"PRODUCTION AND MECHANICAL PROPERTIES OF HIGH PERFORMANCE CONCRETE"

Submitted in partial fulfillment of the requirements

of the degree of

Bachelor of Engineering (B.E)

By

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This is to certify that the project entitled **"Production And Mechanical Properties Of High Performance Concrete"** is a bonafide work of **Arai Affan Irshad (13CE67), Kamble Dinesh Sanjay (12CE24), Jain Babul Jayantilal (12CE96), Lambate Salman Aslam (12CE40)** submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of "Bachelor of Engineering" in Department of Civil Engineering.

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We declare that this written submission represents our ideas in my our words and where others ideas or words have been included, We have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

Increasing demands of the new millennium for sustainable and durable structures, and the limited available resources, have awakened the need for newer construction technologies and the efficient use of structural materials. Strengths of concrete such as tensile, flexural, shearing and bond strength are all related to the compressive strength. For this reason, it means that concrete with high compressive strength will also enhance other properties. Mechanical properties of hardened concrete are the most important property which civil engineers or everyone who work with concretes should pay attention. These properties are compressive strength, modulus of elasticity, tensile strength, creep and shrinkage. In this research, the first three properties of HPC were investigated.

This Experimental investigation presents a study of properties of High performance concrete and comparing the properties with different codes and literature. The study focuses mainly on the properties like compressive strength, spilt tensile strength, modulus of rupture and modulus of elasticity of a high performance GGBS concrete by 0%, 5% and 10% of GGBS replacement with OPC to achieve strength of M60 and M80. For M60 and M80 grade concrete maximum strength achieved by replacing 5% GGBS with OPC and decreased for 10% replacement. In this study statistical equation has been proposed which is the relation between spilt tensile strength and cube compressive strength, and, modulus of rupture and spilt tensile strength. The equations proposed are in good agreement with ACI and other literature. The equations proposed by other literature are too conservative and need to modify for High performance concrete.

Keywords: High Performance Concrete, Mechanical properties, Ground granulated blast furnace slag

Table of Content

List of Tables

List of Figures

Chapter 1

Introduction

1.1 General

Concrete is the most widely used construction material in the world. Its consumption is around 20 billion tonne per year, which is equivalent to 2 tonne per every living person. Concrete is neither as strong nor as tough as steel, so why is it the most widely used engineering material? There are number of reasons. First, concrete possesses “excellent resistance to water”, The second reason for the widespread use of concrete is the ease with which structural concrete elements can be formed in to a variety of shapes and sizes. The third reason for the popularity of concrete with engineers is that it is usually the cheapest and the most readily available material on the job. It is obtained by mixing cementitious materials, water, aggregate and sometimes admixtures in required proportions. Fresh concrete or plastic concrete is freshly mixed material which can be moulded into any shape hardens into a rock-like mass known as concrete.

Increasing the demand for good quality concrete with better durability properties has focused interest on high strength concrete. Most countries have their own programs or joint programs with other countries to develop high strength concrete. In the early 1940s, strength of 30MPa at 28 days was considered to be the representative of high strength concrete (HSC). This level jumped to 50 MPa in the late 1950s and early 1960s. Concrete strength of 100-130 MPa is now being viewed as the criteria for high strength concrete. Moreover, during the last decade, developments in mineral and chemical admixtures have made it possible to produce concrete with relatively much higher strength than was thought possible.

Strength is primarily a function of the porosity of the cementing matrix, the lower the porosity, the higher the strength will be. Thus, to achieve very high strength concrete, the porosity of the paste and the water-to-binder ratio must be reduced as much as possible. At the same time, complete compaction must be maintained. While the final strength of concrete is no higher than the strength of the cementing paste, it also depends upon the strength of aggregate used, their shape, and maximum particle size.

The amount of mixing water for high-strength concrete may be lower than what is needed for complete hydration of the binder, which means that there will be partly un-hydrated cement particles work as filler so that compaction is more complete from the outset. From a strength point of view, having un-hydrated cement particles strength is much higher than that of the hydration products.

Recently, concretes with compressive strength over 100 MPa have been used commercially in construction of many applications such as high rise building, long span bridges, undersea and underground structures. The first use of HSC in building was in Lake Point Tower (Chicago) in 1965. In the Asian countries, the most recognisable building with HSC is the Twins Petronas Towers, Kuala Lumpur, Malaysia, in which concrete with strength around 138 MPa was used.

The concrete that was known as high-strength concrete in the late 1970s is now referred to as HPC because it has been found to be much more than just stronger; it displays enhanced performances in such areas as durability and abrasion resistance. High performance concrete can be defined as an engineered concrete in which one or more specific characteristics have been enhanced through the selection and proportioning of its constituents. HPC can be made with cement alone or any combination of cement and mineral components such as, blast furnace slag, fly ash, silica fume, metkaolin, rice husk ash, and fillers, such as limestone powder. Ternary systems are increasingly used to take advantage of the synergy of some mineral components to improve concrete properties in the fresh and hardened states, and to make high performance concrete more economical and ecological. Rice Husk, an agricultural waste is one of such materials, which constitutes about one fifth of the 580 million metric tones of rice produced annually in the world, and India produces 25 million tones of rice husks annually.

1.2 Definitions of High Performance Concrete (HPC)

1.2.1 SHRP-C-205 (Strategic Highway Research Program)[2]

High Performance Concrete (HPC), is defined by the researchers of the Strategic Highway Research Program of US, as that meeting three requirements.

a) 4 hours compressive strength > 17.5MPa, or
   24 hours compressive strength > 35 MPa, or
   28 day compressive strength > 70 MPa
b) It shall have a durability factor greater than 80% after 300 cycles of freezing and thawing.
c) It shall have a water-cementitious ratio < 0.35

1.2.2 R. N. Swamy[2]

HPC elements is that which is designed to give optimized performance characteristics for a given set of load, usage and exposure conditions, consistent with requirement of cost, service, life and durability.

High Performance Concrete has,

- Very low porosity through a tight and refined pore structure of the cement paste.
- Very low permeability of the concrete.
- High resistance to chemical attack.
- High early strength and continued strength development.
- Low heat hydration.
- High workability and control of slump.
- Low water binder ratio.
- Low bleeding and plastic shrinkage.

1.2.3 Civil Engineering Research Foundation [2]

HPC is a concrete in which some or all of the following properties have been enhanced,

- Ease of placement.
- Long term mechanical properties.
- Early age strength.
- Volume stability.
- Extended service life in severe environments.

1.2.4 American Concrete Institute (ACI) [3]

A more broad definition of HPC was adopted by the ACI. HPC was defined as concrete, which meets special performance and uniformity requirements that can't be always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices. The requirements may involve enhancement of placement and compaction without segregation, long term mechanical properties, early age strength, volume stability or service life in severe environments. Concretes possessing many of these characteristics often achieve higher strength. Therefore, HPC is often of high strength, but high strength concrete may not necessarily be high performance.

1.3 Objectives of the Present Study

The primary aim is to achieve value of thought their effective utilization, rather than viewing this as waste utilization to contain environmental degradation. The objectives of the present study are.

1. Produce 60 and 80 MPa High Performace GGBS Concrete using 0,5,10% of GGBS as a mineral admixture.
2. To Compare Mechanical properties, such as compressive strength, splitting tensile strength, and modulus of rupture of High performance GGBS Concrete with those of the Control Portland Cement Concrete.
3. To determine the optimum percentage of GGBS as a partial Replacement of cement to produce HPC.
4. To Study the stress-strain Characteristics for obtaining modulus of elasticity of HPC using GGBS.
5. To develop the statistical relation for the various mechanical properties. And to compare them with existing relation.

1.4 Methodology

1. Study the material properties such as cement, sand, coarse aggregate and admixtures.
2. Design of GGBS concrete mix from 60 MPa and 80MPa grade Concrete.
3. To achieve the target strength by making trial mixes and finalizing the mix proportions by different trial mixes.
4. Casting of cubes (150mmx150mm), cylinders (150mm dia x 300mm height), for testing under compression.
5. Casting of cylindrical specimens (150mm dia x300mm height) for testing under split tensile strength.
6. Casting of beam specimens (150mmx150mmx700mm), for testing under modulus of rupture.
7. Casting of cylinders specimens (150mm dia x 300mm height), and testing for Stress-strain characteristics and have obtaining modulus of elasticity of HPC using GGBS.

Chapter 2

Literature Review

2.1 General

The quality of concrete is usually characterized by its mechanical properties. These properties have an impact on how the members of higher strength reinforced concrete behave. The important behavioral difference in mechanical properties of normal strength concrete (NSC) and HPC is the stress-strain relationship. As the strength of concrete increases the curve becomes more linear, increasing its modulus of elasticity and reducing the area below the curve and hence affecting the stress-block parameters. Due to this the design parameters derived for NSC cannot be used for HPC.

2.2 Review of Literature

2.2.1 Tensile Strength

There are three methods to determine the tensile strength experimentally: uni-axial tension (direct tensile test), split cylinder test and modulus of rupture. Direct tension is hard to achieve in practice, due to inevitable interaction between specimen and machine that tend to disturb the stress distribution. Splitting tensile strength is used in Europe, but according to Legeron and Paultre (2000) [1], even if a good correlation with direct tensile results was observed, the aggregates are usually fractured along the splitting plane, phenomenon unlikely to happen in direct tension, where they are pulled out. Modulus of rupture is regarded as the best to describe the flexural behavior of the members. Raphael (1984) observed that the results are in a higher range than the last two by about 50%.The same author attributes this fact to the non linear nature of stress-strain diagram of concrete in tension, and to the inappropriate use of the elastic theory to derive the modulus of rupture. A co-efficient of 0.744 that has to affect the modulus of rupture in order to give the actual tensile stress was proposed after approximating the non-linear curve of concrete in tension with a rectangular stress block.

