapakhel, Lalitpur, (Under construction)

1.2 Problem and issues

Nepalese economy is concentrated in Kathmandu valley, most of the physical facilities are available in Kathmandu. Due to various influence factors the population of Kathmandu valley is growth rapidly and the infrastructures such as housing complex, commercial complex, multi national banks and roads were spread over the agricultural land. The many housing development companies are emerged for the purpose of developing the communal housing facilities in one place. Many housing companies have started to construct multistory building. The housing development growth in vertically is the demand of the modern centuries. Due to lack of space availability it is necessary to prefer the multistory building instead of spreading the plinth area of the building. These high- rise buildings coming up to 13 stories luxurious apartment building at heart of Kathmandu, Sundhara, 18 stories Civil Apartment at Dhapakhal, Lalitpur figure 1& 2, multipurpose multistoried commercial complex 'Kathmandu Mall' and office building etc. In future the number of stories may be increase.

In recent years, worldwide construction industry has shown significant interest in the use of high- strength concrete (HSC). This is due to improvements in structural performances, such as high strength and durability, that it can provide as compared to traditional normal-strength concrete (NSC). In recent years its uses has been extended to high-rise buildings. The use of HSC will be only alternative when we will have multistory building. Despite its possible feasibility, the use of HSC is not rising in Nepal just because of lack of expertise and consciousness on use of quality concrete and its stripping time.

In 1982 Mr. J. Moreno's experiment show that the use of the high-strength concrete and minimum steel offers the most economical solution for columns of high- rise building. According to a report, the increase of only 3.1 times in price for an increase of 4.7 times in load-caring capacity, clearly demonstrates the economy of using high-strength concrete in multistory building column. [Concrete –P.Kumar Mehta, Paulo. J. Monteiro, pp-367]

For the strength of structure and their economical aspect the use of high strength concrete (HSC) is essential in Nepal to meet the worldwide standard. Many researchers have shown the possibility of producing the high strength concrete in Nepal by using local available material and admixture. Mr. Krishna Man Shrestha had produced and tested 92-130MPa. [Shrestha, K.M] concrete in 28 days in IOE lab. Recently many multistoried building had used HSC. ARS Commercial Complex, Pulchowk had just finished construction of the structure part, and they used HSC in compressive member and followed the formwork stripping time as per IS 456 -2000. The test report of concrete of this complex shows that the compressive strength was 53.36 N/mm^2 in 28 days. The use of concreter strength 25 MPa has been gradually increased to 40 MPa and 60 MPa in high rise building construction. ARC is the one of the evidence of using HSC of 53.36 MPa. Especially RMC is used for above concrete strength 30MPa. In 90's Indian construction industries has been use HSC of strength varying from 45 MPa to 60 MPa in high-rise buildings at Mumbai, Delhi and other Metropolitan cities. Similarly high-strength concrete was employed in bridges and flyovers. Year 2000 in India, 75 MPa strength of concrete is being used for first time in one of the flyover at Mumbai. [Concrete technology, pp-275, M.S Shetty]

Most of the high- rise buildings have typical floor plan, so that they can re-use same formwork on next floor also without any modification. For the construction of concrete member not only production of required strength of concrete is important, but also the use of formwork and its stripping time. If we use high strength concrete of 40MPa to 60 MPa instead of 25MPa, it can reduce the stripping time of formwork, it will reduce the whole construction time. It is not only the time beneficial but also the economically benefit for entire project.

The temperature variation of Kathmandu valley is from 5^{o} C to 40^{o}C. The strength of concrete depends upon the time and temperature, it is highly necessary to standardize the maturity period of high strength concrete made by locally available ingredient in Kathmandu valley in between 5^{o}C to 40^{o}C temperature.

Maturity concept is very useful tool for determining in- place strength of the concrete. M.N. Soutsos, P.J. Barnett, J.H. Bungey, and S.G. Millard has use maturity method to evaluate early age strength development of concretes containing ground granulated blast furnace slag (ggbs) at cement replacement level of 20, 35 50 and 70% have been investigated to guidance for their use in fast track construction 28- days targeted mean strength for concrete of 40 MPa to 100MPa. [SP-228-19] Maturity method is the globalization standardized procedure for estimating strength and stripping time of formwork at different temperature of HSC as well as NSC. For the future development of the concrete structure in Nepal it is essential to incorporate the HSC and its proper striping time. However, practically no assessment of strength of concrete before the removal of formwork has been conducted in the country to come up with some idea about the possibilities of removing the formworks without consequences. In this thesis work the stripping time of high strength concrete at ambient air temperature in context of Kathmandu valley is try to evaluate.

1.3 Objectives

1.3.1 General Objective

The overall objective is to evaluate the stripping time of formwork of High Strength Concrete in Kathmandu Valley.

1.3.2 Specific Objectives

- To obtain relationship between relative strength and age in days at different temperature.
- To obtain the stripping period of formwork of horizontal member construct by HSC (40MPa and 60MPa) in Kathmandu.
- To compare the stripping period of HSC (40MPa and 60MPa) with NSC evaluated previously.

1.4 Scope and limitation

- Coarse and fine aggregates are collected from single source.
- Ordinary Portland cement is used and other types of cement are not considered.
- M40 and M60 grade of HSC are used.
- Only one kind of admixture is used.
- Castings of cubes are at normal temperature of laboratory.
- Cube test are conducted without Cupric Sulphate and rubber copping .

1.5 Methodology

To obtain the desired objective and conduct the research work in a systematic manner following methodologies will be adopted.

1.5.1 Literature review

Related literature of concrete, high strength concrete and maturity of concrete have been reviewed. Such literatures are collected from books, M.Sc. thesis, journals, internet and articles. Collected literatures have been studied.

1.5.2 Theoretical concept

Theoretical concept of high strength concrete, maturity method and effect of temperature on stripping time of formwork of HSC have been developed on the basis of various literature. Mix designs of M40, M50 and M60 have been calculated and proportion of cement, fine aggregate, coarse aggregate, water cement ratio have been identified. The doses of super-plasticizer and micro silica have been identified on the basis of previous research and manufactures manual. The outcomes and the experiment result have been compared.

1.5.3 Experimental plan

Experimental plans have been prepared to achieve the above objective. The source of fine aggregate, coarse aggregate have been selected. The detail experimental set up have been prepared to conduct the experiment and achieve objective. All experiments have been planning to conduct at IOE heavy lab.

1.5.4 Material collection

The fine aggregate was collected from Belkhu Khola, coarse aggregate was collected from Mahadev Besi, cement from local market and super-plasticizer and micro silica were collected from supplier. The experimental equipment and tools have been selected and set up at IOE lab.

1.5.5 Preparation of specimen

The required numbers of specimen were prepared in the lab. In each range of temperature three specimens of each grade of concrete have been prepared. The entire specimens were prepared with proper care and maintain the consistency.

1.5.6 Result analysis

The obtained results from the experiment were analyses with the basis of theoretical concept.

1.5.7 Conclusion and recommendation

On the basis of the result analysis the conclusions have been drawn and recommendations were recommended.

2 LITRATURE REVIEW

2.1 General

Some literatures on the properties of concrete and its maturity rule are already in hand. The information was found from the literatures and studied with respect to different aspect of maturity of concrete, hardened concrete properties and mixture proportioning methods.

2.2 Cement

The strength of concrete is dependent on the cement and grade of cement. The earlier strength gaining capacity of ordinary Portland cement (OPC) is higher than Pozzolana Portland cement and later strength gain is vice-versa.

The manufacture of Portland cement is ecologically harmful because the production of one tone of cement results in about one tone of carbon dioxide is being discharged into the atmosphere. Supplementary cementitious materials were introduced into the cement due to the above reason as well as their abundant availability at cheaper costs. The average strength of concrete of cement has been gradually improving worldwide due to the recent inventions, change in the composition of cement and modernization of cement plants. Ideal cement for HSC from rheological point of view is not too fine cement with a very low C_3A content (Neville, 2000). Similarly the compressive strength of concrete with 53 grade cement is always higher the concrete with 43 grade cement (Prakash and Krishnamurti, 1998).

2.3 Aggregate

Aggregates are the important constituents in concrete. Aggregate is the granular material, such as sand, gravel, crushed stone, or iron blast –furnace slag, used with a cementing medium to from hydraulic-cement concrete or mortar. The term coarse aggregate refers to aggregate particles larger than 4.75 mm (No 4 sieve). The smaller the aggregate, the stronger it becomes provided its origin is same as large aggregate becomes small reducing its weakest zones. Smooth gravel cracks at lower stress than rough and angular crushed rock because mechanical bond is influenced by the roughness of the surface and also by the shape of coarse aggregates [Mehta, 1997].

Similarly 12 mm aggregate gave higher strength compared to larger size aggregates. Likewise proper grading of aggregate is achieved by volumetric method or maximum density method. [Joshi, 2001]

Raghu et. al. concluded that the elastic and mechanical properties of HPC are greatly influenced by the characteristics of coarse aggregates. They took three sizes of coarse aggregate and content of each varied between 33 to 46% by volume of concrete. Concrete with smaller aggregate size exhibited better compressive strength. Larger size aggregate resulted stress concentration at matrix aggregate interface. The optimum coarse aggregate content was observed to lie between 35% to 40% by volume of HPC [Raghu et. Al, 1999]

Cetin et. Al has concluded that:

- Increasing coarse aggregate content beyond 40% appears to reduce the compressive strength.
- Concrete with smaller size aggregate exhibited higher compressive strength at a given aggregate content level.
- Harden aggregates are likely to cause stress concentration at higher stress level thus introduce micro cracking in the transition zone.
- Mineralogical characteristics of coarse aggregate appear to be an important factor influencing the mechanical properties of concrete.

2.4 High Strength Concrete

High strength concrete is a relatively recent development in concrete technology made possible by the introduction of efficient water-reducing admixture and high strength cementitious materials. A simple definition would be concrete with a compressive strength greater than that covered by current codes and standards. In UK this would include concrete with a characteristic compressive strength of 60 MPa or more, but in

Norway the design code already includes concrete with characteristic cube strength up to 105 MPa (Helland, 1996) as does the forthcoming Euro code (CEN, 2002).

In order to achieve compressive strength, it is important to understand the factors that govern the strength of concrete, i.e.:

- The properties of the cement paste
- The properties of the transition zone between the paste and the aggregate
- The properties of aggregate
- The relative proportions of the cementituent materials.

The strength of the paste is a function of its water/cement ratio. This is true also for high strength concrete but it is also the effect of the porosity within the past, the particle size distribution of the crystalline phases and the presence of in-homogeneities within the hydrated paste that must be considered. The reduction in water/cement ratio will produce a paste in which the cementitious particles are initially closer together in the freshly mixed concrete. This results in less capillary porosity in the hardened paste and hence a greater strength. The capillary porosity can reduce by optimizing the particle size distribution of the cementitious materials in order to increase the potential packing density. The inclusion of finely divided reactive materials such as silica fume will also contribute to an increase in packing density and reduced capillary porosity.

The role of super plasticizers in enabling workable concrete to produce at very low water/cement ratio is critical. The effect of superplastisizers in preventing the flocculation of Portland cement particles and distributing materials such as silica fume homogeneously through the freshly mixed concrete leads to a reduction in-homogeneities within the paste and hence improved paste strength.

Various literatures relating to HSC, concrete technology, admixtures, codes and manuals will be studies.

Concrete is generally classified as Normal Strength Concrete (NSC), High strength Concrete (HSC) and Ultra High Strength Concrete (UHSC). There is no clear cut boundary for the above classification. Indian Standard Recommended Method of Mix

Design denotes the boundary at 35Mpa between NSC and HSC. They did not talk about UHSC. But elsewhere in the international forum, about thirty year s ago, the high strength label was applied to concrete having strength above 40 MPa. More recently, the threshold rose to 50 to 60 MPa. In the world scenario, however, in the last 15 years, concrete of very high strength entered the field of construction, in particular construction of high-rise buildings and long span bridges. Concrete strength of 90 to 120 MPa is occasionally used. [Concrete technology—M.S Shetty]

2.5 Admixture (Super plasticizer)

Admixture is defined as a material other than cement, water and aggregates that is used as an ingredient of concrete and is added to the batch immediately before or during mixing.

2.6 Stripping Period

The removal of forms after the concrete has set is termed stripping of forms. The stripping or striking of forms should proceed in a definite order. The formwork should be so designed and constructed as to allow them to be stripped in the desired order. The period up to which the forms must be left in place before they are stripped is called stripping time. The factors affecting the stripping time are the position of the forms, the loads coming on the elements immediately after stripping, temperature of the atmosphere, the subsequent loads coming on the element etc.

The concrete should have reached a compressive strength of twice the stress to which it may be subjected at the time of stripping [BS CP 110 Part 1 and CP 114] Table 2.1. Its strength may be determined from control specimens or by means of the nondestructive hardness- test apparatus.

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Table 2.1 Minimum stripping time in days for NSC

Parts of Formwork	Ordinary Weather (16-23°C)			Cold Weather (2-4° C)		
	OPC	HESPC	HAC	OPC	HESPC	HAC
Beam Sides, Walls and unloaded Columns	2	1	1	5	4	1
Slabs with props left underneath	5	3	1	10	8	1
Beam soffits, with props left underneath	8	4	1	14	9	1
Removal of props under slabs	7-14	5	1	21	11	2
Removal of props under beams	14-28	8	1	28	21	3

The props should be kept in place until the concrete has reached at least 70 % of its specified 28 days strength [W.H. Taylor, 1975], care being taken to prevent supporting members from being overloaded. Depending on the weather, early stripping of concrete elements, some 2-28 hours after casting may facilitate finishing operations while care is being taken to avoid profile damage. Bulkhead at construction joints should be left in place for at least 15 hours after concrete placement. [W.H.Taylor, 1975]

Removed forms assist initially in curing the concrete. On thick sections, the thermal insulating property of timber forms should be taken in to account when considering the effect of adiabatic conditions and dimensional change due to heat of hydration of the cement [W.H.Taylor, 1975]. Without inducing thermal shock, form-stripping should be followed with appropriate moist curing. On large projects, laser beam can serve as a precise survey-control deflection detector and guidance systems for alignment purposes, such as that required for the setting or resetting of formwork, slip forms and automated equipment.