When, considering higher compressive strength, one expects that the tensile strength will increase as well. This assumption is true, though the increase is not proportional to that of compressive strength. Li and Ansari [1] reported a decrease in the ratio of tensile to compressive strength as the compressive strength increases. On the other hand, the same author observes a large difference between the modulii of elasticity in tension and compression at higher strength. Marzouk and Chen [1] reported that the tensile strength of high strength concrete in direct tension was 5% of compressive strength compared to 8% of fc’ for NSC. The author concluded that overall, high strength concrete has more brittle and stiffer behavior than NSC.

Various authors tried to establish a relationship between tensile and compressive strength in splitting tension and flexure and the equations are as shown in Tables 2.1 and 2.2

Table 2.1 Equations for splitting tensile strength as given in codes and research papers

ACI 318-95 [3]	$ft = 0.62\sqrt{fc'}$
ACI 363 [4]	$ft = 0.94\sqrt{fc'}$
Ahmad and Shah [5]	$ft = 0.44(fc')^{0.7}$
Setunge [2]	$ft = 0.44(fc')^{0.65} \pm 2.5\%$
J.Xie and A.E.Elwi [2]	$f_{ct} = \frac{2p}{\Pi 2LD}$
S.Bhanja and B.Senguptha [2]	$f_{sp} = 0.248(fc)^{0.717}$
Mary Beth D.Hueste [2]	$ft = 0.55\sqrt{fc'}$
Burg and Ost [2]	$ft = 7.3\sqrt{fc'}$
Oluokun [2]	$ft = 1.38(fc')^{0.69}$

Table 2.2 Equations for flexural tensile strength as given in codes and research papers

Ping-Konchang [2]	$fr = 0.62[fc']^{0.5}$
S.Bhanja and B.Senguptha [2]	$fr = 0.275(fc)^{0.81}$
Burg and Ost [2]	$fr = 12.4\sqrt{fc'}$
ACI 318 [3]	$fr = 7.5\sqrt{fc'}$
ACI 363 [4]	$fr = 11.7\sqrt{fc'}$

2.2.3 Modulus of Elasticity of High performance Concrete

Modulus of elasticity or Young's Modulus is a property that characterizes the elastic response of concrete. For the design of flexural members the modulus is important because it determines the contribution of the concrete to the flexural rigidity of the member. Apart from other materials that have linear elastic curve, the concrete maintains a fairly non-linear behavior in the pre peak zone. This creates difficulties in defining the elastic modulus of the material. That is the reason why, we do not have generally accepted definition.

Table 2.3 Equations for modulus of elasticity by codes and researchers

Sr. No.	Researchers Name/ Code	Equation suggested
01	Euro Code 2 [2]	$E_c = 21500\left[\frac{f_c'}{10}\right]^{\frac{1}{3}}$
02	ACI 363[4]	$E_c = 6900 + 3300\sqrt{f_c'}$ 21 MPa< f_c'< 83MPa
03	CSAA23.2-94[2]	$E_c = 5050\sqrt{f_c'}$
04	Mary Beth et al.[2]	$E_c = 5230\sqrt{f_c'}$ 40MPa< f_c'<90MPa
05	IS 456-2000[6]	$E_c = 5000\sqrt{f_{ck}}$ f_{ck} is characteristic strength of concrete

2.3 Review of papers on mechanical properties of high Performance concrete using GGBS mineral admixture.

Our aim is to develop high performance concrete. So for this we need to go for the addition of pozzolanic materials along with superplasticizer with having low water cement ratio. The use of GGBS is many, which is having good pozzolanic activity and is a good material for the production high performance concrete. The past studies in the earlier researches related to Mechanical properties of High Performance Concrete using GGBS as a mineral admixture is presented below.

According to study of Shariq et al.(2008) studied the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating groundadmixtures. The optimum cement replacement by FA and SF in this experiment was 10%. The strength and permeability of concrete containing silica fume, fly ash and high slag cement could be beneficial in the utilization of these waste materials in concrete work, especially in terms of durability.

Reginald Kogbaraetal. (2011) investigated the potential of GGBS activated by cement and lime for stabilization/solidification (S/S) treatment of a mixed contaminated soil. The results showed that GGBS activated by cement and lime would be effective in reducing the leachability of contaminants in contaminated soils.

Martin et al.(2012) studied the influence of pH and acid type in theconcrete. The conclusions were that concrete testedcannot adequately address the durability threat to all parts of wastewater infrastructure over a significant life span due to the extraordinarily harsh nature of this form of attack.

Wang Ling et al. (2004) analyzed the performance of GGBS and the effect of GGBS on fresh concrete and hardened concrete. GGBS concrete ischaracterized by high strength, lower heat of hydration and resistance to chemical corrosion.

AtulDubey, Dr. R. Chandak, Prof. R.K.Yadav

Throughout the long history of the iron and steel industries, ways have been sought to make effective use of these slag, but their traditional use as landfill material has been nearing its limit with the massive expansion of the steel industry since the mid-1970. The steel companies have since taken on as among their important management challenges the development of technology, the maintenance of production facilities and certi-fication for ferrous slag products in the market in order to ex-pand the applications of these slag, and the Japan Iron and Steel Federation (JISF) and Nippon Slag Association (NSA) have promoted the institution and widespread adoption of Japan Industrial Standards (JIS). As a result, 99% of slag is now useful material, employed by such national agencies as the Ministry of Land, Infrastructure and Transport and by local governments and other users, and it has gained both high acclaim and certification. The history of recycling ferrous slag is a long one. Production of Portland blast-furnace slag cement began in 1910, and the Japanese national standard for Portland blast-furnace slag cement (JES 29) was formulated in 1926.

I.Papayianni, et al.studied on Influence of superplasticizer type and mix design parameters on the performance of them in concrete mixtures. According to them use of superplasticizers in concrete plays a central role in the development of high strength and performance concrete. Superplasticizers are admixtures, which are added to concrete mixture in very small dosages. Their addition results in significant increase of the workability of the mixture, in reduction of water/cement ratio or even of cement quantity. Their performance depends on the type of the superplasticizer, the composition of the concrete mixture, the time of addition and the temperature conditions during mixing and concreting. They tested on three type of superplasticizer. for study the performance of the admixtures, three Dosage of admixture(1%, 1.5%, 2% per weight of cement) were checked for every type of superplasticizers in concrete casting. He casted concrete and compressive strength was observed.

Ajdukiewicz and Radomski examine into Trends in the Polish research on high-performance concrete. The fundamental engineering and economical problems concerning the structural applications of HPC in Poland are presented as well as the needs justifying the increased use of this material are briefly described.

Aitcin cited on development in the application of high performance concrete. Over the last few years, the compressive strength of some of the concrete used has increased dramatically. In 1988, a 120 MPa concrete was delivered on site, while, until relatively recently, 40 MPa was considered indicative of high strength. The spectacular increase in compressive strength is directly related to a number of recent technological developments, in particular the discovery of the extraordinary dispersing action of superplasticizers with which flowing concretes can be made with about the same mixing water that is actually required to hydrate all the cement particles or even less. The reduction in water/cement ratio results in a hydrated cement paste with a microstructure so dense and strong that coarse aggregate can become the concrete's weakest constituent. Silica fume, a highly reactive pozzolana, considerably enhances the paste/aggregate interface and minimizes de-bonding. Lastly, the use of supplementary cementitious materials, such as fly ash and especially slag, helps solve slump loss problems which become critical at low w/c ratios.

Chapter 3

Ground Granulated Blast Furnance Slag

3.1 Introduction

Ground-granulated blast-furnace slag (GGBS or GGBFS) obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that dried and ground into a fine powder.

The chemical composition of a slag varies considerably depending on the composition of raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the blast furnace the slag floats on the top of the iron and is decanted for separation. Slow cooling of slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates. To obtain a good slag reactivity or hydraulicity, the slag melt needs to be rapidly cooled or quenched below 800 ^{o}C in order to prevent the crystallization of merwinite and melitite.

3.2 GGBS Is More Stable Than Fly Ash

- BF slag is the by product from control process of iron production , which result in very uniform composition from source to source . where as quality of fly ash collected from ESP varied widely.
- GGBS is made by using the state of art vertical roller grinding mill (VRM) german roller press technology .
- The fineness and micro structure can be controlled and therefore consistent quality is attainable .
- In addition to pozzolanic reaction, GGBS react with water and produces C-S-H from its available supply of calcium oxide and silica.

3.3 Application Of GGBS

1. All types of residential ,commercial and industrial complexes
2. Dams and other mass concrete works
3. Water retaining structure
4. Concrete roads and flyover
5. All civil structural works
6. Idea for using in marine construction
7. Precast concrete product
8. Foundation and pile construction
9. Increased flexibility to meet indivisual requirement in RMC.

GGBS is used to make durable concrete structure in combination with ordinary portland cement or pozzolanic material .to improve durability of structure uses of GGBS along with OPC in concrete is recommended in BS 6699:1986 , astm c989:1982, is 456:2000 and GGBS to OPC in the range of 25 to 70% shall be added to manufacture Portland slag cement as per is 456:1989 .

3.4 GGBS Advantages

1. Reduction in heat of hydration and minimization of thermal crack.
2. Permeability and surplus lime released out of OPC to form in to secondary hydrated mineralogy.

3. Pore refinement and grain refinement due to the secondary hydrated mineralogy ,thus contributing for impermeability and enrichment of transition zones
4. Impermeablility is the foremost mechanism for making the concrete more durable and is best achieved by using GGBS.
5. Reduce requirement of cement for same strength thus reduces the cost of concrete .
6. is 456:2000 Recommends addition of more than 50% GGBS where chloride is encountered along with sulphates in place of SRC.

3.5 Sustainable Material

1. Replacing the Portland cement by GGBS help In reducing co2 emission and in Conserving non renewable resources of lime stone.
2. Use of GGBS in concrete recognized by LEED (leadership in energy and environmental design) and add points towards its certification.
3. The high volume GGBS concrete system is environment friendly and the concrete so produce also demonstrate the attributes of high performance concrete (HPC).

Chapter 4

Materials And Mixture Proportioning

4.1 Introduction

Mix proportioning is the process of determining the right combination of component materials that will produce a concrete mixture with the desired characteristics at the lowest possible cost. Even with ordinary concrete the process is not easy because it involves the art of balancing various conflicting requirements. Extensive laboratory testing must often be carried out before a satisfactory proportion of materials.

High-performance concrete is evolving very fast, but our field experience is still limited. Strength performance remains the most important property of structural concrete, from an engineering view point. The relation between concrete composition and mechanical properties has long been a matter of research interest. Some results of research on conventional concrete are not entirely applicable. An extended comprehensive knowledge of the fundamental properties of high-performance concrete is necessary. The current empirical equations presented in codes, standards, and recommended practices for estimating fundamental properties of concrete, such as tensile strengths are based on the tests of concrete with compressive strength of 40MPa or less without supplementary cementitious materials. The validity of these equations for HPC with supplementary cementious materials should be investigated.

An experimental investigation was carried out to investigate the mechanical properties of three series of G.G.B.S High Performance Concrete mixes designated as M60and M80 Mpa having 28 days compressive strength of 60 and 80MPa respectively. The results are presented in the subsequent sections.

4.2 Design of HPC mixes

A mixture proportioning method only provides a starting mix design that will have to be modified to meet the desired concrete characteristics. In spite of the fact that mix proportioning is an art, it is unquestionable that some essential scientific principles can be used as a base for mix calculations.

4.2.1 ACI 211.4R Standard Practice

Data needed include- F.M. of sand, dry rodded unit weight (DRUW) of the C.A., Specific gravity of the aggregates.

1. Slump selection: Selected from the given table.
   The target strength $f_{cr} = (f_c + 9.65) / 0.9$
   Where f_{cr} = Specified design compressive strength
   f_c = Required average compressive strength
2. Selection of maximum size of aggregate (MSA): Based on the strength requirement, select the maximum size of aggregate.
3. Selection of optimum coarse aggregate content:
   Weight of C.A. = (% x DRUW) x DRUW
4. Estimation of mixing water and air content: From the table get the estimate of mixing water and air content percentage.
   Mixing Water adjustment, kg/m3 + (V-35)x4.74
5. Selection of W / (C+P) Ratio: Table gives the recommended maximum W/(C+P) ratio as the function of the maximum size of aggregate to achieve different compressive

strengths either at 28 days or 56 days for a mix made without HRWRA and a mix made using HRWRA.

6. Calculate cementitious Materials content: obtained by dividing the amount of mixing water by the W / (C+P) ratio.
7. Sand content: After determining the weights of C.A., cement and water and air content, the sand content can be calculated using absolute volume methods.
8. Proportion Companion mixture using *FLY ASH.*
9. Trial mixtures.
10. Adjustment of Trial mix proportions.

4.2.2 Mix Design Adopted in the Present Project Work

The mix design procedure adopted in the present project is from an eminent researcher who is working in the field of high performance concrete. The method adopted here is, method purpose by **P.C. Aitcin [53].** The method is simple and follows the same approach as ACI 211-1 standard practice for selecting proportion of normal, heavy and mass concreting. It is a *combination of mathematical calculation and empirical results based on absolute volume method*. It also considered the contribution of water by super plasticizer.

The procedure is initiated by selecting five different mix characteristics or materials.
proportions in the following sequence:

No. 1 – Selection of W/B ratio;

No. 2 – Selection of water content;

No. 3 – Selection of super plasticizer dosage;

No. 4 – Selection of the coarse aggregate content;

No. 5 –Assuming the entrapped air content.

No: 1. Water/binder Ratio

The suggested water/binder ratio can be found from Fig. 4.1 for a given 28 days compressive strength. Owing to variations in the strength efficiency of different supplementary cementitious materials, the curve shows a broad range of water/binder values for a given strength. If the efficiency of the different supplementary cementitious material is not known from the prior experience, the average curve can be used to give an initial estimate of the mix proportions.

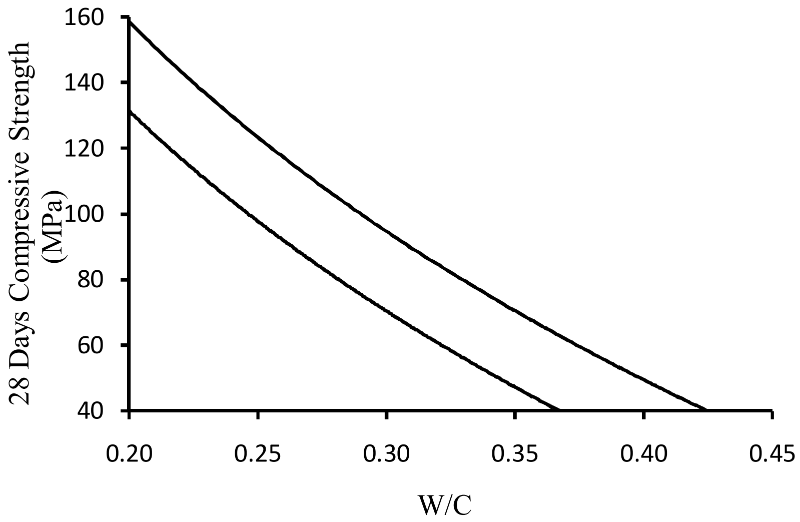


Fig. 4.1 Compressive Strength Vs W/C for HPC

No: 2 Water Content

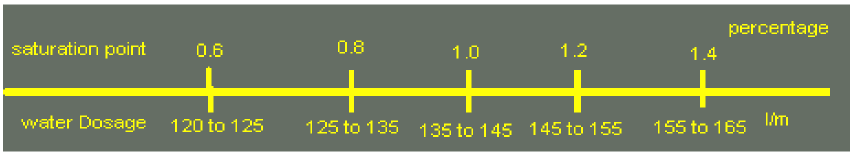


Fig. 4.2 Determination of minimum water dosage

The water content can be found by the figure (above) to design a very safe mix, 5 l/m^3 of water can be added to the values presented in Fig 4.2. If the saturation point of the super plasticizer is not known, it is suggested starting with water content of 1451/m^3.

No: 3 Superplasticizer Dosages

The Superplasticizer dosage can be deduced from the dosage at the saturation point. If the saturation point is unknown, it is suggest starting with a trial dosage of 1% of cement mass. Because the solid content present in the superplasticizer is active agent for its water reducing action. From solid content the liquid dosage has to be calculated. Typical mix design is given in section 4.4. Saturation point can be found by using flow table test or Marsh Cone.

No: 4. Coarse Aggregate Content

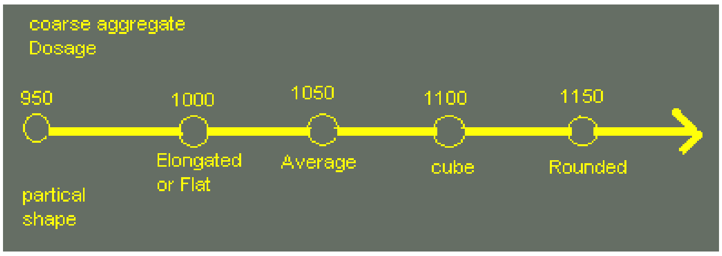


Fig. 4.3 Determination of Coarse Aggregate

The coarse aggregate content can be found from fig. 4.3 as a function of the typical particle shape. If there is any doubt about the shape of the coarse aggregate or if its shape is not known, a content of 1000 kg/m^3 of coarse aggregate can be used to start.

No: 5 Air Content

For high-performance concretes that are to be used in non-freezing environments, theoretically there is no need for entrained air, so the only air that will be present in the mix is entrapped air, the volume of which depends partly on the mix proportions. However, in order to improve concrete handling placeability and finishability, use of an amount of entrained air is recommended.

4.3 Materials used in the present Study

4.3.1 Cement

As the target strength to be achieved is High strength range **O**rdinary **P**ortland **C**ement 53 Grade, Conforming to the relevant Indian standard code IS 12269-1987[54] was used throughout the investigation. The Properties of OPC 53 Grade is shown in Table 4.1 below.

4.3.2 Coarse Aggregate (CA)

The samples of CA from 6 different stone crusher quarries were selected around Bagalkot. After visual observation of shape, size, texture, Sieve Analysis & Crushing value Test, the CA was selected and procured. The CA used in the present work is 20 mm down size and 12.5 mm down size. All tests has been carried out as per IS: 383-1970[55]. Table 4.2 shows the properties of CA.