In high rise building construction, elastic- plastic load/ deformation props can be used to optimize loading on successive floors, so that each carries a load commensurate with its age-dependent, load-carrying capacity.

IS 456:2000; clause- 11.3 recommended the stripping time for ordinary Portland cement with temperature above 20^o C. table 2.2.

Table 2.2 Stripping time for different conditions

Element and supporting condition (Location of formwork)	**Stripping time, Days.**
Vertical formwork to columns, walls, beams	1 to 2
Slab with props left in position	3
Beam soffits with props left in position	7
Slabs: removal of props	
(a) Span up to 4.5 m	7
(b) Span over 4.5 m	14
Beam and arches: removal of props (support)	
(a) Span up to 6 m	14
(b) Span over 6 m	21

The average times for summer and winter stripping but it is assumed that no loads will be placed on the concrete. The actual time of stripping varies with individual cases and depends on such considerations as type of structure, size of beams, span of slabs, day-by-day temperature, etc. It is usually decided by the engineer in charge

Table 2.3 Stripping Times for Concrete (days)

Shutters and supports	**Ordinary Portland Cement**		**Rapid hardening Portland Cement**	
	36^o to 40^{o}F (2.2 to 4.4^o C)	60^{o}F (15.5^o C)	36^o to 40^o F (2.2 to 4.4^{o}C)	66^{o}F (15.5^{o}C)
All vertical forms	6	1	4	1
Slabs stripped and re-shored	10	3	8	2
Beam bottom stripped and re-shored	14	7	9	4
Props under slabs removed	21	7 to 10	11	4
Props under beams removed	35	16	21	8

2.7 Maturity

The temperature effect is cumulative and can be expressed as a summation of the product of temperature and time during which it prevails. This is known as maturity. We should note that it is the temperature of the concrete itself that is relevant. Maturity can be expressed as

$$M = \sum T . \Delta t \qquad [1]$$

Where, Δt is the time interval (usually in days) during which the temperature is T, and T is the temperature measured form a datum of -11^{o}C, which is the temperature below which strength development cases. Thus, for 30^{o}C, T=41^{o}C. Hence, the units of maturity are ^{o}C days (^{o}F days) or ^{o}C h (^{o}F h). [A.M.Neville, J.J. Brooks—Concrete Technology]

The origins of the maturity method can be traced to a series of paper from England dealing with accelerated curing methods [McIntosh, 1049; Nurse, 1949; Saul, 1951]. The term "maturity" was for the first time liked to the product of time and temperature. Saul suggested that maturity should be calculated with respect to a "datum temperature", which is the lowest temperature at which strength gain is observed. Thus maturity is computed from the temperature history using the famous *Nurse- Saul maturity function*:

$$M = \sum_{0}^{t} (T - T_o)\, \Delta t \qquad [2]$$

Where

M = maturity at age t, ^{o}C- hours or ^{o}C- days)

T = average concrete temperature ^{o} C, during the time interval Δt, and

T_o = datum temperature (usually taken to -10^{o} C),

T = elapsed time (hours or days),

Δt time interval (hours or days).

This equation is known as Nursc-Saul recognized that once concrete has set it will continue to harden at temperature below $0^{o}C$. Thus, Saul recommended a datum temperature of $-10.5^{o}C$ for the use of equation (2). In 1956, Plowman reported the result of a study designed to determine the temperature at which concrete, which has previously undergone setting, ceases to gain strength with time. Based on the test data, Plowman suggested a value of -12.0oC for the datum temperature.

In a paper, Saul presented the principle which has become known as the maturity rule as *"concrete of the same mix at the same maturity has approximately the same strength whatever combination of temperature and times go to make up that maturity"*.

The Nurse-Saul function can be used to convert a given temperature-time curing history to an equivalent age of curing at a reference temperature as follows:

$$t_e = \frac{\sum(T - T_o)}{(T_r - T_o)} \Delta t \qquad [3]$$

Where,

t_e = the equivalent age at the reference temperature

T_r = the reference temperature.

Equation (2) is based on the assumption that the initial rate of strength gain is linear function of temperature, after soon it was realized that this linear approximation might not be valid when curing temperature vary over a wide range. As a result, other researchers proposed a series of alternatives to the Nurse- Saul function [malhotra, 1971; Carino, 1991]. None of the alternatives, however, received widespread acceptance, and the Nurse- Saul function was used worldwide until an improved function was proposed in the late 1970s.

In 1977, Freiesleben Hansen and Pedersen proposed a new function to compute a maturity index from the recorded temperature history of the concrete. This function was based on the Arrhenius equation [Brown and LeMay, 1988] that is used to describe the effect of temperature on the rate of a chemical reaction. The new function allowed the computation of *equivalent age* of concrete as follows:

$$t_e = \sum_{0}^{t} e^{\frac{-E}{R}\left(\frac{1}{273+T}-\frac{1}{273+T_r}\right)} \Delta t \qquad [4]$$

Where,

$t_e =$ The equivalent age at the reference temperature,

E = apparent activation energy, J/mol,

R = universal gas constant, 8.3144 J/ mol-K,

T = average absolute temperature of the concrete during interval Δt, Kelvin,

T_r = absolute reference temperature, Kelvin.

The exponential function is the age conversion factor and is a function of the absolute temperature. According to the Freiesleben Hansen and Pederson had the following values:

For T≥ 20^o C; E= 33500 J/mol

For T< 20^o C; E= 33500 + 1470 (20- T) J/mol

Effect of Temperature on Strength Gain

The key parameter in eq. [4] is the "activation energy" that describes the effect of temperature on the rate of strength development. In 1980s, a procedure was developed to obtain the "activation energy" of a cementitious mixture. The produces is based on determining the effect of curing temperature on the rate constant for strength development. The rate constant is related to the curing time needed to reach a certain fraction of the long- term strength, and can be obtained by fitting an appropriate equation to the strength versus age data acquired under constant temperature (isothermal) curing. The procedure to determine the "activation energy" includes the following steps:

- Curing specimens at different constant temperature.
- Determine compressive strengths at regular age intervals.

- Determine the value of rate constant at each temperature by fitting a strength-age relationship to each set of strength- age data.
- Plot the natural logarithms of the rate constants versus the inverse of the curing temperature (in Kelvin).
- Determine the best- fit Arrhenius equation to represent the variation of the rate constant with the temperature.

By using the procedure, the “activation energy” was determined for concrete and specimens made with different cementitious materials [Tank and Carino, 1991]. It was found that for concrete with water- cement ratio (w/c) = 0.45, the ‘activation energy” ranged from 30 and 64 kJ/mol; while for w/c= 0.60 it ranged from 31 to 56 kJ/ mol, depending on the type of cementitous materials and admixtures.

The exponential term within the summation converts increments of curing time at the actual concrete temperature to equivalent increments at the reference temperature. Thus the exponential term can be considered as an *age conversion factor*, α:

$$\alpha = e^{\frac{-E}{R}\left(\frac{1}{T}-\frac{1}{T_r}\right)} \qquad [5]$$

The reference temperature is taken as 23^{o} C (273+ 23= 296 K)

Strength Development Relationships

The most appropriate maturity function for a particular concrete mixture is to determine the variation of the rate constant with curing temperature. The rate constant is related to the rate of strength gain at a constant temperature, and it can be obtained from an appropriate equation of strength gain versus age. The relationship that have been used to represent strength development of concrete is the hyperbolic equation fro strength gain under isothermal curing up to equivalent ages at 23^{o} C of about 28 days:

$$S = S_{\propto} \frac{K_r (t - t_o)}{1 + K_r (t - t_o)} \qquad [6]$$

Where,

S = strength at age t,

S∞ = limiting strength,

K_r = rate constant, 1/day.

t_o = age at start of strength development.

The parameters $S\infty$, K_r, and t_o are obtained by least- squares curve fitting to strength versus age data. The limiting strength $S\infty$ is the asymptotic value of the strength for the hyperbolic function that fits the data. The best fit value for $S\infty$ does not necessarily represent the actual long- term strength of the concrete. For the hyperbolic model, the rate constant has the following property; when the age beyond t_o is equal to *1/K*, the strength equals 50% of the limiting strength $S\infty$.

Relative Strength Gain

The maturity method is generally used to estimate the in- place strength of concrete by concrete using in- place maturity index and a previously established relationship between maturity index and strength. This assumes that a given concrete possesses a unique relationship between strength and maturity index. This assumption would be acceptable if the long-term strength of concrete was independent of the curing temperature, but this is not the case. It is known that the initial temperature of the concrete affects the long term strength. It is known that the initial temperature of the concrete affects the long- term strength [Verbeck and Helmuth, 1968]. Thus if the same concrete mixture were used for a cold weather placement and a hot weather placement, the strength would not be the same for a given maturity index. It is proposed that the correct application of the maturity method is to estimate *relative strength*. Tank and Carino [1991] proposed the rate constant model of relative strength development, $S/S\infty$, in terms of equivalent age t_e:

$$\frac{S}{S_{\propto}} = \frac{K_r(t_e - t_o)}{1 + K_r[t_e - t_o]} \qquad [7]$$

Strength- Maturity Relationship

The term maturity refers to either a temperature- time factor computed using the Nurse- Saul function or equivalent age computed using any of the maturity functions.

In 1956, Nykanen proposed an exponential strength- maturity relationship.

$$S = S_{\propto}\left(1 - e^{-kM}\right) \quad [8]$$

Where,

S = compressive strength

S_{∞} = limiting compressive strength,

M = maturity,

K = a constant

The limiting compressive strength would be a function of the water- cement ratio. The constant k is related to the initial rate of strength development. According to Nykanen, the value of k would be expected to depend on the water-cement ratio and type of cement.

Plowman observed that when strength was plotted as a function of the logarithm of maturity (based on the Nurse- Saul function) the data fell very close to a straight line. Therefore, he suggested the following empirical strength- maturity relationship:

$$S = a + b\log(M) \quad [9]$$

Where,

a = strength of maturity index M = 1,

b = slope of line

M = maturity index.

The constant a and b are also related to the water – cement ratio of the concrete and the type of cement. The equation [9] is popular because of its simplicity; it plots as a straight line when a log scale is used for the maturity index axis, but it has limitations. It does not provide a good representation of the relationship between strength and maturity index for low or high values of the maturity index. It predicts that strength keeps on increasing with maturity index, that is, there is no limiting strength. In fact the slop of the line, b, represents the strength increase for every ten-fold increase in maturity index.

The maturity method is equally applicable to HSC as well as NSC fro estimates of in-place strength of concrete during construction. Many Journal, research paper has been indicates that the maturity method is the best approach to estimate the in-place strength of HSC as well as NSC. M.N. Soutsos, P.J. Barnett, J. H. Bungey, and S.G. Millard has use maturity method to evaluate early age strength development of concretes containing ground granulated blast furnace slag (ggbs) at cement replacement level of 20, 35, 50 and 70% have been investigated to give guidance for their use in fast track construction 28-days targeted mean strength for concretes of 100 MPa. [SP-228-19]

3 EXPERIMANTAL INVESTIGATION

3.1 Material Collection and Material Testing

The materials have been collected from single source, the source from where most of the sand and aggregate were supplied to Kathmandu Valley. The fine aggregate is collected from Belkhu and coarse aggregate are collected from Mahadev Besi. 53 grade branded cement and plasticizer are collected from local supplier.

The collected materials are tested in IOE lab and the properties of materials are identified and tabulated below.

3.1.1 Cement

Although there are different types of cements available in the market including imported. However, for the research work only ordinary port land cement has been used. Ordinary port land cement of grade 53 has been used for testing.

3.1.2 Coarse Aggregate

Coarse aggregates are collected from single source (Mahadev Besi). The collected aggregate was sieved through 12.5 mm sieve. After sieving the aggregate was washed and surface dried on air temperature. 12.5 mm down aggregate has been used throughout the experiment. The test of physical properties of aggregate has been conducted, but chemical properties are not tested.

Following Test was conducted in IOE lab for identifying the physical properties:-

Crushing Strength Test for aggregate

The strength of coarse aggregate is assessed by the aggregate crushing test. The aggregate crushing value is obtained by measuring the relative resistance to crushing under a gradually applied crushing load. The aggregate crushing value is the indirect measure of the crushing strength of concrete. Procedure of crushing strength test of aggregate has been followed as per IS: 2386 (part-IV) – 1963 and obtained values were tabulated below in table 3.1. The value of crushing strength of aggregate was 23%, as per the IS: 383- 1970 prescribes a 45% limit for the crushing strength.

Specific gravity aggregate

The specific gravity and water absorption of aggregate are useful for the design mix and determination of water contain. The procedure to determine specific gravity has been followed as per IS: 2386 (part-III) – 1963. Similarly procedures of determining of Bulk Density, Water Absorption and Percentage of Void carried out as per IS: 2386 (part- III) – 1963. All obtained values were tabulated in table 3.1

Table 3.1: Physical properties of coarse aggregate

Particulars	Value
Crushing Value	23%
Specific gravity	2.64
Water absorption %	0.62
Dry bulk density	1638 kg/m^3
Percentage of Void	40.96 %

3.1.3 Fine Aggregate

Fine aggregate (Sand) has been sieved through 600 micron and 150 micron sieve. So, that 150-600 micron sand has been used in this research. The physical properties of fine aggregates have been carried out as described in IS: 2386 (part- III) -1963 and identified value are tabulated in Table 3.2

Table 3.2: Physical properties of fine aggregate

Particulars	Value
Specific gravity	2.6
Water absorption %	3.62
Dry bulk density	1726 kg/m^3

3.2 Water

Normal tap water available in the IOE laboratory was used in the experimental purposed. The properties of water are not tested, because for the construction purpose in Nepal the water are not tested.

3.3 Admixture

Powerflow 2239 super-plasticizer is used for the mix of concrete. Required percentage super-plasticizer by weight of cement was used.