Table 4.1 Properties of UltraTech OPC 53 grade

Sl. No.	Particulars	Test Results	IS 12269 Req.
Chemical Properties:			
1	$\frac{CaO - 0.7SO_3}{2.8\ SiO_2 + 1.2Al_2O_3 + 0.65\ Fe_2O_3}$ Lime Saturation Factor (%)	0.86	0.80 Min 1.02 Max
2	Al_2O_3 / Fe_2O_3 Alumina Iron Ratio (%)	1.29	0.66 Min
3	Insoluble Residue (% by mass)	1.36	3.00 Max
4	Magnesia (% by mass)	0.86	6.00 Max
5	Sulphuric Anhydride (% by mass)	2.12	3.00 Max
6	Total Loss on Ignition (% by mass)	2.97	4.00 Max
7	Total Chlorides (% by mass)	0.003	0.10 Max
8	Performance Improver: Limestone (%)	2.00	Not Specified
Physical Properties:			
1	Fineness (Specific surface)	303 m^2/kg	225 m^2/kg Min
2	Soundness test a. By Le Chatelier b. By Autoclave	 0.8 mm 0.048 %	 10.0 mm Max 0.8 % Max
3	Setting time test (Minutes) a. Initial setting time b. Final setting time	 210 285	 30 Min. 600 Max.
4	Compressive strength a. 3 days b. 7 days c. 28 days	 42.0 MPa 54.7 MPa 71.0 MPa	 27.0 MPa Min 37.0 MPa Min 53.0 MPa Min
5	Specific gravity	3.15	Not Specified
6	Particle Size Range	31 µm – 7.5 µm	Not Specified
7	**Manufacturer:** UltraTech Cement Ltd		

Table 4.2 Properties of Coarse Aggregate

Sl. No.	**Particulars**		**C.A. 20 mm down**	**C.A. 10 mm down**
1	Maximum size		20 mm	12 mm
2	Specific gravity		2.61	2.56
3	Bulk Density		1314.44 kg/m^3	1235.53 kg/m^3
4	Water Absorption		3.3 %	4.7 %
5	Fineness Modulus		2.74	2.25
6	**Sieve analysis of C.A. 20 mm Down:**			
	Sieve size	%Weight retained	Cumulative% Weight Retained	Cumulative% Passing
	40 mm	0	0	100
	20 mm	8.91	8.91	91.09
	16 mm	57.1	66.01	33.99
	10 mm	33	99.01	0.99
	4.75mm	0.99	100	0
	2.36mm	0	0	0
7	**Sieve analysis of C.A. 10 mm Down:**			
	Sieve size	%Weight retained	Cumulative% Weight Retained	Cumulative% Passing
	20 mm	0	0	100
	16 mm	0.8	0.8	99.2
	10 mm	24.2	25	75
	4.75mm	73.85	98.85	1.15
	2.36mm	1.1	99.95	0.05
	Pan	0.05	100	0
9.	**Quarry Location:** J.M.MAHATRE QUARY.URAN-PANVEL ROAD			

4.3.3 Fine Aggregate (FA)

The samples of FA were collected. After visual observation of silt, clayey material, and sieve analysis test, Fineness Modulus and confirmation of grading zone; FA was procured. All tests has been carried out as per IS: 383-1970[58]. Table 4.3 Shows Properties of FA.

Table 4.3 Properties of Fine Aggregate (as per IS 383)

Sl. No.	Particulars			Test Result
1	Grading zone			I
2	Specific gravity			2.07
3	Bulk density			1401.34 kg/m^3
4	Water absorption			
5	Moisture content			0 %
6	Fineness modulus			3.14
7	Silt Content			2.76
8	**Sieve analysis:**			
	Sieve size	% Weight retained	Cumulative% retained	Cumulative % passing
	4.75 mm	0	0	100
	2.36 mm	0.98	0.98	199.02
	1.18 mm	37.07	38.05	61.95
	600μ	40	78.05	21.95
	300μ	19.91	97.56	2.44
	150μ	1.95	99.51	0.49
	PAN	0.49	100	0
Brand Name:Gujrat Sand				

4.3.4 Superplasticizer

For high strength, concrete w/b ratio will be very low so use of superplasticizer or high range water reducer is essential. In the present experiment, third generation superplasticizer Polycarboxylate Ether based, **Glenium B233** is used. This is plasticiser is compatible with almost all types of cements. Table 4.4 shows the properties of Glenium B233 as per the manufacturer's Technical Sheet.

Table 4.4 Properties of Superplasticizer Master Glenium SKY 8233

Sl. No.	Particulars	Value
1	Chemical content	Poly Carboxylic Ether(PCE)
2	Aspect	Light Brown Liquid
3	Specific gravity	1.08
4	Chloride content	< 0.2 %
5	Recommended dosage	500-1500 ml per 100 kg cement
6	Solid content	30% by weight
7	Compatibility	All types of cement
8	Ph	>6
9	Reference specification	IS 9103: 1999
10	**Manufacturer:** BASF Chemicals Ltd.	

4.3.5 Mineral admixture

G.G.B.S is grey colure very fine powder made by controlled burning of covering of rice grain. RHA is having high silica content and low carbon content among available SCMs. The properties of RHA are detailed below Table 4.5 As per the manufacturer's specifications.

Table 4.5 Properties of G.G.B.S

<table>
<tr><th>Sl.</th><th colspan="9">Properties</th><th colspan="3">Value</th></tr>
<tr><td>1</td><td colspan="9">Fineness Modulus</td><td colspan="3">3.36</td></tr>
<tr><td>2</td><td colspan="9">Appearance</td><td colspan="3">Very fine powder</td></tr>
<tr><td>3</td><td colspan="9">Particle size</td><td colspan="3">25 μ (mean size)</td></tr>
<tr><td>4</td><td colspan="9">Colour</td><td colspan="3">off-white</td></tr>
<tr><td>5</td><td colspan="9">Odour</td><td colspan="3">Odourless</td></tr>
<tr><td>6</td><td colspan="9">Specific Gravity</td><td colspan="3">3.44</td></tr>
<tr><td>7</td><td colspan="9">Loss on Ignition (%)</td><td colspan="3">1.41</td></tr>
<tr><td rowspan="3">9</td><td colspan="12">Chemical Composition (%):</td></tr>
<tr><td>SiO_2</td><td>Al_2O_3</td><td>Fe_2O_3</td><td>CaO</td><td>MgO</td><td>MnO</td><td colspan="2">Sulphide sulphur</td><td colspan="2">Insoluble Residue</td><td colspan="2">Glass Content</td></tr>
<tr><td>37.73</td><td>14.42</td><td>1.11</td><td>37.34</td><td>8.71</td><td>0.02</td><td colspan="2">0.39</td><td colspan="2">1.59</td><td colspan="2">92</td></tr>
<tr><td rowspan="3">10</td><td colspan="12">Particle Size Distribution:</td></tr>
<tr><td colspan="2">Particle</td><td>45μ</td><td colspan="2">45-20μ</td><td colspan="2">20-10μ</td><td>10-05μ</td><td colspan="2">05-02μ</td><td colspan="2">< 02μ</td></tr>
<tr><td colspan="2">%</td><td>0.43</td><td colspan="2">17.41</td><td colspan="2">29.20</td><td>31.15</td><td colspan="2">14.55</td><td colspan="2">7.25</td></tr>
<tr><td>11</td><td colspan="12">Manufacturer: JSW Steel,Uran.</td></tr>
</table>

4.3.6 Water

The strength of the cement concrete comes mainly from the binding action of the hydrated cement gel. The requirement of water should be reduced to that just required for chemical reaction of un-hydrated cement as the excess water would end up in only formation of undesirable voids and capillaries in the hardened concrete. Especially in HPC little excess water to the extent of 3-5 liters will reduce 10-20 MPa compressive strength and also may lead to segregation. Water used for mixing and curing should be free from deleterious materials as per clause 4.3 of IS: 456 [56]. Potable water (pH value between 7 and 7.5) is generally considered satisfactory for mixing and curing of concrete.

The tap water supplied to the Concrete Technology Lab of KALSEKAR TECHNICAL CAMPUS NEW PANVEL was used for Mixing and . pH of water was checked using pH strip (pH=7, neutral).

Fig.4.4.Ingradient used in present study

4.3.7 Grading of CA

In the project work Total quantity of CA was made by 60% of 20 mm CA & 40% of 12.5 mm CA to get minimum voids ratio and IS:383-1970[55] required grading.

4.4 Typical Calculation of Mix Design

The mix design calculations are as per the method suggested by Aitcin in section 4.2.2

A) Materials and Their properties required for Mix design calculation:		
Cement : Specific gravity – 3.15	**Coarse Aggregate:** Shape – Cubical Specific gravity –2.56 Water absorption –4.7%	**Fine Aggregate:** Specific gravity – 2.07 Water absorption–
G.G.B.S: Specific gravity – 3.44	**Superplasticizer:** Specific gravity – 1.08 Solid content, S – 30 %	

Mix Proportion for 1 m^3 for M60:

W/C	Cement	GGBS	CA	FA	WATER	SP	SP (%)
	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	lit/m^3	lit/m^3	
0.35	457	0	1158	700.19	160	4.89	0.4%

Table 4.6 No. of Specimens to be casted

Sl. No.	Test To be Conducted	3 Days	7 Days	28 Days	Total x No. of Mixtures	Total No. Of Specimens
1.	Compressive Strength Test on Cube	3	3	3	9 x 3 =27	27x2=54
2.	Split Tensile Strength Test on Cylinder 150mm Diax300mm Height.	-	-	3	3x2 =6	6x2=12
3.	Flexural Strength Test on Beams 100x100x500mm	-	-	3	3x2=6	6x2=12
3.	Stress-Strain Test on Cylinders of 150mm Dia.x300mm Height.	-	-	3	3x1=3	3x2=6
4.		Total No. of Specimens to be casted = **84**				

4.5 Final Mix Proportion obtained by Trials

Sl. No.	Particulars	M60	M80
1	W/C	0.35	0.30
2	Cement (kg/m^3)	457	517
3	Coarse Aggregates (kg/m^3)	1158	1302
	20 mm Down (%)	60	60

	12.5 mm Down (%)	40	40
4	Fine Aggregates (kg/m^3)	695	550
5	Superplasticizer Dosage (%)	0.4	0.4
6	Superplasticizer Dosage (lit/m^3)	4.81	5.44
7	Water (lit/m^3)	160	155
8	Density (kg/m^3)	2471.95	2525.91
9	Slump (mm)	170	150
10	No. of Trials	3	4

Mix Proportion by reference:

Sl. No.	Particulars	M60	M80
1	W/C	0.35	0.30
2	Cement (kg/m^3)	457	517
3	Coarse Aggregates (kg/m^3)	1158	1302
	20 mm Down (%)	60	60
	12.5 mm Down (%)	40	40
4	Fine Aggregates (kg/m^3)	695	550
5	Superplasticizer Dosage (%)	0.4	0.4
6	Superplasticizer Dosage (lit/m^3)	4.81	5.44
7	Water (lit/m^3)	160	155

8	Density (kg/m^3)	2471.95	2525.91
9	Slump (mm)	210	200
10	No. of Trials	3	4

Chapter 5

Experimental Programme

5.1 Introduction

We have seen in the preceding chapter that making HPC start with careful selection of the materials that are to be used. The materials that are presently used to make usual concrete with a compressive strength in the 20-40 Mpa range may be inappropriate as soon as the water /binder ratio is lowered in order to achieve higher strength. It has also been shown how the selection of materials used to make a HPC becomes more and more critical as the water/ binder ratio is decreased further and compressive strength increases, but usually a concrete producer still has some choices to make.