3.4 Theoretical Calculation

Theoretical mix designing of mix grade M40, M50, M60, was calculated with reference to the literature and previous research as per the properties of the collected material which are tested in IOE laboratory and the available admixture. The identified mix proportions are tabulated below in table 3.4.1 and the mix design process and calculation are illustrated in appendix B. The proportion of water, cement, fine aggregate, coarse aggregate are as per calculation and the proportion of admixture and micro silica are as per manufactures dosages.

Table 3.4.1: Mix proportion obtained from calculation

Mix Concrete Grade	Mix Proportion					
	W/C	Cement	Fine Aggregate	Coarse Aggregate	Admixture by weight of cement	Micro Silica by weight of cement
M40	0.4	1	1.65	2.92	1.2%	4%
M50	0.35	1	1.472	3.043	1.2%	4%
M60	0.29	1	1.35	2.19	1.2%	4%

3.5 Experimental Plan

3.5.1 Production of High Strength Concrete in Lab

To produce the concrete of M40 and M60, the locally available cement, fine and coarse aggregate was used and w/c ratio was controlled by using super plasticizer. To determine tentative dose of application of super plasticizer, necessary tests was conducted. Trial and error approach was adopted to prepare the mix design of HSC.

3.5.2 Parameters for Maturity

Age of Concrete: - Eight different ages of concrete in 1, 2, 3, 4, 7, 14, 28, days was adopted for compressive test. In each age of day 3 specimens of each temperature group of each mix M 40and M60 was tested. The average compressive strength of Grade M40 and M60 concrete cubes are tabulated in Appendix A

Temperature: - The specimens were prepared and casted at normal laboratory temperature of 20^{o}C to 24^{o}C. The specimens were cured at temperatures range from 5^{o}-10^{o}, 10^{o}-15^{o}, 15^{o}-20^{o}, 20^{o}-25^{o}, 25^{o}-30^{o}, and 30^{o} -35^{o} C.

Mix design: - Trial mix design was done for identify the mix proportion of M40 and M60 grade concrete. For M40 concrete the mix proportion was 0.4:1:1.65:2.92 (W: C: FA: CA) and Admixture (MC-powerflow 2239) 1.2% by weight of cement and micro silica 4% by weight of cement was mixed. For M60 concrete the mix proportion was 0.29:1:1.35:2.19 (W: C: FA: CA) and Admixture (MC-powerflow 2239) 2% by weight of cement and micro silica 4% by weight of cement was mixed.

Sample preparation and testing: - Concrete has been mixed on plate concrete mixing machine as per the identified mixed proportion. All the test specimens has been cast in moulds in two layers, each layer was compacted on a vibrating table and kept in the moulds for 24 hours and re-molded and placed into a curing tank at designated temperature 5-10^{o}C, 10-15^{o}C, 15-20^{o}C, 20-25^{o}C, 25-30^{o}C, 30-35^{o}C The compressive test was conducted.

Stripping Time Estimation: - Three cubes have been tested on each specific temperature at the specific age. Compressive tests have been conducted at IOE laboratory. The load Application on the specimen has been managed as required until its failure. The Strength-Maturity relationship has been obtained by the empirical formula. The stripping time of formwork has been obtained by calculating the equivalent age in terms of a desired strength ratio and number of days required to reach an equivalent age at 23^{o} C, which is obtained by dividing the required equivalent age by the conversion factor.

3.5.3 Experimental Schedule

The experimental schedule of preparing cube samples was illustrated below for two different concrete grades of M40 and M60 at different curing temperature of 5^{o}C to40^{o}C. Experimental schedule is given in Table 3.5.3

Table 3.5.3.Laboratory experiment were conducted as per schedule

Specimen name	Grade of Concrete	Temperature (^{o}C)	Age (Days)	Source of aggregate	Source of sand	Cement	Total Number of Specimen
M40.5.10	M40	5-10	1,2 ,3, 4, 7, 14, 21, 28	Mahadev Besi	Belkhu	OPC	27
M60.5.10	M60						
M40.10.15	M40	10-15					
M60.10.15	M60						
M40.15.20	M40	15-20					
M60.15.20	M60						
M40.20.25	M40	20-25					
M60.20.25	M60						
M40.25.30	M40	25-30					
M60.25.30	M60						
M40.30.35	M40	30-35					
M60.30.35	M60						
M40.35.40	M40	35-40					
M60.35.40	M60						

3.5.4 Experimental Procedure

As per the experimental plan, experimental procedure was carried out to fulfill the targeted objective. The following steps were followed:

Material collection and testing: - Required quantity of materials such as Fine Aggregate, Coarse Aggregate, Cement, Superplasticizer and Micro Silica has been collected from the local market and suppliers. Fine and Coarse Aggregates were washed by tap water and dried in room temperature. The physical properties of the fine and coarse aggregates were identified. Crushing strength of coarse aggregate was tested in IOE lab. All obtained values are tabulated in above table 3.1 and 3.2

Mix design and trial error mix: - Several Trial mix was done for identify the mix proportion of M40 and M60 grade concrete. For M40 and M60 concrete the mix proportion were obtain as 0.4:1:1.65:2.92 (W: C: FA: CA) , Admixture (MC-powerflow 2239) 1.2% by weight of cement and micro silica 4% by weight of cement and 0.29:1:1.35:2.19 (W: C: FA: CA) , Admixture (MC-powerflow 2239) 2% by weight of cement and micro silica 4% by weight of cement respectively. In photo 7 shows the jar of powerflow 2239 superplastisizer, which is manufactured on the date of 2009 Jun. In photo 8 and 9 shows the bag of micro silica and the power of micro silica.

Sample preparation and Curing: - Concrete was mixed as per the above mixed design. The concrete mix was mixed mechanically in plate mixing machine. All the specimens were cast in moulds (100x100x100mm) in two layers, each layer was compacted on a vibrating table and kept in the moulds for 24 hours and re-molded and placed into a curing tank at designated temperature 5-10^{o}C 10-15^{o}C, 15-20^{o}C, 20-25^{o}C, 25-30^{o}C, 30-35^{o}C. The curing temperature above the room temperature was maintained in thermostat heating curing tank and curing temperature below the room temperature maintained by pouring the melted ice on the air tight curing tank. Picture shown in Photo 3 is the concrete mixing machine, photo 4 is mould with concrete cube, and photo 5 is the thermostat curing tank, where the cubes were cured at higher temperature. Photo 6 and 10 shows the UTM machine, use for test the compressive strength of the cubes.

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Figure 3.5.1: Plate concrete mixture machine. ***Figure 3.5.2: Mould with specimens***

Figure 3.5.3: Thermostat curing tank. ***Figure 3.5.4: Compression test on UTM***

Compression testing: - The specimens were prepared and casted at normal laboratory temperature i.e. 20^{o}C to 24^{o}C. The specimens were cured at specified temperature as mansion above. Three cubes have been tested on each specific temperature on the age of 1, 2, 3, 4, 7, 14, 21, and 28 days. Compressive tests have been conducted at IOE laboratory. The load Application on the specimen has been managed as required until its failure. The obtained compressive strength of the specimens were tabulated given in Appendix-A, Table-A

Figure 3.5.5: Super Plasticizer

Figure 3.5.6: Micro Silica bag

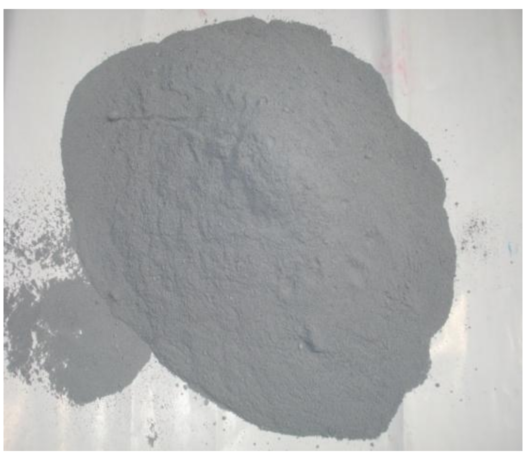


Figure 3.5.7: micro Silica Power

Figure 3.5.8: UTM

4 EXPERIMANTAL RESULTS ANALYSIS AND DISCUSSIONS

Experimental works of production of M40 and M60 concrete has been carried out with the local materials and the experiment has been conducted and the experimental test data has been collected. The compressive strength was collected and the average compressive strength of cubes has been tabulated according to the age and temperature. The stripping time has been obtained by the maturity method as per ASTM C 1074. The maturity method is a technique to account for the combine effect of time and temperature on the strength development of concrete. The method provides a relative simple approach for making reliable estimate of in-place strength during construction. Weaver and Sadgrove used the equivalent age concept to develop a manual for formwork removal times under various temperature conditions. In this thesis the strength of concrete and stripping time of formwork of M40 and M60 grade concrete has been obtained by maturity method and equivalent age approach.

4.1 *Compressive Strength and Equivalent age*

Compressive strength of Specimens of concrete grade M40 and M60 has been found at different temperature and age (Days) and tabulated in Table 1A to 10A, Appendix- A, The equivalent age of the concrete grade M40 and M60 at 23^o C has been computed by the maturity method. The actual age of the concrete is converted to its equivalent age, in terms of strength gain, at the reference temperature. In European practice, the reference temperature is usually taken to be 20^o C, whereas in North American practice it is usually taken to be 23^{o}C. [NIST, Maturity Method: From Theory to Application]. Mr. Shidhartha Shanker has also adopted 23^{o}C as reference temperature to evaluate the maturity of NSC on his M.Sc. thesis. Hence, for this work the reference temperature also adopted as 23^{o}C. The number of days required to reach an equivalent age at 23^o C is obtained by dividing the required equivalent age by age conversion factor and tabulated on Table 4.1.1 D and 4.1.2 D. The stripping period of slab and beam of HSC has been computed on the bases of table 4.1.1 D and 4.1.2 D, and tabulated on Table 4.1.2 E and table 4.1.2.F. The sample calculation of M40 and M60 grade concrete at reference temperature 23^{o}C is illustrated below in topics 2.1.1 and 2.1.2.

4.1.1 Concrete grade M40, at 20-25^{o}C

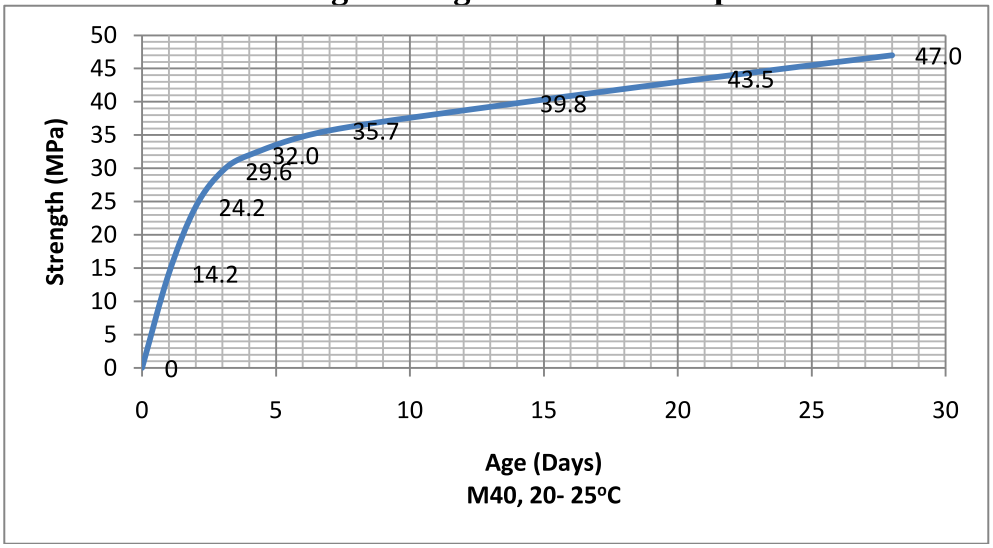
Specimens of concrete grade M40 of mix proportion 0.4: 1: 1.65: 2.92 (W:C:FA:CA) and super plasticizer (MC-Powerflow 2239) 1.2% by weight of cement and micro silica 4% by weight of cement have been mixed and casted at normal laboratory temperature 24^{o}C and de-mould after 24 hr of casting and cured at 20-25^{o}C temperature. The table 4.1.1A gives the average compressive strength of the specimen vs. concrete age in days of 100 mm concrete cubes bathing cured at temperature 20-25^{o}C.Detail information are given in Table-A1, Appendix-A.

Table 4.1.1 A
Compressive strength vs. age, for M40 at 20-25^{o}C

Age in days	Average compressive strength (MPa)
1	14.2
2	24.2
3	29.6
4	32.0
7	35.7
14	39.8
21	43.5
28	47.0

The strength-maturity relationship curve (Figure 4.1.1A) has been plotted from the above data Table 4.1.1A to illustrate how the maturity method could be applied on a construction project.

Figure 4.1.1 A
Strength vs. age at 20-25°C temp.