5.2 Preparation before mixing

Concrete mixing, and more critically HPC mixing, does not start with the mixing of the ingredients in the concrete mixer, but rather with the control of the quality of the materials used. Although providing good quality control is important in making usual concrete, it is crucial step in manufacturing of HPve the same properties as the one's chosen during selection process.

5.3 Casting of Test Specimens

1) Quantity of concrete and ingredients of mix was calculated.
2) Required moulds (Cube, cylinders and Small Beams) confirming to IS: 516 – 1959 [57] were assembled and thinly coated with mould oil to prevent adhesion of the concrete.
3) Moulds were kept on vibrating table so that concrete can be poured immediately after mixing.
4) The Cement, GGBS, CA, FA, water & superplasticizer(Master glanium B233) brought to the room temperature & weighed.
5) The laboratory concrete mixer was cleaned and dried. The Mixer used in the experimental work is ribbon type mixer .
6) The ingredients were poured in the following sequence –
   ½ portion of 20mm CA → ½ portion of 12.5 mm CA → ½ portion of FA → Total Cement → Total GGBS → ½ portion of FA → ½ portion of 12.5 mm CA→ ½ portion of 20mm CA
7) ½ portion of measured Plain water taken and sprinkled on top of materials poured in the Step 6.
8) The material was dry mixed for 4-5 minutes.
9) While keeping the mixer in running condition remaining portion of water + Superplastisizer solution was sprayed in the mixer. The care was taken that the liquid should not fall at one place in mixer so that maximum surface area will be covered.
10) The mixer was run until the concrete appears to be homogenous and has the desired consistency.
11) The mixer door opened in running condition and concrete was collected in a tray.
12) The concrete was filled into the mould in layers approximately 2" deep. In placing each scoopful of concrete, the scoop was moved around the top edge of the mould as the concrete slides from it, in order to ensure a symmetrical distribution of the concrete within the mould. Each layer was compacted by vibration. After the top layer

has been compacted, the surface of the concrete was finished level with the top of the mould, using a trowel. Concrete was consolidated on vibrating table as per IS: 7246.

13) Moulds were transferred to leveled surface.
14) After inspecting the setting of top surface of moulds, moulds were covered with wet gunny bags to avoid shrinkage of top surface by evaporation.
15) After 24 hrs of setting the specimens were demoulded without harming the edges.
16) Each specimen was marked with Identification mark.

Labelling of Specimens:

0% GGBS Mix 60 Grades.

5% GGBS Mix 60 Grades

10% GGBS Mix 60

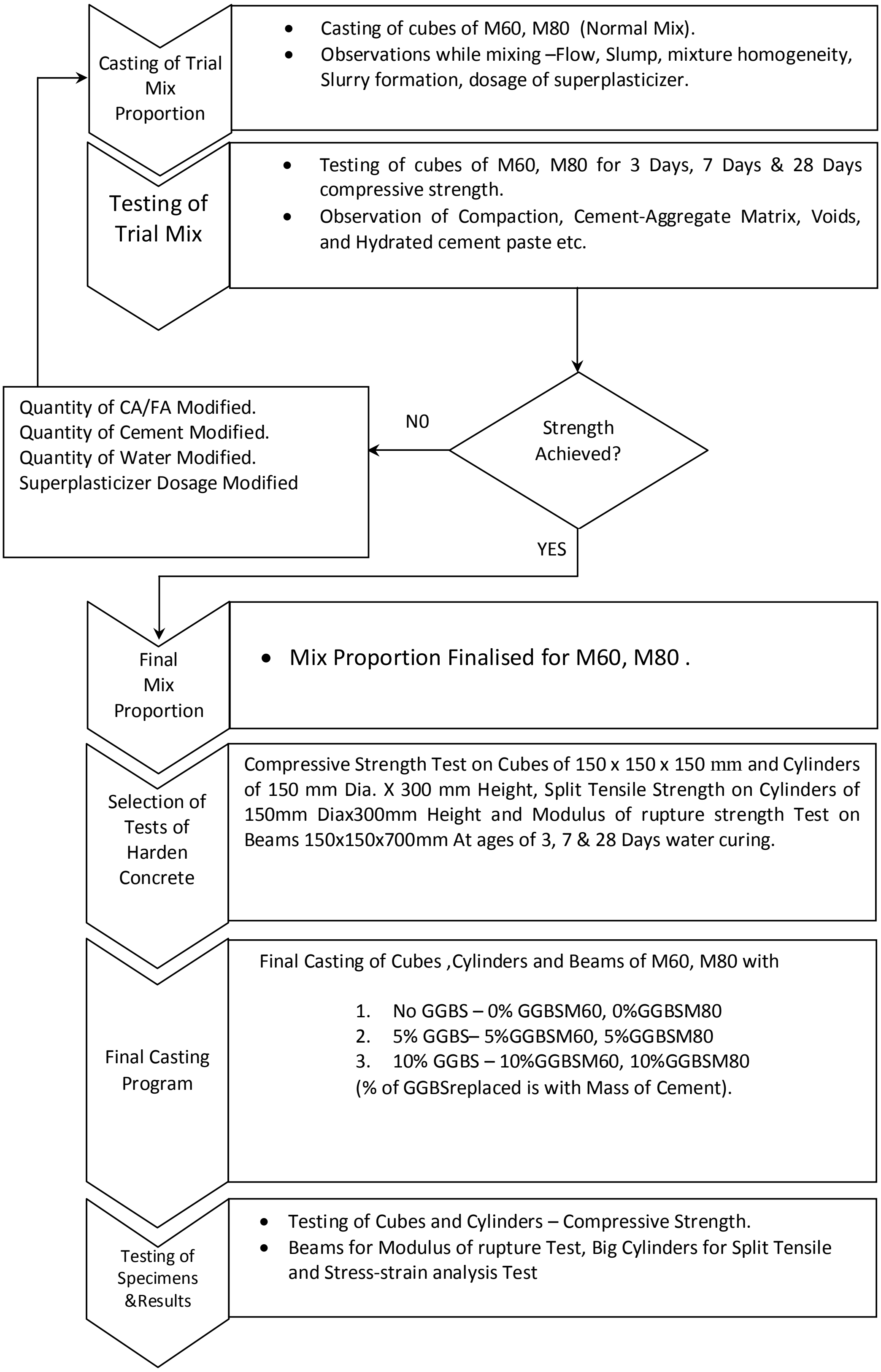
Grades Similarly for M80.

5.4 Outline of Experimental Work

Flow chart showing Experimental Work Steps

Selection o f Target Strength	• M60, M80 .
Selection of Material	• Samples Collection of CA & FA. • Selection of Cement – UltraTech OPC 53 Grade. • Selection of Superplasticizer – Glenium B233, BASF Ltd.
Testing of Material's Properties	• CA – Crushing Value, Sieve Analysis, Water Absorption, Specific Gravity, Bulk Density, FM. • FA – Sieve Analysis, Water Absorption, Specific Gravity, Bulk Density, FM, Bulking, Moisture Content. • Cement – Setting Time, Compressive Strength.
HPC Mix Design Method	• HPC Mix Design Method used given in Book on 'High Performance Concrete' By Pierre-Claude Aïtcin
Calculation of Mix Proportion for Target Strength	• HPC Mix Design Calculation as per given in book 'High Performance Concrete' By Pierre-Claude Aïtcin. For M60, M80 ,

Fig. 5.1 Flow chart showing Experimental Work Steps



5.5 Observations while mixing and demoulding

1) The mix prepared was at SSD condition of CA & FA.
2) The water required for mixing was always less than assumed. Stringent control on water was kept from strength and workability aspect.
3) The mix prepared was very homogenous and consistent.
4) Excess slurry was not formed.
5) The mix was spreading without any external pressure because of superplasticizer.
6) The colour of mix without G.G.B.S was grey in colour while with G.G.B.S it was pale black to dark black depending upon G.G.B.S percentage.
7) The mix without G.G.B.S was found retaining its slump for long time compared to the mix with G.G.B.S. However, the Slump of both was within range.i.e.14 – 90 cm.
8) While vibrating, the mix was showing flowing action.
9) The finishing of top surface was not requiring any extra efforts because of sufficient slurry formation at top while vibrating.
10) After demoulding, specimens were having smooth surface and sharp edges.
11) Specimens of M60 & M80 mix was dried out.