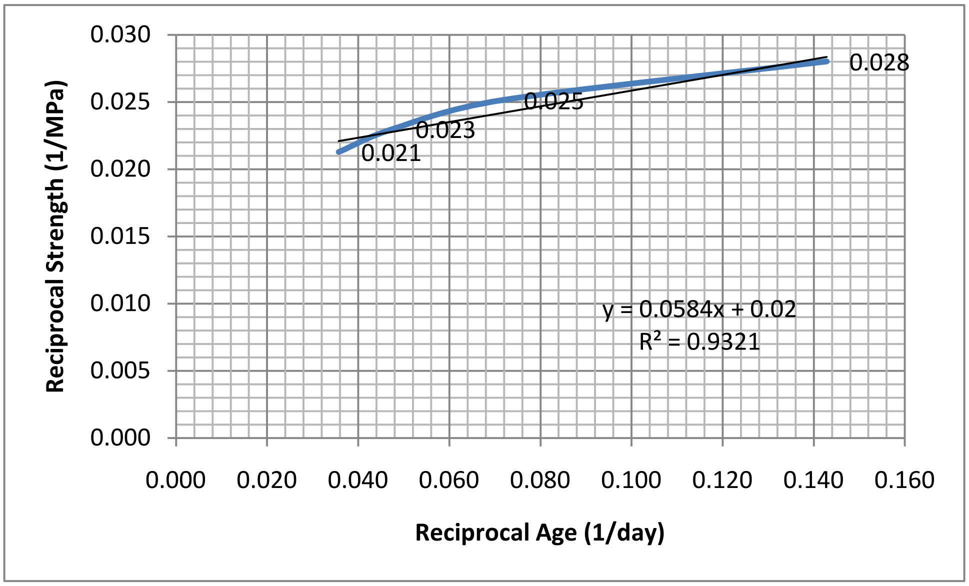


The limiting strength is estimated by considering the data beyond 4days. Figure 4.1.1 B shows the reciprocal of strength plotted against the reciprocal of age. From linear regression analysis, the intercept is 0.02, which equals the reciprocal of limiting strength. Therefore, the limiting strength is S_∞ = 1/ 0.02 MPa, S_∞ = 50.00 MPa

Table 4.1.1 B
Reciprocal Strength vs. Reciprocal Age

Reciprocal Age	Reciprocal Strength
0.143	0.028
0.071	0.025
0.048	0.023
0.036	0.021

Figure 4.1.1 B
Reciprocal Strength vs. Reciprocal Age for evaluating the limiting strength



Next, the rate constant and age is estimated when strength development began by considering the first three test results in table 4.1.1. In accordance with equation S/ $(S_\infty$-S) $=k_r t_o + k_r t$, the quantity has been estimate S/$(S_\infty$-S) is plotted against age as shown in Figure 4.1.1 C. From linear regression analysis, the slope of the line is found to be 0.527 day^{-1}, which is the value of the rate constant at 23^{o}C. The intercept of the line with the age axis is 0.2570days.

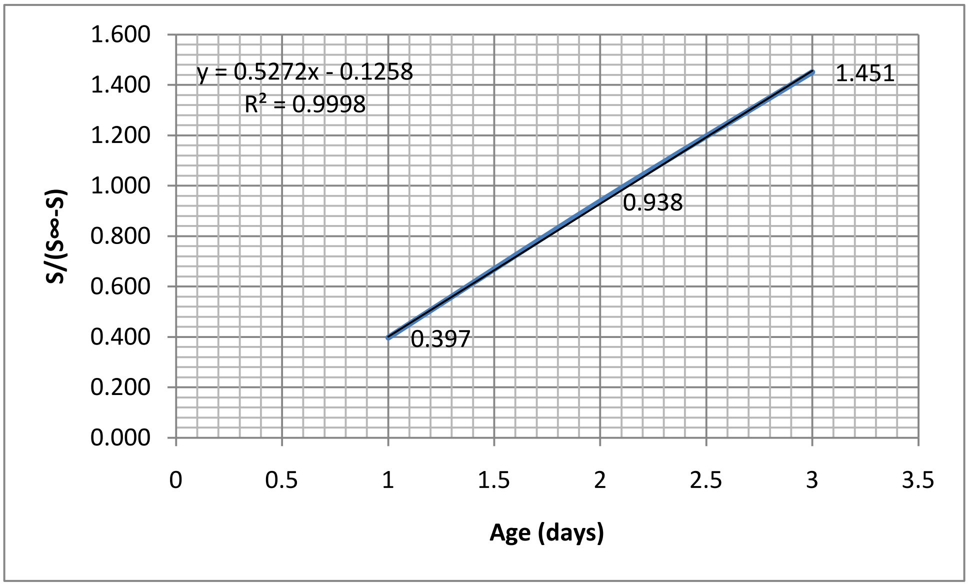
Table 4.1.1 C
S/ (S_∞ - S) vs. Age

Age (Days)	S/ (S_∞ - S)
1	0.397
2	0.938
3	1.451

Figure 4.1.1 C

S/ (S_∞ - S) vs. Age

Plot to evaluate the rate constant and the age When strength development begins



The values of constants are obtained from the above figure:

Limiting Strength S_∞ = 1/ 0.02 MPa,

= 50.00 MPa

Rate constant at 23°C K_r = 0.527days^{-1}

Equivalent age at 23°C t_o = 0. 125/0.527

= 0.2570 days

The hyperbolic strength-equivalent age relationship

$$S(MPa) = S\infty * \frac{K_r(t_e - t_o)}{1 + K_r(t_e - t_o)}$$

$$S_{28} = 46.799\ MPa$$

Fraction of limiting strength

$$RS_\propto = \frac{S}{S_\propto}$$

$$\frac{S}{S_\propto} = 0.936$$

Therefore, the strength of 28 days is 93.6% of the limiting strength.

So the limiting strength is 1/0. 936= 1.068 times the 28 days strength.

Planning of Construction

70% of design strength = 70*46.799/100 = 32.759 MPa

Equivalent Age,

Equivalent age in terms of a desired strength ratio is obtained by the relation:

$$t_e = \frac{RS_\propto}{K_r(\varphi - RS_\propto)} + t_o$$

$$t_e = 3.61\ days$$

` The equivalent age of 3.61 days would be the actual age only if the curing temperature were 23^o C.

Age Factor

Age factor values have been obtained for different concrete temperatures. The number of days needed to reach an equivalent age of 3.61 days at 23^o C is obtained by dividing the required equivalent age by the age factors. Temperature, equivalent Age conversion factor and the formwork stripping time for the slab are tabulated below Table 4.1.1 D.

$$\alpha = e^{\frac{-E}{R}\left[\frac{1}{273+T} - \frac{1}{273+T_r}\right]}$$

Where,

R= 8.3144 J/ (mol.K)

Activation Energy E

If T ≥ 20^o C, E = 33,500 J/(mol.K)

If T < 20 ^{o} C, E= 33,500+1470 (20-T) J/ (mol.K)

For Temperature	0^o C,	E = 62,900 J/mol
	5^o C,	E = 55,550 J/mol
	10 ^{o} C,	E = 48,200 J/mol
	15^o C,	E = 40,850 J/mol

20^o C, E = 43,500 J/mol

25^o C, E = 43,500 J/mol

30^o C, E = 43,500 J/mol

35^o C, E = 43,500 J/mol

40^o C, E = 43,500 J/mol

Table 4.1.1.D, Equivalent age conversion factor and Formwork stripping period of concrete grade M40 of slab.

Temperature (^{o}C)	Age conversion factor	Days to reach t_o = 3.61 days at 23^o C
0	0.116	31.09
5	0.232	15.57
10	0.407	8.88
15	0.630	5.73
20	0.870	4.15
25	1.095	3.30
30	1.369	2.64
35	1.699	2.12
40	2.094	1.72

4.1.2 Concrete grade M60, at 20-25^{o}C

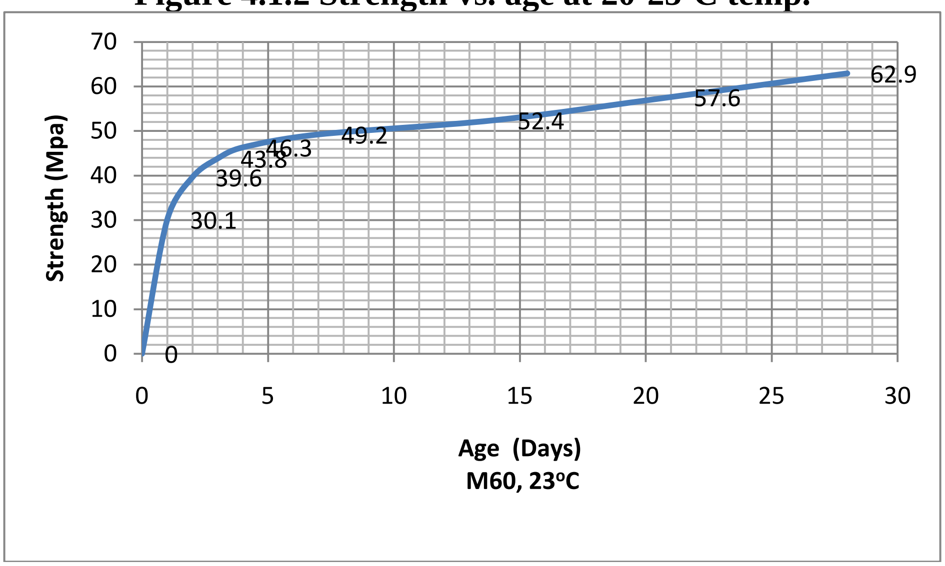
Specimens of concrete grade M60 of mix proportion 0.29:1:1.35:2.19 (W:C:FA:CA) and super plasticizer (MC-Powerflow 2239) 3% by weight of cement and micro silica 4% by weight of cement have been casted at normal laboratory temperature and cured at 20-25oC temperature. The table 4.1.2 gives the average compressive strength of the specimen vs. concrete age in days of 100 mm concrete cubes bathing cured at temperature 20-25oC.Detail information are given in Table-A2, Appendix-A.

Table 4.1.2 Compressive strength vs. age, For M60 at 20-25°C

Age in days	Average compressive strength (MPa)
1	30.1
2	39.6
3	43.8
4	46.3
7	49.2
14	52.4
21	57.6
28	62.9

The strength-maturity relationship curve has been plotted from the above data Table 4.1.2 to illustrate how the maturity method could be applied on a construction project.

Figure 4.1.2 Strength vs. age at 20-25°C temp.

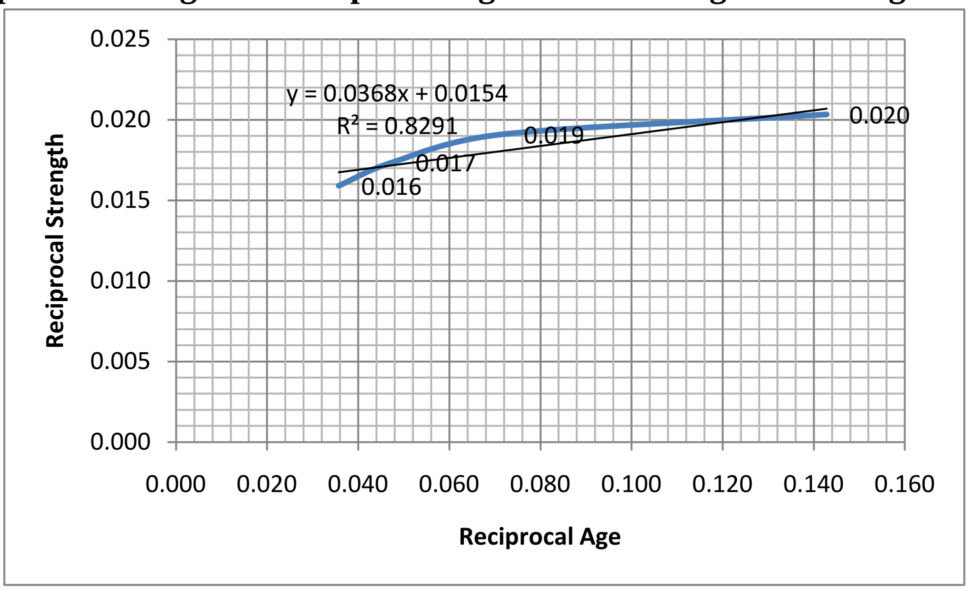


The limiting strength is estimated by considering the data beyond 4days. Figure 4.1.2 B shows the reciprocal of strength plotted against the reciprocal of age. From linear regression analysis, the intercept is 0.015, which equals the reciprocal of limiting strength. Therefore, the limiting strength is S∞ = 1/ 0.015 MPa, S∞ = 66.70 MPa

Table 4.1.2 B
Reciprocal Strength vs. Reciprocal Age

Reciprocal Age	Reciprocal Strength
0.143	0.020
0.071	0.019
0.048	0.017
0.036	0.016

Figure 4.1.2 B
Reciprocal Strength vs. Reciprocal Age for evaluating the limiting strength

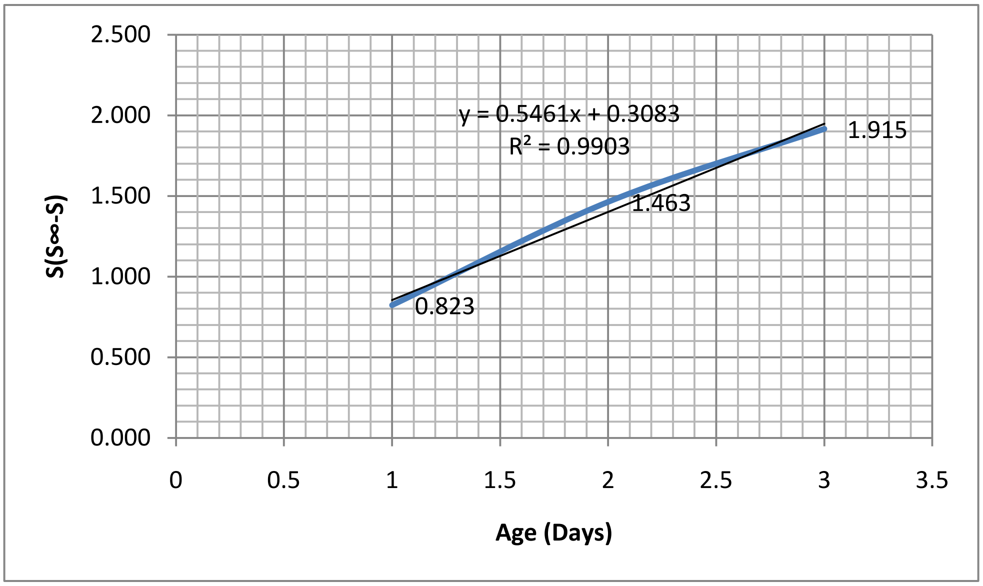


Next, the rate constant and age is estimated when strength development began by considering the first three test results in table 4.1.2. In accordance with equation S/ $(S_\infty\text{-}S) = k_r t_o + k_r t$, the quantity has been estimate $S/(S_\infty\text{-}S)$ is plotted against age as shown in Figure 4.1.2 C. From linear regression analysis, the slope of the line is found to be 0.546 day^{-1}, which is the value of the rate constant at 23^{o}C. The intercept of the line with the age axis is 0.5641days.

Table 4.1.2 C
S/ (S_∞ - S) vs. Age

Age (Days)	S/ (S_∞ - S)
1	0.823
2	1.463
3	1.915

Figure 4.1.2 C
S/ (S_∞ - S) vs. Age
Plot to evaluate the rate constant and the age when strength development begins



The values of constants are obtained from the above figure:

Limiting Strength S_∞ = 1/ 0.015 MPa,

= 66.70 MPa

Rate constant at 23°C K_r = 0.546 $days^{-1}$

Equivalent age at 23°C t_o = 0. 308/0.546

= 0.5641 days

The hyperbolic strength-equivalent age relationship

$$S(MPa) = S\infty * \frac{K_r(t_e - t_o)}{1 + K_r(t_e - t_o)}$$

$$S_{28} = 62.50\ MPa$$

Fraction of limiting strength

$$RS_{\propto} = \frac{S}{S_{\propto}}$$

$$\frac{S}{S_{\propto}} = 0.937$$

Therefore, the strength of 28 days is 93.7% of the limiting strength.

So the limiting strength is 1/0. 937= 1.067 times the 28 days strength.

Planning of Construction

70% of design strength = 70*62.5/100 = 43.75 MPa

Equivalent Age,

Equivalent age in terms of a desired strength ratio is obtained by the relation:

$$\mathrm{t_e} = \frac{\mathrm{RS_{\propto}}}{\mathrm{K_r}(\varphi - \mathrm{RS_{\propto}})} + \mathrm{t_o}$$

$$t_e = 3.50\ days$$

The equivalent age of 3.50 days would be the actual age only if the curing temperature were 23^{o} C.

Age Factor

Age factor values have been obtained for different concrete temperatures. The number of days needed to reach an equivalent age of 3.50 days at 23^{o} C is obtained by dividing the required equivalent age by the age factors. Temperature, equivalent Age conversion factor and the formwork stripping time for the slab are tabulated below Table 4.1.2 D.

$$\alpha = e^{\frac{-E}{R}\left[\frac{1}{273+T} - \frac{1}{273+T_r}\right]}$$

Where,

R= 8.3144 J/ (mol.K)

Activation Energy E

If T ≥ 20^o C, E = 33,500 J/ (mol.K)

If T < 20 ^{o} C, E= 33,500+1470 (20-T) J/ (mol.K)

For Temperature	0^o C,	E = 62,900 J/mol
	5^o C,	E = 55,550 J/mol
	10 ^{o} C,	E = 48,200 J/mol
	15^o C,	E = 40,850 J/mol
	20^o C,	E = 43,500 J/mol
	25^o C,	E = 43,500 J/mol
	30^o C,	E = 43,500 J/mol
	35^o C,	E = 43,500 J/mol
	40^o C,	E = 43,500 J/mol

Table 4.1.2.D, Equivalent age conversion factor and Formwork stripping period of concrete grade M60 for slab.

Temperature (^{o}C)	Age conversion factor	Days to reach t_o = 3.50 days at 23^o C
0	0.116	30.17
5	0.232	15.08
10	0.407	8.60
15	0.630	5.55
20	0.870	4.02
25	1.095	3.20
30	1.369	2.55
35	1.699	2.06
40	2.094	1.67

According to the IS 456: 2000, the stripping period of formwork of beam is twice the stripping time of the slab and for the vertical member the stripping period of formwork is not assured from the load carrying capacity, but it is assure from the curing time at which no any crack and damaged are formed at the corner of the column. So the stripping period of the formwork of compression member is identify by in terms of curing time at which no cracks of damage formed at the edge specimen during de-moulding or removing of formwork.

The identified stripping period of high strength concrete of grade M40 and M60 are tabulated below table 4.1.2 E and table 4.1.2.F

Table 4.1.2.E, Formwork stripping time of concrete grade M40

Temperature (^{o} C)	Types of Formwork	
	Horizontal Member (Days)	
	Slab	Beam
0	31.09	62.18
5	15.57	31.14
10	8.88	17.76
15	5.73	11.46
20	4.15	8.30
25	3.30	6.60
30	2.64	5.28
35	2.12	4.24
40	1.72	3.44

Table 4.1.2.F, Formwork stripping time of concrete grade M60

Temperature (^{o} C)	Types of Formwork	
	Horizontal Member (Days)	
	Slab	Beam
0	30.17	60.34
5	15.08	30.16
10	8.60	12.20
15	5.55	11.10
20	4.02	8.04
25	3.20	6.40
30	2.55	5.10
35	2.06	4.12
40	1.67	3.34

4.1.3 Concrete grade M40 and M60, at different temperature

The average compressive strength of age 1, 2, 3, 4, 7, 14, 21, 28 days at temperature range 5-10^o C, 10-15^{o}C, 15-20^{o}C, 25-30^{o}C, 30-35^{o}C has been obtain and separately tabulated below according to the temperature range. The tables give the average compressive strength of the specimen vs. concrete age in days of 100 mm concrete cubes bathing cured at different temperature. Limiting Strength S_∞, Rate of Constant

K_r, Equivalent Age t_e and Age Conversion Factor α were obtained by above process and tabulated below in Table 4.1.8.Detail information of compressive strength were given in Table-A3, Appendix-A.

Table 4.1.3 Compressive strength vs. age, M60 and M40 grade concrete at 30-35^oC

Age in days	Average compressive strength (MPa) of M60	Average compressive strength (MPa) of M40
1	15.5	10.7
2	24.0	21.6
3	31.3	23.6
4	34.0	27.6
7	36.1	29.6
14	38.5	32.5
21	56.0	33.5
28	64.3	40

The strength-maturity relationship curve has been plotted from the above data Table 4.1.3 to illustrate how the maturity method could be applied on a construction project.

Figure 4.1.3 Strength vs. age

M60 and M40 grade concrete at 30-35^oC temp.

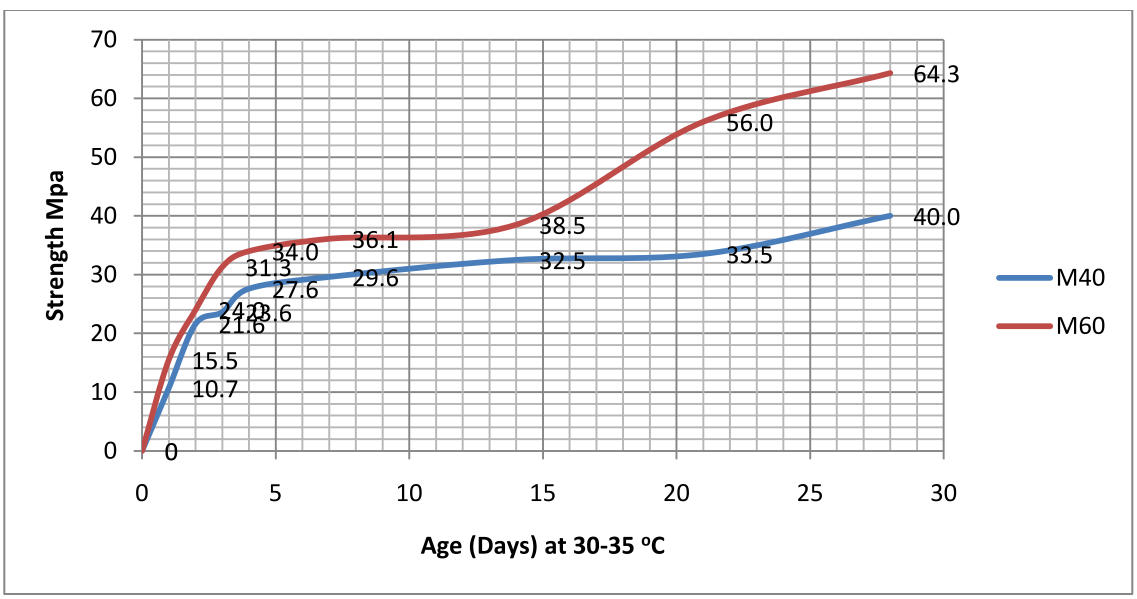


**Table 4.1.4Compressive strength vs. age,
M60 and M40 grade concrete at 25-30°C**

Age in days	Average compressive strength (MPa) of M60	Average compressive strength (MPa) of M40
1	23.2	16.2
2	30.3	22.0
3	45.2	30.5
4	45.9	32.0
7	46.3	35.7
14	52.8	43.5
21	60.9	45.5
28	65.3	49.2

The strength-maturity relationship curve has been plotted from the above data Table 4.1.5to illustrate how the maturity method could be applied on a construction project.

Figure 4.1.4 Strength vs. age

M40 grade concrete at 25-30°C temp

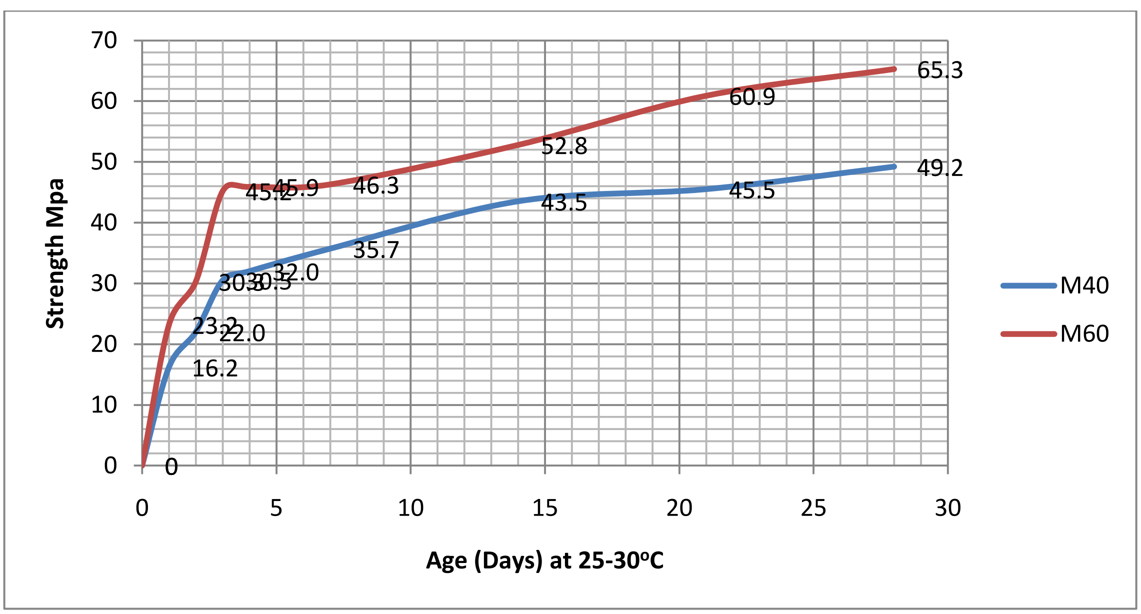


Table 4.1.5Compressive strength vs. age,
M60 and M40 grade concrete at 15-20°C

Age in days	Average compressive strength (MPa) of M60	Average compressive strength (MPa) of M40
1	12.3	7.2
2	20.6	15.2
3	32.4	18.9
4	34.4	20.3
7	38.4	22.8
14	45.3	26.5
21	53.0	31.5
28	62.5	40.6

The strength-maturity relationship curve has been plotted from the above data Table 4.1.5to illustrate how the maturity method could be applied on a construction project.

Figure 4.1.5 Strength vs. age
M60 and M40 grade concrete at 15-20°C

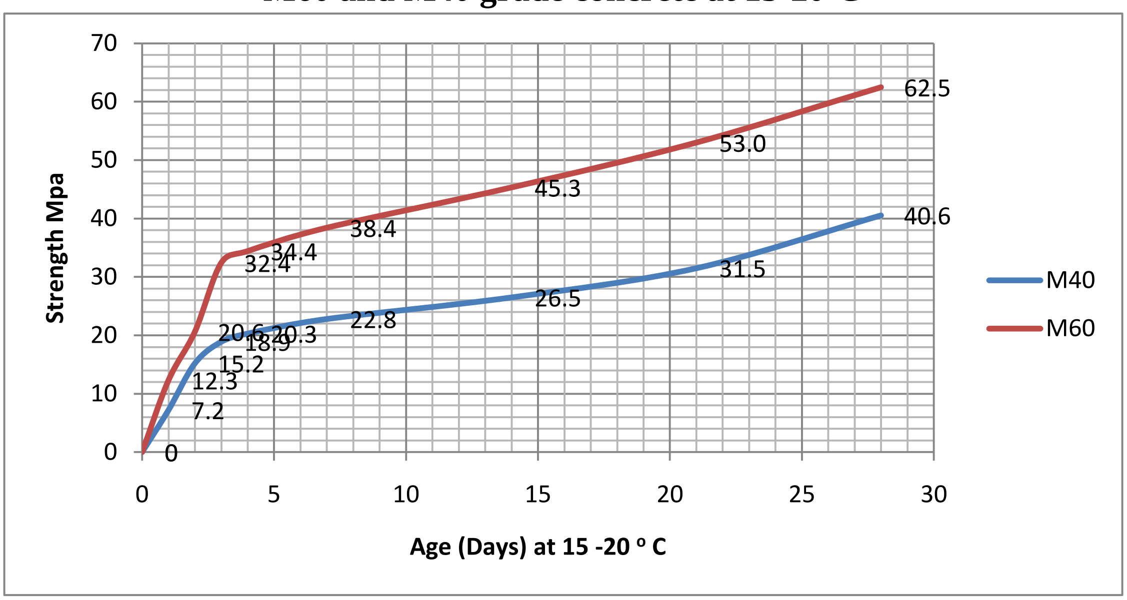


Table 4.1.6Compressive strength vs. age,
M60 and M40 grade concrete at 10-15°C

Age in days	Average compressive strength (MPa) of M60	Average compressive strength (MPa) of M40
1	9.1	7.2
2	18.8	13.5
3	26.7	17.1
4	30.4	20.3
7	38.4	22.8
14	45.3	27.3
21	53.0	33.2
28	63.6	43.1

The strength-maturity relationship curve has been plotted from the above data Table 4.1.5to illustrate how the maturity method could be applied on a construction project.