5.6 Mechanical Properties of HPC

5.6.1 Introduction

It is wrong to believe that the mechanical properties of HPC are simply those of a stronger concrete. It also as wrong to consider that the mechanical properties of HPC can be deduced by extrapolating those of usual concretes as it would be wrong to consider that none of them are related.

The microstructure of HPC is more compact, including the transition zone with the coarse aggregate, resulting in a thin or no transition zone at all. Therefore, the mechanical properties of the coarse aggregate influence some of the mechanical properties of HPC. Therefore the sacrosanct water/binder ratio law is no longer true in the case of some HPC made with 'weak' coarse aggregates. For any coarse aggregate there is a critical value of the water/binder ratio below which any further decrease of the water/binder ratio does not result in a significant increase of the compressive strength. This critical value depends on the strength of the rock from which the coarse aggregate is made, but also on the maximum size of the coarse aggregate. This is because when crushing a particular rock the smallest fragments are usually stronger than the coarsest because they content less defects. This phenomenon is sometimes referred as a ‘size effect phenomenon.

5.6.2 Compressive strength test

Compressive test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.

The compressive test is carried out on specimens cubical or cylindrical in shape. Prism is also sometimes used, but it is not common in our country. Sometimes, the compressive strength of concrete is determined using parts of a beam tested in flexure. The end parts of the beam are left intact after failure in flexure and, because the beam is usually of square cross section, this part of the beam could be used to find out the compressive strength.

5.6.2.1 Cube strength (IS: 516-1959)

The cube specimen is of the size 150 X 150 X 150 mm. If the largest nominal size of the aggregate does not exceed 20 mm, 100 mm size cubes may also be used as an alternative (IS: 10086-1982). The rate of loading as per IS: 516-1959 is 315 KN/min (14 N/mm^2/ min).

The specimens casted are demoulded after 24 hours of casting and tested after 28 days. The cube compressive strength of various grades of concrete are recorded after crushing them under the compression testing machine (3000 kN Capacity). The results are shown in

Table 6.1.

$$\text{Compressive strength} = \frac{\text{Ultimate crushing load}}{\text{Area of loading}} \text{ in N/mm}^2.$$

5.6.2.2 Cylindrical strength

The cylindrical specimen is of the size 150 X 300 mm. If the largest nominal size of the aggregate does not exceed 20 mm, 100X 200 mm size cylinders may also be used as an alternative (IS: 10086-1982).

The compressive cylindrical strength of various grades of concrete are recorded after crushing them under the compression testing machine. The specimens cured for 3 days, 7 days and 28 days are crushed and ultimate compressive loads are recorded and the strength are obtained as shown in table 6.2.

$$\text{Compressive strength} = \frac{\text{Ultimate crushing load}}{\text{Area of loading}} \text{ in N/mm}^2.$$

5.6.3 Tensile strength of concrete

Concrete is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since reinforcement is provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of reinforcement, temperature gradients and many other reasons. Therefore, the knowledge of tensile strength of concrete is of importance.

Tensile strength of concrete is determined by the following two tests.

1. Split tensile strength test and
2. Modulus of rupture strength test.

5.6.3.1 Split tensile strength

It is also called as indirect tension test method. This also sometimes referred as, "Brazilian Test". This test was developed in Brazil in 1943. At about the same time this was also independently developed in Japan.

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

When the load is applied along the generatrix, an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress of

$$= \frac{2P}{\pi LD}\left[\frac{D^2}{r(D-r)}-1\right] \tag{5.1}$$

and a horizontal stress of

$$= \frac{2P}{\pi LD} \tag{5.2}$$

where, P is the compressive load on the cylinder

L is the length of cylinder

D is its diameter

The main advantage of this method is that the same type of specimen and the same testing machine as are for the compression test can be employed for this test. That is why this test is gaining popularity. The splitting test is simple to perform and gives more uniform results than other tension tests. Strength determined in the splitting test is believed to be closer to the true tensile strength of concrete, than the modulus of rupture. Results of cylinder splitting strengths are shown as in the table 6.3. Tensile splitting strength is an important property that greatly affected the extent and size of cracking in structures under shear and torsion.

5.6.3.2 Modulus of rupture strength

The value of the modulus of rupture (extreme fibre stress in bending) depends on the dimension of the beam and the manner of loading. The systems of loading used in finding out the flexure tension are central point loading and third point loading; maximum fibre stress will come below the point of loading where the bending moment is maximum.

In case of symmetrical two point loading, the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum. It can be expected that the two point loading will yield a lower value of the modulus of rupture than the centre point loading. IS: 516-1959, specifies two points loading.

The standard size of specimens are 150 X 150 X 700 mm. Alternatively, if the largest nominal size of the aggregate does not exceed 20mm, specimens 100 X 100 X 500 mm may be used.

The flexure strength of the specimen is expressed as the modulus of rupture f_b which if ‘a’ equals the distance between the line of fracture and the nearer support, measured on the tensile side of the specimen, in mm, is calculated to the nearest 0.05 MPa as follows.

$$fb = \frac{P \times l}{b \times d^2} \qquad 5.3$$

When ‘a’ is greater than 200 mm for 150 mm specimen or greater than 133 mm for 100 mm specimen, or

$$fb = \frac{3p \times a}{b \times d^2} \qquad 5.4$$

when ‘a’ is less than 200 mm but greater than 170 mm for 150 mm specimen, or less than 133 mm but greater than 110 mm for 100 mm specimen where

b = measured width in mm of the specimen i.e.100 mm,
d = measured depth in mm of the specimen at the point of failure i.e. 100 mm,
l = length in mm of the span on which the specimen was supported i.e. 400 mm, and
p = maximum load in kg applied to the specimen.

If ‘a’ is less than 170 mm for 150 mm specimen, or less than 110 mm for a 100 mm specimen, the results of the test be discarded. Results of flexural tensile strengths are shown in Table 6.4. To take full advantage of HSC its higher tensile strength must be taken in to consideration as it governs the permissible tensile strength, minimum shear and tensile reinforcement and the shear strength of concrete