Figure 4.1.6 Strength vs. age
M60 and M40 grade concrete at 10-15°C

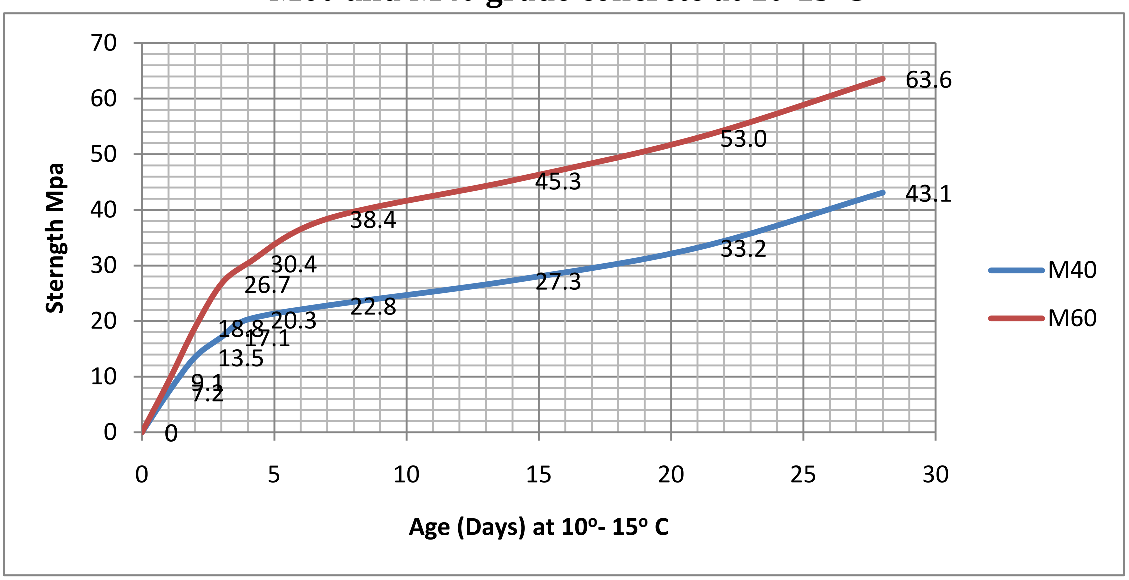


Table 4.1.7Compressive strength vs. age,
M40 grade concrete at 5-10^{o}C

Age in days	Average compressive strength (MPa) of M60	Average compressive strength (MPa) of M40
1	12.3	7.2
2	19.0	10.1
3	20.7	13.3
4	24.7	15.6
7	29.0	16.5
14	35.3	25.5
21	53.0	32.2
28	62.5	41.3

The strength-maturity relationship curve has been plotted from the above data Table 4.1.5to illustrate how the maturity method could be applied on a construction project.

Figure 4.1.7 Strength vs. age
M40 grade concrete at 5-10^{o}C

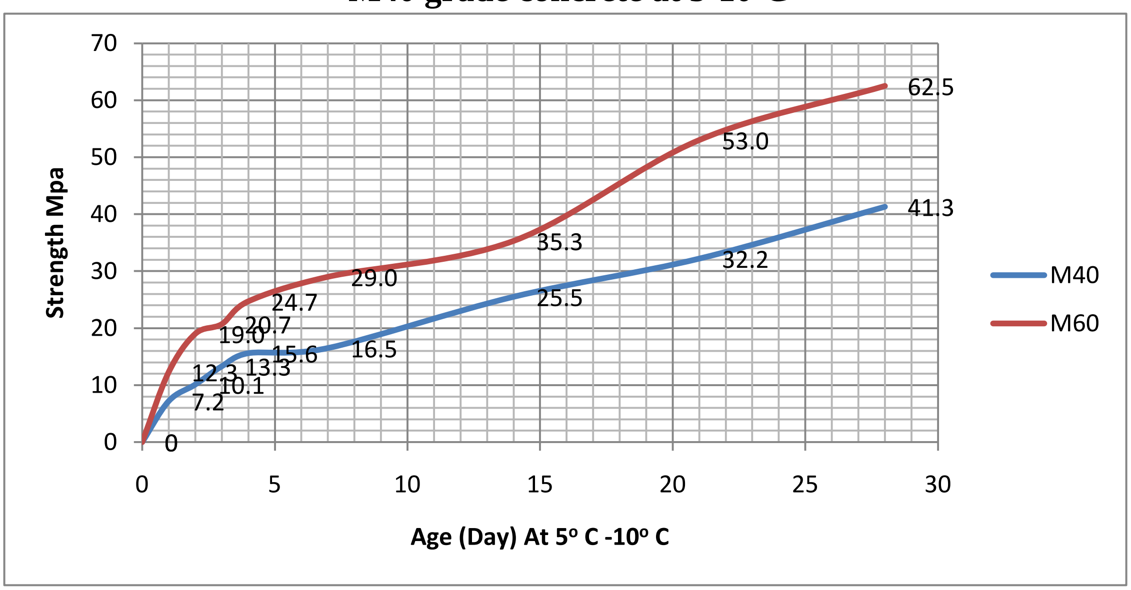


Table 4.1.8 Value of Limiting Strength, Rate of Constant and Equivalent Age of M40 and M60 concrete at different temperature range

Concrete Grade	Temperature Range ^oC	Limiting Strength S_∞ (MPa)	Rate of Constant K_r (Days^{-1})	Equivalent Age t_e (Days)
M40	5-10	71.43	0.058	12.90
M60		83.33	0.078	11.48
M40	10-15	50.00	0,175	7.93
M60		71.43	0.225	6.75
M40	15-20	45.50	0.621	6.12
M60		71.40	0.311	5.4
M40	20-25	50.00	0.527	3.61
M60		66.70	0.5641	3.50
M40	25-30	55.56	0.402	4.47
M60		76.9	0,496	3.79
M40	30-35	40.0	0.536	3.56
M60		76.90	0.216	2.75

4.2 Average Stripping period of M40 and M60 concrete

According to the above experimental data, the stripping period of formwork of slab and beam of concrete grade M40 and M60 has been identifying for the weather condition and are tabulated in table: 4.2.1and 4.2.2.

Table: 4.2.1. Average Stripping Time of M40 concrete in days

Part of formwork	**Cold weather 0^o C – 9^oC in days**	**Ordinary weather 10^oC- 25^oC in days**	**Hot weather 24^oC- 35^oC in days**
Removal of formwork under slab	18.51	4.34	2.16
Removal of formwork under beam	37.02	8.78	4.32

Table: 4.2.2. Average Stripping Time of M60 concrete in days

Part of formwork	Cold weather 0^o C – 9^oC in days	Ordinary weather 10^oC- 25^oC in days	Hot weather 24^oC- 35^oC in days
Removal of formwork under slab	17.95	4.25	2.09
Removal of formwork under beam	34.23	8.51	4.18

4.3 Comparative study of striping period of formwork of HSC and NSC

Comparative study of the stripping period of formwork of M40, M60 and M20 has been conducted. Comparison chart of is tabulated below Table 4.3.1. It gives the clear picture, that in low temperature formwork of slab and beam of M40 and M60 will remove 8 and 10 days earlier than the M20 and in high temperature 1 day earlier.

Table 4.3.1, Stripping Period of Formwork of HSC and NSC

S.no	Temp (^{o}C)	High strength Concrete Horizontal Member				Normal Strength Concrete Horizontal Member	
		Concrete Grade M40		Concrete Grade M60		Concrete Grade M20	
		Slab in days	Beam in days	Slab in days	Beam in days	Slab in days	Beam in days
1	0	31.09	62.18	30.17	60.34	38	76
2	5	15.57	31.14	15.08	30.16	20	40
3	10	8.88	17.76	8.60	12.20	11	22
4	15	5.73	11.46	5.55	11.10	7.5	15
5	20	4.15	8.30	4.02	8.04	5.5	11
6	25	3.30	6.60	3.20	6.40	4.5	9
7	30	2.64	5.28	2.55	5.10	3.5	7
8	35	2.12	4.24	2.06	4.12	3.0	6
9	40	1.72	3.44	1.67	3.34	2.5	5

5 CONCLUSION

1. Maturity concept is the very useful tools for determining stripping time of formwork at different temperature of High Strength Concrete as well as Normal Strength Concrete. It has been known from the various literatures, journal, research paper and this experimental investigation.
2. Formwork stripping time of slab of High Strength Concrete of grade M40 using OPC at 0^oC is 31.09 days which is 7 days earlier than the M20 concrete. At moderated temperature 15^o C is 5.73 days which is 2 days earlier and high temperature 40^oC is 1.72 days which is one days earlier. Similarly concrete grade M60 is 8dayes, 2 days and one day earlier respectively.
3. Formwork stripping time of beam of High Strength Concrete grade M40 at low temperature of 0^oC is 62.18 days, which is 13 82 days earlier than the M20 concrete. At moderate temperature 15^oC is 11.46 days, which is 3.54 days earlier and high temperature of 40^oC is 3.44 days, which is 1.56 days earlier. Similarly concrete grade M60 is 15.66 days, 4 days and 1.66 days earlier respectively.
4. It has been observed from the experimental investigation is that the initially the strength is gained rapidly up to fourth days then after fourth days the strength will gain slowly up to the 28^{th} days.
5. It has been found from the experimental investigation is that 28^{th} days average compressive strength of concrete is increased with the increase in the curing temperature from 0^oC to 35^oC. At curing temperature. 28^{th} days compressive strength of M40 concrete at $10\,^o$C, $15\,^o$C, $20\,^o$C, $25\,^o$C, $30\,^o$C and $35\,^o$C is 41.3 MPa, 43.1 MPa, 40.6 MPa, 47.0 MPa, 49.2 MPa, 40.0 MPa respectively. Similarly compressive strength of M60 concrete at $10\,^o$C, $15\,^o$C, $20\,^o$C, $25\,^o$C, $30\,^o$C and $35\,^o$C is 62.5 MPa, 63.6 MPa, 62.5 MPa, 62.9 MPa, 65.3 MPa, 64.3 MPa respectively
6. In Kathmandu at cold weather temperature from 0^oC to 10^o C the stripping time of M40 and M60 concrete of slab has been found 18.51 and 17.95 days. Whereas at temperature 10^o C to 25^o C the stripping time of concrete M40 and M60 is 4.34 and 4.25 days. Similarly at high temperature 25^o C to 35^o C the stripping time of M40 and M60 concrete is 2.16 and 2.09 days respectively.

7. In Kathmandu at cold weather temperature from 0^oC to 10^o C the stripping time of M40 and M60 concrete of beam has been found 37.02 and 34.23 days. Whereas at temperature 10^o C to 25^o C the stripping time of concrete M40 and M60 is 8.78 and 8.51 days. Similarly at high temperature 25^o C to 35^o C the stripping time of M40 and M60 concrete is 4.32 and 4.18 days respectively.
8. At higher temperature the stripping time of M40 and M60 grade concrete is same. At lower temperature of 0^o C the stripping time of M60 is two Days earlier then the M40 grade concrete

6 RECOMMENDATION

Maturity of High strength Concrete with the use of superplastisizer and micro silica has been widely studied. But in context of Nepal such studies are not done. By applying the maturity method the stripping time of formwork at different temperature of concrete M40 and M60 are identified in this thesis. There are many other aspect can be identified for the further studies related to the stripping time of concrete and the maturity of the concrete. Some of the aspects are recommended as follows:

1. The effect of admixture and superplastizer on the strength gaining capacity of concrete at cyclic temperature.
2. Study of stripping time of high strength concrete using fine and coarse aggregate from different source.

REFERENCES

1) Ambuja Technical Literature Series -66; Commentary and Guidelines for application of IS 456: 2000, Section -2
2) ASTM C 1074, 1998, "practice for Estimating Concrete Strength by the Maturity Method" 2000 ASTM Standards Vol.o4.o2, ASTM Conshohoken, PA
3) Gambhir M.L; CONCRETE TECHNOLOGY, 2nd edition; Tata Mc Graw-Hill Publishing Company Ltd. New Delhi, 8th Reprint 2001
4) IS 456: 2000; IS Code of Practice for Plain and Reinforced Concrete, 4yh revision; Bureau of Indian Standards, Manak Bhawan, New Delhi.
5) M. Neville & J.J. Brooks; Concrete Technology; International Student edition; Addisonwesly; 1999.
6) M.N. Soutsos, S.J. Barnett, J.H. Bungey, and S.G. Millard.; FAST TRACK CONSTRUCTION WITH HIGH- STRENGTH CONCRETE MIX CONTAINING GROUND GRANULATED BLAST FURNACE SLAG, SP-228-19
7) Malhotra V.M., Carino N.J.; CRC HANDBOOK ON NONDESTRUCTIVE TESTING OF CONCRETE.
8) Melhotra V M; ADVANCES IN CONCRETE TECHNOLOGY; International Conference-2000
9) N.J. Carino and H.S. Lew; THE MATURITY METHOD: FROM THEORY TO APPLICATION. Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg. MD 20899-8611 USA.
10) Neville A. M; PROPERTIES OF CONCRETE; 4th and Final edition; pearson Edition Asia,2006
11) P. Kumar Mehta and Paulo J.M. Monteiro; CONCRETE; Microstructure, properties and Material, Indian Edition

12) Shanker S.; THE EFFECT OF AMBIENT AIR TEMPERATURE ON STRIPPING TIME OF FORMWORK OF REINEORCED CEMENT CONCRETE STRUCTURES, M.Sc thesis, IOE Pulchowk Campus, Jan 2007

13) Shetty M.S; CONCRETE TECHNOLOGY; Theory and Practice, S. Chand and Company Ltd. 1998

14) Shrestha K M; PRODUCTION OF VERY HIGH STRENGTH CONCRETE IN NEPAL; M.Sc. Thesis, IOE Pulchowk Campus, Dec. 2005.