Fig. 5.1. Specimen in CTM after crushed

Fig.5.2.Casting of concrete

Fig.5.3. During vibration

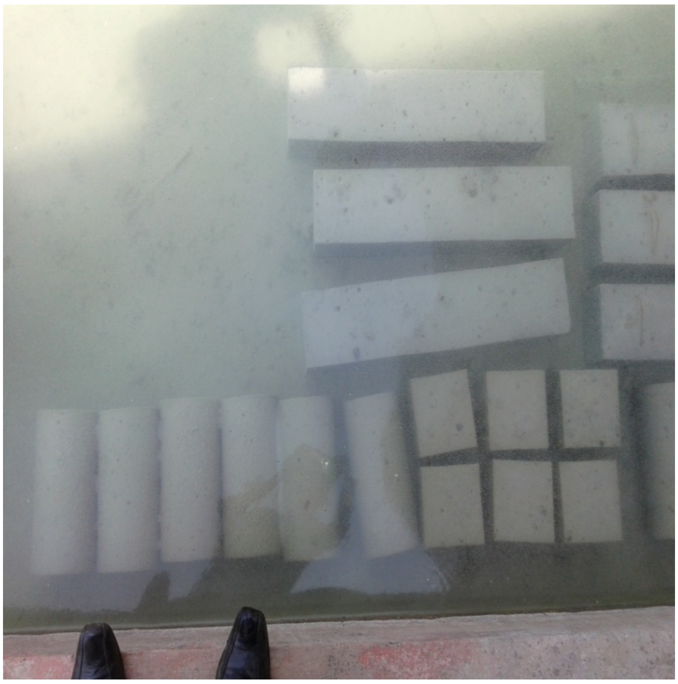


Fig.5.4.During curing

Fig.5.5.Testing of beam

Fig.5.6.Testing of cylinder

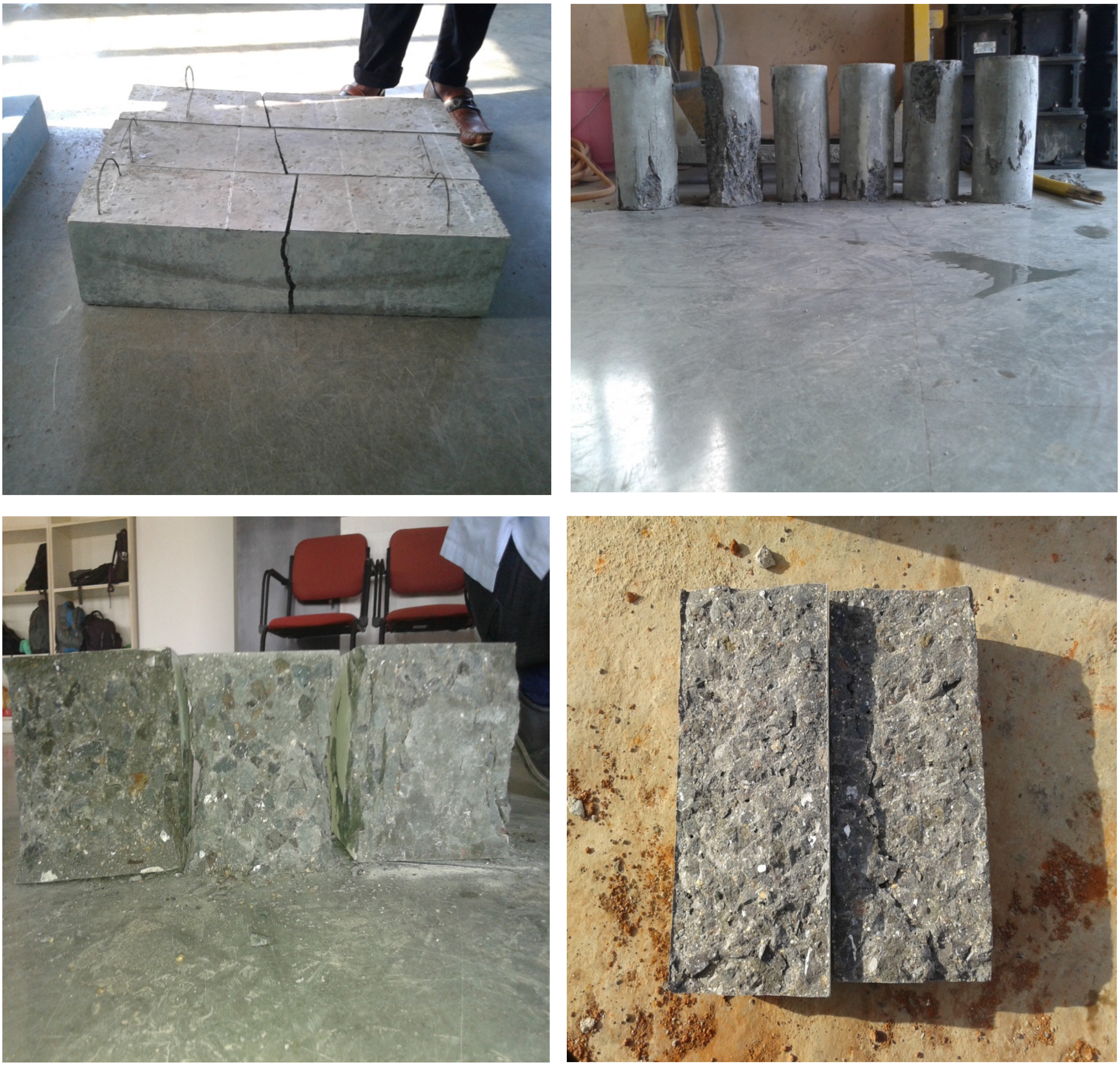


Fig.5.7.Specimen after crushed

Fig.5.8.Slump cone test

Fig.5.9.Compression Testing Machine

Fig.5.10.Flexural Testing Machine

CHAPTER 6

RESULTS AND DISCUSSION

6.1 General

This chapter deals with the presentation of test results and discussions on Mechanical Properties of High Performance concrete containing G.G.BS. The present study is based on trial mixes and achieving target strength. Mix proportions have been obtained for M60, M80 Control concrete. Then cement is replaced by 5%, 10% of G.G.B.S of cement mass to study the compressive strength split tensile strength, modulus of rupture and modulus of elasticity.

6.2 Cube Compressive Strength

Table 6.1 Cube Compressive Strength (MPa)

Mix Designation	3 Days	7 Days	28 Days
M60 Mix			
0%M60	39.43	47.23	62.76
5%M60	31.43	47.73	69.06
10%M60	37.83	42.10	69.63
M80 Mix			
0%M80	51.7	59.4	72.4
5%M80	48.46	58.23	80.21
10%M80	48.6	49.20	65.93

The above Table 6.1 gives the cube compressive strength of M60, M80 and at 3, 7 and 28 days curing with 0,5,and 10% G.G.B.S replacement. The strengths obtained are average of three specimens each.. The results are shown graphically in Fig. 6.1, Fig. 6.2 and Fig. 6.3.

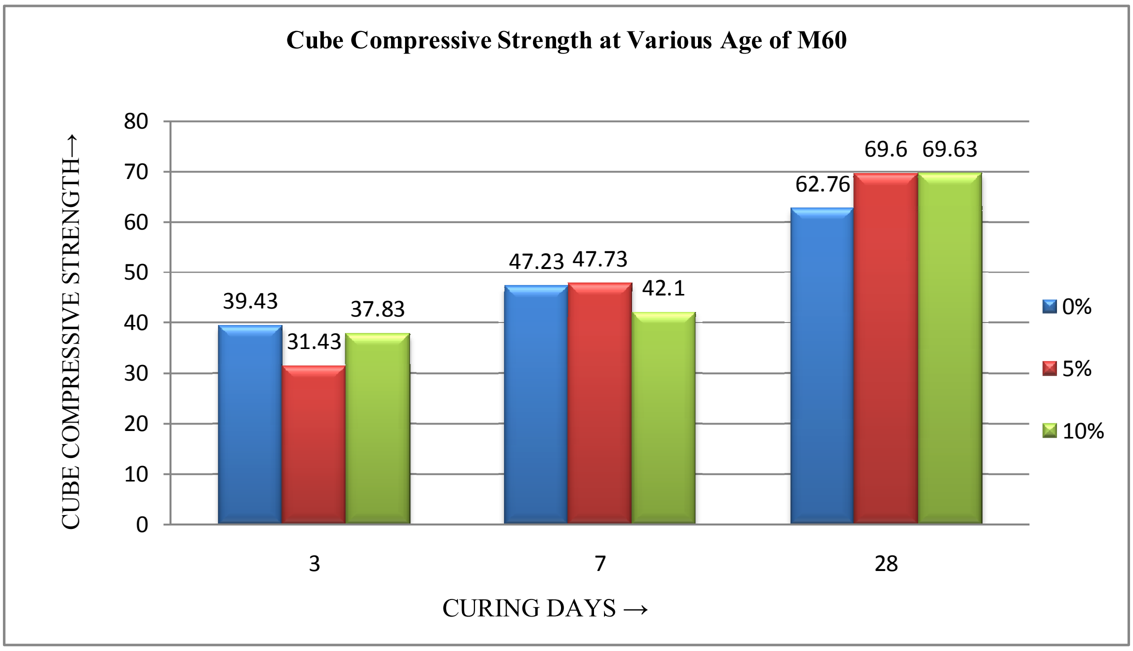


Fig.6.1 Variation in Cube Compressive Strength at Various Ages of M60 mixes

At 3 days, strength is decreased by 20.28% in 5% and 4% in 10% G.G.B.S replacement compared respect to reference concrete.

At 7 days, strength is increased by 1% in 5% G.G.B.S replacement compared to reference concrete while it is decreased by 10.86% in 10% G.G.BS replacement with respect to reference concrete.

At 28 days, strength is increased by 10.89% in 5% and 10.94 in 10% G.G.BS replacement compared to reference concrete.

From the above graph, we can see that all mixes of M60 are reached target strength. Mix with 5% G.G.BS replaced concrete is giving more strength than other percentage replaced concrete and reference concrete at all ages of curing.

At 28 days, the maximum strength achieved among M60 mixes is 69.60 and it is at 5% G.G.BS replacement which is 16% more than the target strength. Other mixes are also reached the target strength.

Rate of gain of strength is slower in 10% G.G.BS replaced mix compared to reference mix and 5% G.G.BS replaced mix.

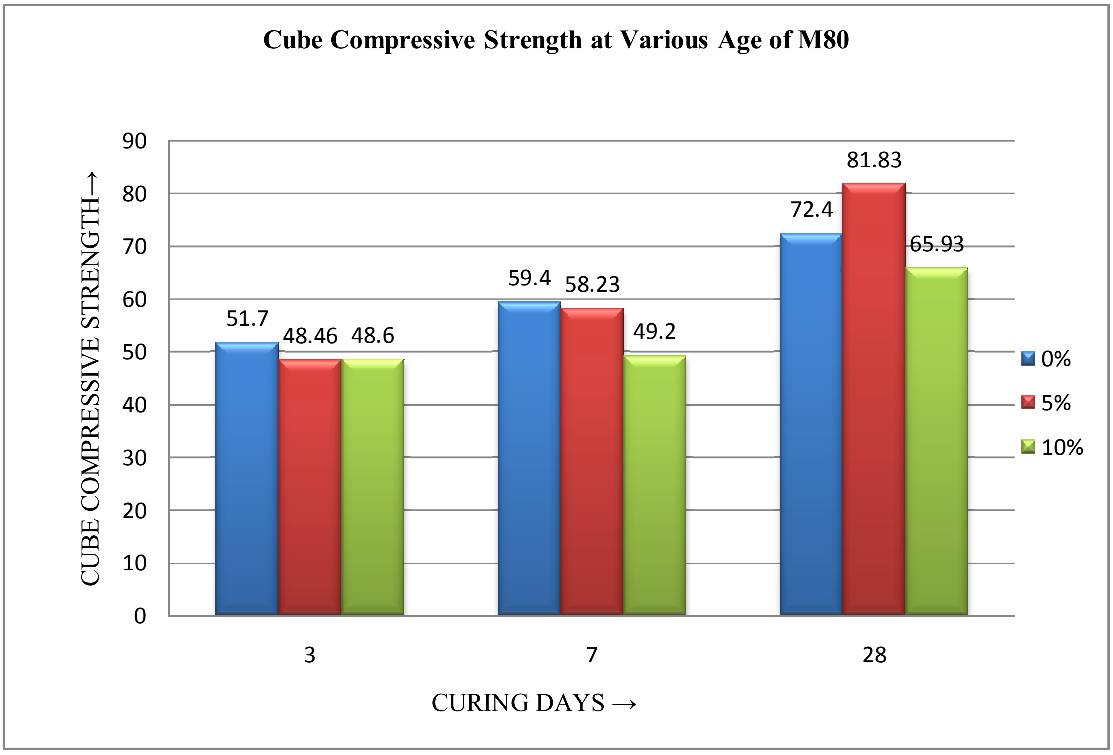


Fig. 6.2 Variation in Cube Compressive Strength at Various Ages of M80 mixes

At 3 days, strength is decreased by 6.26% in 5% and 6% in 10% G.G.BS replacement compared to reference concrete.

At 7 days, strength is decreased by 1.96% in 5% and 17.17% in 10% G.G.BS replacement compared to reference concrete.

At 28 days, strength is increased by 13% in 5% G.G.BS replacement compared to reference concrete while it is decreased by 8.936% in 10% G.G.BS replacement with respect to reference concrete.