15) Taylor W H; CONCRETE TECHNOLOGY AND PRACTICE; 4th edition

APPENDIX A

Table 1A: Compressive Strength of Concrete Grade M40 at 23^{O} C

S.no	Sample name	Targeted Grade	Temp (°C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp. Strength (N/mm^2)
1	S1	M40	20-25	1	150	15.0	
2	S2	M40	20-25	1	130	13.0	14.2
3	S3	M40	20-25	1	147	14.7	
4	S4	M40	20-25	2	250	25.0	
5	S5	M40	20-25	2	230	23.0	24.2
6	S6	M40	20-25	2	245	24.5	
7	S7	M40	20-25	3	313	31.3	
8	S8	M40	20-25	3	276	27.6	29.6
9	S9	M40	20-25	3	300	30.0	
10	S10	M40	20-25	4	320	32.0	
11	S11	M40	20-25	4	340	34.0	32.0
12	S12	M40	20-25	4	300	30.0	
13	S13	M40	20-25	7	351	35.1	
14	S14	M40	20-25	7	370	37.0	35.7
15	S15	M40	20-25	7	349	34.9	
16	S16	M40	20-25	14	397	39.7	
17	S17	M40	20-25	14	398	39.8	39.8
18	S18	M40	20-25	14	395	39.5	
19	S19	M40	20-25	14	400	40.0	
20	S20	M40	20-25	21	439	43.9	
21	S21	M40	20-25	21	421	42.1	43.5
22	S22	M40	20-25	21	443	44.3	
23	S23	M40	20-25	21	438	43.8	
24	S24	M40	20-25	28	472	47.2	
25	S25	M40	20-25	28	454	45.4	47.0
26	S26	M40	20-25	28	500	50.0	
27	S27	M40	20-25	28	452	45.2	

Table 2A: Compressive Strength of Concrete Grade M60 at 23^{O} C

S.no	Sample name	Targeted Grade	Temp (^{o}C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp. Strength (N/mm^2)
1	P1	M60	20-25	1	240	24.0	
2	P2	M60	20-25	1	343	34.3	30.1
3	P3	M60	20-25	1	319	31.9	
4	P4	M60	20-25	2	421	42.1	
5	P5	M60	20-25	2	390	39.0	39.6
6	P6	M60	20-25	2	376	37.6	
7	P7	M60	20-25	3	453	45.3	
8	P8	M60	20-25	3	435	43.5	43.8
9	P9	M60	20-25	3	427	42.7	
10	P10	M60	20-25	4	456	45.6	
11	P11	M60	20-25	4	490	49.0	46.3
12	P12	M60	20-25	4	443	44.3	
13	P13	M60	20-25	7	480	48.0	
14	P14	M60	20-25	7	530	53.0	49.2
15	P15	M60	20-25	7	465	46.5	
16	P16	M60	20-25	14	520	52.0	
17	P17	M60	20-25	14	530	53.0	52.4
18	P18	M60	20-25	14	510	51.0	
19	P19	M60	20-25	14	535	53.5	
20	P20	M60	20-25	21	592	59.2	
21	P21	M60	20-25	21	553	55.3	57.6
22	P22	M60	20-25	21	598	59.8	
23	P23	M60	20-25	21	562	56.2	
24	P24	M60	20-25	28	593	59.3	
25	P25	M60	20-25	28	620	62.0	62.9
26	P26	M60	20-25	28	640	64.0	
27	P27	M60	20-25	28	662	66.2	

Table 3A: Compressive Strength of Concrete Grade M60 at 15- 20^{O} C

S.no	Sample name	Targeted Grade	Temp (^{o}C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp. Strength (N/mm^2)
1	P28	M60	15-20	1	110	11.0	
2	P29	M60	15-20	1	125	12.5	12.3
3	P30	M60	15-20	1	134	13.4	
4	P31	M60	15-20	2	228	22.8	
5	P32	M60	15-20	2	190	19.0	20.6
6	P33	M60	15-20	2	200	20.0	
7	P34	M60	15-20	3	310	31.0	
8	P35	M60	15-20	3	344	34.4	32.4
9	P36	M60	15-20	3	319	31.9	
10	P37	M60	15-20	4	350	35.0	
11	P38	M60	15-20	4	351	35.1	34.4
12	P39	M60	15-20	4	332	33.2	
13	P40	M60	15-20	7	382	38.2	
14	P41	M60	15-20	7	380	38.0	38.4
15	P42	M60	15-20	7	389	38.9	
16	P43	M60	15-20	14	450	45.0	
17	P44	M60	15-20	14	430	43.0	45.3
18	P45	M60	15-20	14	470	47.0	
19	P46	M60	15-20	14	460	46.0	
20	P47	M60	15-20	21	500	50.0	
21	P48	M60	15-20	21	547	54.7	53.0
22	P49	M60	15-20	21	543	54.3	
23	P50	M60	15-20	21	529	52.9	
24	P51	M60	15-20	28	589	58.9	
25	P52	M60	15-20	28	612	61.2	62.5
26	P53	M60	15-20	28	640	64.0	
27	P54	M60	15-20	28	657	65.7	

Table 4A: Compressive Strength of Concrete Grade M40 at 15- 20^{O} C

S.no	Sample name	Targeted Grade	Temp (^{o}C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp. Strength (N/mm^2)
1	S28	M40	15-20	1	62	6.2	
2	S29	M40	15-20	1	79	7.9	7.2
3	S30	M40	15-20	1	75	7.5	
4	S31	M40	15-20	2	165	16.5	
5	S32	M40	15-20	2	154	15.4	15.2
6	S33	M40	15-20	2	138	13.8	
7	S34	M40	15-20	3	180	18.0	
8	S35	M40	15-20	3	186	18.6	18.9
9	S36	M40	15-20	3	200	20.0	
10	S37	M40	15-20	4	230	23.0	
11	S38	M40	15-20	4	200	20.0	20.3
12	S39	M40	15-20	4	180	18.0	
13	S40	M40	15-20	7	250	25.0	
14	S41	M40	15-20	7	234	23.4	22.8
15	S42	M40	15-20	7	200	20.0	
16	S43	M40	15-20	14	275	27.5	
17	S44	M40	15-20	14	230	23.0	26.5
18	S45	M40	15-20	14	254	25.4	
19	S46	M40	15-20	14	300	30.0	
20	S47	M40	15-20	21	300	30.0	
21	S48	M40	15-20	21	310	31.0	31.5
22	S49	M40	15-20	21	320	32.0	
23	S50	M40	15-20	21	330	33.0	
24	S51	M40	15-20	28	360	36.0	
25	S52	M40	15-20	28	410	41.0	40.6
26	S53	M40	15-20	28	420	42.0	
27	S54	M40	15-20	28	432	43.2	

Table 5A: Compressive Strength of Concrete Grade M40 at 25- 30^{O} C

S.no	Sample name	Targeted Grade	Curing Temp (^{o}C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp. Strength (N/mm^2)
1	S55	M40	25-30	1	179	17.9	
2	S56	M40	25-30	1	168	16.8	16.2
3	S57	M40	25-30	1	140	14.0	
4	S58	M40	25-30	2	234	23.4	
5	S59	M40	25-30	2	195	19.5	22.0
6	S60	M40	25-30	2	230	23.0	
7	S61	M40	25-30	3	285	28.5	
8	S62	M40	25-30	3	289	28.9	30.5
9	S63	M40	25-30	3	340	34.0	
10	S64	M40	25-30	4	320	32.0	
11	S65	M40	25-30	4	301	30.1	32.0
12	S66	M40	25-30	4	340	34.0	
13	S67	M40	25-30	7	350	35.0	
14	S68	M40	25-30	7	365	36.5	35.7
15	S69	M40	25-30	7	356	35.6	
16	S70	M40	25-30	14	429	42.9	
17	S71	M40	25-30	14	438	43.8	43.7
18	S72	M40	25-30	14	440	44.0	
19	S73	M40	25-30	14	439	43.9	
20	S74	M40	25-30	21	420	42.0	
21	S75	M40	25-30	21	450	45.0	45.5
22	S76	M40	25-30	21	460	46.0	
23	S77	M40	25-30	21	490	49.0	
24	S78	M40	25-30	28	500	50.0	
25	S79	M40	25-30	28	489	48.9	49.2
26	S80	M40	25-30	28	487	48.7	
27	S81	M40	25-30	28	490	49.0	

Table 6A: Compressive Strength of Concrete Grade M60 at 25- 30^{O} C

S.no	Sample name	Targeted Grade	Temp (^{o}C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp. Strength (N/mm^2)
1	P55	M60	25-30	1	254	25.40	
2	P56	M60	25-30	1	245	24.50	23.2
3	P57	M60	25-30	1	197	19.70	
4	P58	M60	25-30	2	296	29.60	
5	P59	M60	25-30	2	303	30.30	30.3
6	P60	M60	25-30	2	310	31.00	
7	P61	M60	25-30	3	456	45.60	
8	P62	M60	25-30	3	423	42.30	45.2
9	P63	M60	25-30	3	478	47.80	
10	P64	M60	25-30	4	478	47.80	
11	P65	M60	25-30	4	456	45.60	45.9
12	P66	M60	25-30	4	442	44.20	
13	P67	M60	25-30	7	473	47.30	
14	P68	M60	25-30	7	445	44.50	46.3
15	P69	M60	25-30	7	470	47.00	
16	P70	M60	25-30	14	580	58.00	
17	P71	M60	25-30	14	520	52.00	52.8
18	P72	M60	25-30	14	513	51.30	
19	P73	M60	25-30	14	500	50.00	
20	P74	M60	25-30	21	634	63.40	
21	P75	M60	25-30	21	570	57.00	60.9
22	P76	M60	25-30	21	632	63.20	
23	P77	M60	25-30	21	601	60.10	
24	P78	M60	25-30	28	620	62.00	
25	P79	M60	25-30	28	685	68.50	65.3
26	P80	M60	25-30	28	640	64.00	
27	P81	M60	25-30	28	665	66.50	

Table 7A: Compressive Strength of Concrete Grade M60 at 10- 15^{O} C

S.no	Sample name	Targeted Grade	Temp (^{o}C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp. Strength (N/mm^2)
1	P82	M60	10-15	1	88	8.8	
2	P83	M60	10-15	1	98	9.8	9.2
3	P84	M60	10-15	1	89	8.9	
4	P85	M60	10-15	2	175	17.5	
5	P86	M60	10-15	2	190	19.0	18.8
6	P87	M60	10-15	2	200	20.0	
7	P88	M60	10-15	3	240	24.0	
8	P89	M60	10-15	3	304	30.4	26.7
9	P90	M60	10-15	3	257	25.7	
10	P91	M60	10-15	4	332	33.2	
11	P92	M60	10-15	4	249	24.9	30.4
12	P93	M60	10-15	4	332	33.2	
13	P94	M60	10-15	7	382	38.2	
14	P95	M60	10-15	7	380	38.0	38.4
15	P96	M60	10-15	7	389	38.9	
16	P97	M60	10-15	14	450	45.0	
17	P98	M60	10-15	14	430	43.0	45.3
18	P99	M60	10-15	14	470	47.0	
19	P100	M60	10-15	14	460	46.0	
20	P101	M60	10-15	21	500	50.0	
21	P102	M60	10-15	21	547	54.7	53.0
22	P103	M60	10-15	21	543	54.3	
23	P104	M60	10-15	21	529	52.9	
24	P105	M60	10-15	28	589	58.9	
25	P106	M60	10-15	28	612	61.2	62.5
26	P107	M60	10-15	28	640	64.0	
27	P108	M60	10-15	28	657	65.7	

Table 8A: Compressive Strength of Concrete Grade M40 at 10- 15^{O} C

S.no	Sample name	Targeted Grade	10-15	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp.Strength (N/mm^2)
1	P82	M40	10-15	1	62	6.2	
2	S83	M40	10-15	1	79	7.9	7.2
3	S84	M40	10-15	1	75	7.5	
4	S85	M40	10-15	2	139	13.9	
5	S86	M40	10-15	2	133	13.3	13.5
6	S87	M40	10-15	2	134	13.4	
7	S88	M40	10-15	3	180	18.0	
8	S89	M40	10-15	3	186	18.6	17.1
9	S90	M40	10-15	3	146	14.6	
10	S91	M40	10-15	4	230	23.0	
11	S92	M40	10-15	4	200	20.0	20.3
12	S93	M40	10-15	4	180	18.0	
13	S94	M40	10-15	7	250	25.0	
14	S95	M40	10-15	7	234	23.4	22.8
15	S96	M40	10-15	7	200	20.0	
16	S97	M40	10-15	14	275	27.5	
17	S98	M40	10-15	14	254	25.4	27.3
18	S99	M40	10-15	14	264	26.4	
19	S100	M40	10-15	14	300	30.0	
20	S101	M40	10-15	21	323	32.3	
21	S102	M40	10-15	21	354	35.4	33.2
22	S103	M40	10-15	21	320	32.0	
23	S104	M40	10-15	21	330	33.0	
24	S105	M40	10-15	28	430	43.0	
25	S106	M40	10-15	28	410	41.0	43.1
26	S107	M40	10-15	28	420	42.0	
27	S108	M40	10-15	28	465	46.5	
27	S108	M40	10-15	28	465	46.5	

Table 9A: Compressive Strength of Concrete Grade M60 at 5- 10^{O} C

S.no	Sample name	Targeted Grade	Temp (°C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^2)	Avg.Comp.Strength (N/mm^2)
1	P109	M60	5.-10	1	123	12.3	
2	P110	M60	5.-10	1	124	12.4	12.3
3	P111	M60	5.-10	1	122	12.2	
4	P112	M60	5.-10	2	185	18.5	
5	P113	M60	5.-10	2	190	19.0	19.0
6	P114	M60	5.-10	2	196	19.6	
7	P115	M60	5.-10	3	208	20.8	
8	P116	M60	5.-10	3	204	20.4	20.7
9	P117	M60	5.-10	3	208	20.8	
10	P118	M60	5.-10	4	300	30.0	
11	P119	M60	5.-10	4	249	24.9	29.0
12	P120	M60	5.-10	4	321	32.1	
13	P121	M60	5.-10	7	352	35.2	
14	P122	M60	5.-10	7	350	35.0	35.3
15	P123	M60	5.-10	7	358	35.8	
16	P124	M60	5.-10	14	450	45.0	
17	P125	M60	5.-10	14	430	43.0	45.3
18	P126	M60	5.-10	14	470	47.0	
19	P127	M60	5.-10	14	460	46.0	
20	P128	M60	5.-10	21	500	50.0	
21	P129	M60	5.-10	21	546	54.6	53.0
22	P130	M60	5.-10	21	543	54.3	
23	P131	M60	5.-10	21	529	52.9	
24	P132	M60	5.-10	28	589	58.9	
25	P133	M60	5.-10	28	612	61.2	62.5
26	P134	M60	5.-10	28	640	64.0	
27	P135	M60	5.-10	28	657	65.7	

Table 10A: Compressive Strength of Concrete Grade M40 at 5- 10^{O} C

S.no	Sample name	Targeted Grade	Temp (^{o} C)	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^{2})	Avg.Comp.S trength (N/mm^{2})
1	S109	M40	5.-10	1	62	6.2	
2	S110	M40	5.-10	1	79	7.9	7.2
3	S112	M40	5.-10	1	75	7.5	
4	S113	M40	5.-10	2	101	10.1	
5	S114	M40	5.-10	2	103	10.3	10.1
6	S115	M40	5.-10	2	100	10.0	
7	S116	M40	5.-10	3	132	13.2	
8	S117	M40	5.-10	3	136	13.6	13.3
9	S118	M40	5.-10	3	131	13.1	
10	S119	M40	5.-10	4	156	15.6	
11	S120	M40	5.-10	4	158	15.8	15.6
12	S121	M40	5.-10	4	154	15.4	
13	S122	M40	5.-10	7	169	16.9	
14	S123	M40	5.-10	7	161	16.1	16.5
15	S124	M40	5.-10	7	164	16.4	
16	S125	M40	5.-10	14	255	25.5	
17	S126	M40	5.-10	14	254	25.4	25.5
18	S127	M40	5.-10	14	264	26.4	
19	S128	M40	5.-10	14	247	24.7	
20	S129	M40	5.-10	21	323	32.3	
21	S130	M40	5.-10	21	313	31.3	32.2
22	S131	M40	5.-10	21	320	32.0	
23	S132	M40	5.-10	21	330	33.0	
24	S133	M40	5.-10	28	430	43.0	
25	S134	M40	5.-10	28	410	41.0	43.1
26	S135	M40	5.-10	28	420	42.0	
27	S136	M40	5.-10	28	465	46.5	

Table 11A: Compressive Strength of Concrete Grade M40 at 30- 35^{O} C

S.no	Sample name	Targeted Grade	Temperature ^{o}C	Curing age (days)	Comp. Load (KN)	Com. strength (N/mm^{2})	Avg.Comp.Strength (N/mm^{2})
1	S28	M40	30-35	1	110	11.00	
2	S29	M40	30-35	1	100	10.00	10.7
3	S30	M40	30-35	1	110	11.00	
4	S31	M40	30-35	2	220	22.00	
5	S32	M40	30-35	2	218	21.80	21.6
6	S33	M40	30-35	2	210	21.00	
7	S34	M40	30-35	3	225	22.50	
8	S35	M40	30-35	3	245	24.50	23.6
9	S36	M40	30-35	3	237	23.70	
10	S37	M40	30-35	4	270	27.00	
11	S38	M40	30-35	4	260	26.00	27.6
12	S39	M40	30-35	4	298	29.80	
13	S40	M40	30-35	7	297	29.70	
14	S41	M40	30-35	7	300	30.00	29.6
15	S42	M40	30-35	7	290	29.00	
16	S43	M40	30-35	14	310	31.00	
17	S44	M40	30-35	14	320	32.00	32.5
18	S45	M40	30-35	14	310	31.00	
19	S46	M40	30-35	14	360	36.00	
20	S47	M40	30-35	21	360	36.00	
21	S48	M40	30-35	21	330	33.00	33.5
22	S49	M40	30-35	21	340	34.00	
23	S50	M40	30-35	21	310	31.00	
24	S51	M40	30-35	28	360	36.00	
25	S52	M40	30-35	28	390	39.00	40.0
26	S53	M40	30-35	28	410	41.00	
27	S54	M40	30-35	28	440	44.00	

APPENDIX B

Theoretical mix design of M40, M50 and M60 concrete

Mix design M40

Grade Designation = M-40

Type of cement = O.P.C-55 grade

Admixture = MC-Powerflow 2239

Fine Aggregate = Zone-II

Sp. Gravity Cement = 3.15

Fine Aggregate = 2.61

Coarse Aggregate (20mm) = 2.64

Coarse Aggregate (10mm) = 2.6

Minimum Cement (As per contract) = 400 kg / m^3

Maximum water cement ratio (As per contract) = 0.45

Mix Calculation: -

1. Target Mean Strength = 40 + (5 X 1.65) = 48.25 Mpa

2. *Selection of water cement ratio:*-

Assume water cement ratio = 0.4

3. *Calculation of cement content:* -

Assume cement content 400 kg / m^3

(As per contract Minimum cement content 400 kg / m^3)

4. *Calculation of water:* -

400 X 0.4 = 160 kg which is less than 186 kg (As per Table No. 4, IS: 10262)

Hence o.k.

5. Calculation for C.A. & F.A.: - As per IS: 10262, Cl. No. 3.5.1

$V = [W + (C/S_c) + (1/p). (f_a/S_{fa})] \times (1/1000)$

$V = [W + (C/S_c) + \{1/(1-p)\} . (ca/S_{ca})] \times (1/1000)$

Where

V = absolute volume of fresh concrete, which is equal to gross volume (m^3) minus the volume of entrapped air,

W = mass of water (kg) per m^3 of concrete,

C = mass of cement (kg) per m^3 of concrete,

S_c = specific gravity of cement,

(p) = Ratio of fine aggregate to total aggregate by absolute volume,

(fa) , (ca) = total mass of fine aggregate and coarse aggregate (kg) per m^3 of Concrete respectively, and

Sfa , Sca = specific gravities of saturated surface dry fine aggregate and Coarse aggregate respectively.

As per Table No. 3, IS-10262, for 20mm maximum size entrapped air is 2%.

Assume F.A. by % of volume of total aggregate = 36.5 %

0.98 = [160 + (400 / 3.15) + (1 / 0.365) (Fa / 2.61)] (1 /1000)

=> Fa = 660.2 kg

Say Fa = 660 kg.

0.98 = [160 + (400 / 3.15) + (1 / 0.635) (Ca / 2.655)] (1 /1000)

=> Ca = 1168.37 kg.

Say Ca = 1168 kg.

Considering 20 mm: 10mm = 0.6: 0.4

20mm = 701 kg.

10mm = 467 kg.

Hence Mix details per m^3

Cement = 400 kg

Water = 160 kg

Fine aggregate = 660 kg

Coarse aggregate 20 mm = 701 kg

Coarse aggregate 10 mm = 467 kg

Admixture = 1.2 % by weight of cement = 4.8 kg.

Micro Silica = Centrilit Fume SF

Water: cement: F.A.: C.A. = 0.4: 1: 1.65: 2.92

Mix design M50

Grade Designation = M-50

Type of cement = O.P.C-55 grade

Admixture = MC-powerflow 2239

Fine Aggregate = Zone-II

Sp. Gravity

Cement = 3.15

Fine Aggregate = 2.61

Coarse Aggregate (20mm) = 2.64

Coarse Aggregate (10mm) = 2.6

Minimum Cement (As per contract) =400 kg / m^3

Maximum water cement ratio (As per contract) = 0.45

Mix Calculation: -

1. Target Mean Strength = 50 + (5 X 1.65) = 58.25 Mpa

2. *Selection of water cement ratio:*-

Assume water cement ratio = 0.35

3. *Calculation of water:* -

Approximate water content for 20mm max. Size of aggregate = 180 kg /m^3 (As per Table No. 5, IS: 10262). As plasticizer is proposed we can reduce water content by 20%.

Now water content = 180 X 0.8 = 144 kg /m^3

4. *Calculation of cement content:*-

Water cement ratio = 0.35

Water content per cum of concrete = 144 kg

Cement content = 144/0.35 = 411.4 kg / m^3

Say cement content = 412 kg / m^3 (As per contract Minimum cement content 400 kg / m^3)

Hence O.K.

5. Calculation for C.A. & F.A.: [Formula's can be seen in earlier posts]-

Volume of concrete = 1 m^3

Volume of cement = 412 / (3.15 X 1000) = 0.1308 m^3

Volume of water = 144 / (1 X 1000) = 0.1440 m^3

Volume of Admixture = 4.994 / (1.145 X 1000) = 0.0043 m^3

Total weight of other materials except coarse aggregate = 0.1308 + 0.1440 +0.0043 = 0.2791 m^3

Volume of coarse and fine aggregate = 1 – 0.2791 = 0.7209 m^3

Volume of F.A. = 0.7209 X 0.33 = 0.2379 m^3 (Assuming 33% by volume of total aggregate)

Volume of C.A. = 0.7209 – 0.2379 = 0.4830 m^3

Therefore weight of F.A. = 0.2379 X 2.61 X 1000 = 620.919 kg/ m^3

Say weight of F.A. = 621 kg/ m^3

Therefore weight of C.A. = 0.4830 X 2.655 X 1000 = 1282.365 kg/ m^3

Say weight of C.A. = 1284 kg/ m^3

Considering 20 mm: 10mm = 0.55: 0.45,

20mm = 706 kg.

10mm = 578 kg.

Hence Mix details per m^3

Increasing cement, water, admixture by 2.5% for this trial

Cement = 412 X 1.025 = 422 kg

Water = 144 X 1.025 = 147.6 kg

Fine aggregate = 621 kg

Coarse aggregate 20 mm = 706 kg

Coarse aggregate 10 mm = 578 kg

Admixture = 1.2 % by weight of cement = 5.064 kg.

Water: cement: F.A.: C.A. = 0.35: 1: 1.472: 3.043

Mix design M60

Target strength = 60Mpa

Max size of aggregate used = 12.5 mm

Specific gravity of cement = 3.15

Specific gravity of fine aggregate (F.A) = 2.6

Specific gravity of Coarse aggregate (C.A) = 2.64

Dry Rodded Bulk Density of fine aggregate = 1726 Kg/m^3

Dry Rodded Bulk Density of coarse aggregate = 1638 Kg/m^3

Step-1

Calculation for weight of Coarse Aggregate:

From ACI 211.4R Table 4.3.3 Fractional volume of oven dry Rodded C.A for 12.5mm size aggregate is $0.68m^3$

Weight of C.A = 0.68*1638 = 1108.13 Kg/m^3

Step-2

Calculation for Quantity of Water:

From ACI 211.4R Table 4.3.4

Assuming Slump as 50 to 75mm and for C.A size 12.5 mm the Mixing water = 148 ml

Void content of FA for this mixing water = 35%

Void content of FA (V)

V = {1-(Dry Rodded unit wt / specific gravity of FA*1000)}*100

= [1-(1726/2.6*1000)]*100

= 34.62%

Adjustment in mixing water = (V-35)* 4.55

= (34.62 – 35)*4.55

= -1.725 ml

Total water required = 148 + (-1.725) = 146.28 ml

Step-3

Calculation for weight of cement

From ACI 211.4R Table 4.3.5(b)

Take W / C ratio = 0.29

Weight of cement = 146.28 / 0.29 = 504.21 kg/m^3

Step-4

Calculation for weight of Fine Aggregate:

Cement = 504.21 / 3.15*1000= 0.1616

Water = 146.28 / 1*1000= 0.1462

CA = 1108.13 / 3*1000= 0.3690

Entrapped Air = 2 / 100= 0.020

Total = 0.7376m^3

Volume of Fine Aggregate= 1-0.7376

Weight of Fine Aggregate= 0.2624*2.6*1000= 683.24 kg/m^3

Step-5

Super plasticizer:

For 0.8% = (0.8 / 100)*583.53 = 4.668 ml

Step-6

Correction for water:

Weight of water (For 0.8%) =146.28 – 4.668 =141.61 kg/m^3

Requirement of materials per Cubic meter

Cement = 504.21 Kg/m^3

Fine Aggregate = 683.24 Kg/m^3

Coarse Aggregate = 1108.13 Kg/m^3

Water = 141.61 Kg/ m^3

Super plasticizers = 4.6681 / m^3

So the final ratio becomes

Cement: Fine agg (kg/m^3): Coarse agg (kg/m^3) : Water (l/m^3): Super plasticizer (l/m^3)

1: 1.35: 2.19: 0.29: 0.8

TERMINOLOGY

Maturity: The extent of the development of a property of a cementitious mixture.

Maturity function: A mathematical expression that uses the measured temperature history of a cementitious mixture during the curing period to calculated an index that is indicative of the maturity at the end of that period.

Maturity index: An indicator of maturity that is calculated from the temperature history of the cementitious mixture by using a maturity function.

Maturity method: A technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strength if they attain equal value of the maturity index.

Equivalent age: The number of days or hours at a specified temperature required to produce a maturity equivalent to the maturity achieved by a curing period at a temperature different from the specified temperature.

Datum temperature: The temperature that is subtracted from the measured concrete temperature for calculating the temperature- time factor.

Limiting strength: Limiting strength is estimated by considering for data for test beyond four days. It is the regression constant analogous to the maturity when strength gains begins.

Rate constant: Rate constant is temperature function, it effect the initial rate of strength development. It is related to the curing time needed to reach a certain fraction of long term strength, and can be obtained by fitting an appropriate equation to the strength versus age data acquired under constant temperature (isothermal) curing.

Age conversion factor: It is the function of the absolute temperature. It is the exponential term of the equivalent age function within the summation converts increment of curing time at the actual concrete temperature to equivalent increments at the reference temperature.