From the above graph, we can see only 5% G.G.B.S replaced mix have reached target strength except refrence concrete and 10% G.G.B.S replaced mix at 28 days. Mix with 5% G.G.BS replaced concrete is giving more strength than other percentage replaced concrete and reference concrete at all ages of curing.

At 28 days, the maximum strength achieved among M80 mixes is 81.83 MPa and it is at 5% G.G.BS replacement which is 2.28% more than the target strength. Only 5% G.G.B.S replaced mix have reached the target strength except refrence concrete and 10% G.G.BS replacement.

Rate of gain of strength is slower in 10% G.G.BS replaced mix compared to reference mix and 5% G.G.BS replaced mix.

6.3 Split Tensile Strength

Following Table 6.2 gives the split tensile strength of M60 and M80 at 3, 7 and 28 days with 0,5,10% G.G.BS replacement. The strengths obtained are average of three specimens each. The results are shown graphically in Fig. 6.4, Fig. 6.5 and Fig. 6.6.

Table 6.2 Split tensile Strength (MPa)

M60 Mix	**28 Days**
0%M60	4.82
5%M60	3.196
M80 Mix	**28 Days**
0%M80	5.29
5%M80	5.42

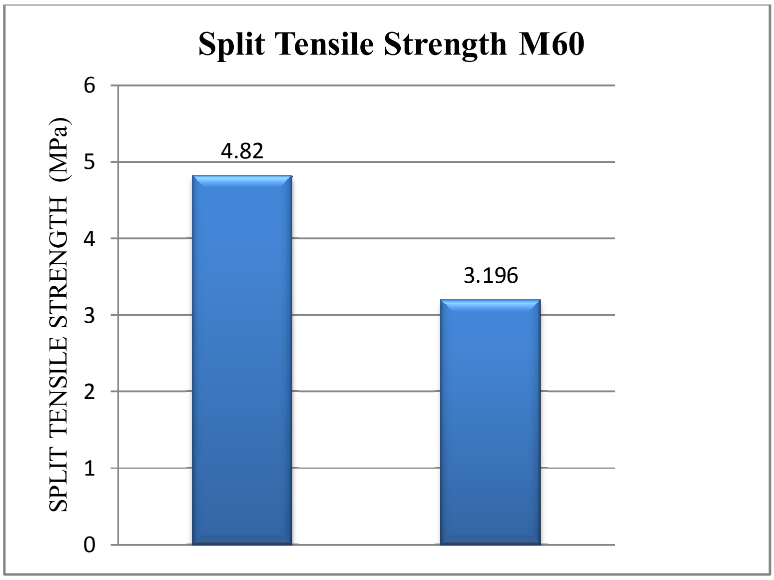


Fig. 6.3 Variation in Split Tensile Strength at 28 Days of M60 mixes

At 28 days, split tensile strength is decreased by 33.69% in 5% G.G.BS replacement compared to reference concrete.

At 28 days, the maximum split tensile strength achieved among M60 mixes is 4.82 MPa and it is at 5% G.G.BS replacement.

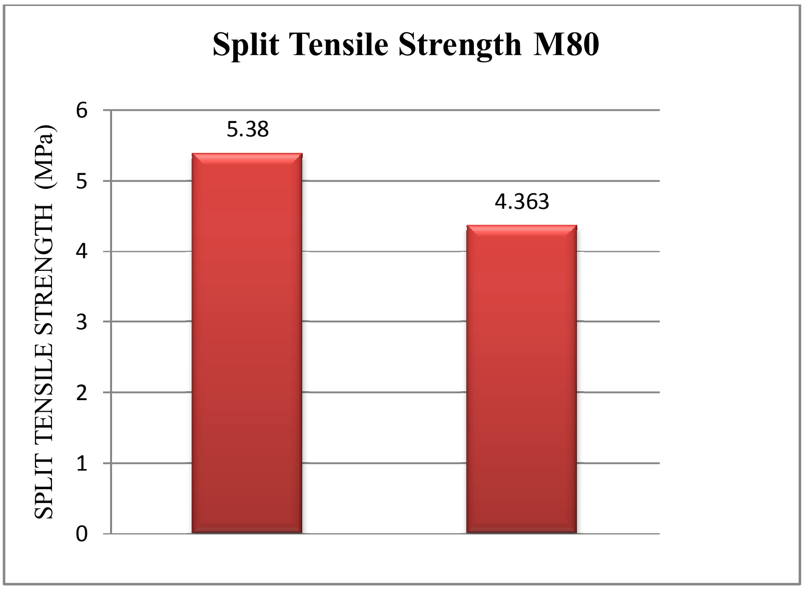


Fig. 6.4 Variation in Split Tensile Strength at 28 Days of M80 mixes

At 28 days, split tensile strength is decreased by 18.90% in 5% G.G.BS replacement compared to reference concrete.

From the above graph, we can see that mix with 5% G.G.BS replaced concrete is giving more split tensile strength than other percentage replaced concrete and reference concrete at all ages of curing.

At 28 days, the maximum split tensile strength achieved among M80 mixes is 5.38 MPa and it is at 5% G.G.BS replacement

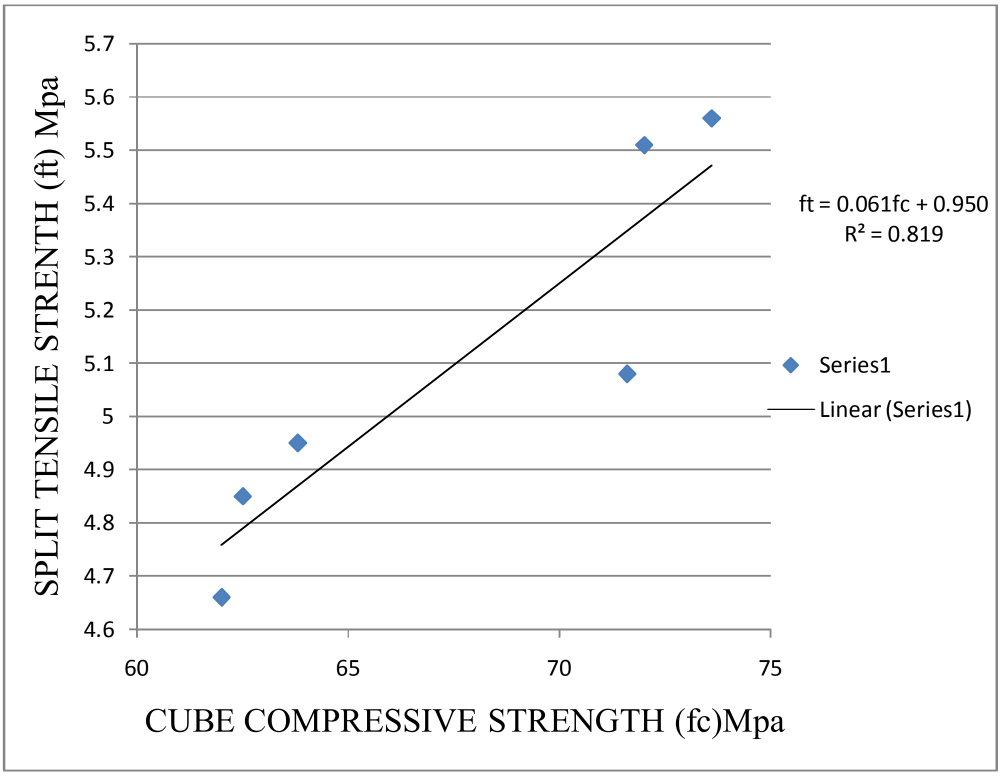


Fig. 6.5 Relation between compressive strength of concrete and split tensile strength

Split tension test was done to assess tensile strength of concrete. The empirical equation developed to relate cube compressive strength with split tensile strength is given in Fig. 6.5, and in equation 6.1

The relation of cube compressive strength versus split tensile strength is as shown in equation 6.1.

$$ft=0.061fc+0.950 \quad (6.1)$$

This graph is plotted to compare the results of HPC with existing relations for NSC. The relationship for split tension observed in this study is:

ACI 363R-84[6] gave equation based on the study of Carrsquillo et al, as (11) [26];

$$f_{sp} = 0.59\sqrt{f_{cy}}\,. \qquad 21\text{MPa} < f_{cy} < 83\text{MPa} \qquad 6.2$$

Said Irvani and Burg et al., [26] gave equations for split tensile strength as in equation 6.3

$$f_{sp} = 0.57\sqrt{f_{cy}} \qquad 50\text{MPa} < f_{cy} < 100\ \text{MPa} \qquad 6.3$$

The equation for the split tensile strength, by S. Bhanja et al,[10] is as follows

$$f_t = 0.248 f_{cy}^{\ 0.717} \qquad 6.4$$

Ahmad and Shah [7] gave equations for split tensile strength as in equation 6.5

$$ft = 0.44(fc')^{0.7}$$

6.5

The comparison of equation 6.1 may be made with the analytical equation given in codes and research papers as shown above. The proposed equation of present study has good match with that of ACI 363R-84 Carrsquillo et al, as (11). However, the equation Ahmad and Shah overestimate the split tensile strength.

6.4 Modulus of Rupture Strength

Following Table 6.3 gives the modulus of rupture Strength of M60 and M80 at 3, 7 and 28 days with 0,5, and 10% G.G.BS replacement. The strengths obtained are average of three specimens each. The results are shown graphically in Fig. 6.6, Fig. 6.7 and Fig. 6.8.

Table 6.3 Modulus of rupture Strength (MPa)

M60 Mix	**28 Days**
0%M60	5.80
5%M60	5.03
M80 Mix	**28Days**
0%M80	5.51
5%M80	5.65

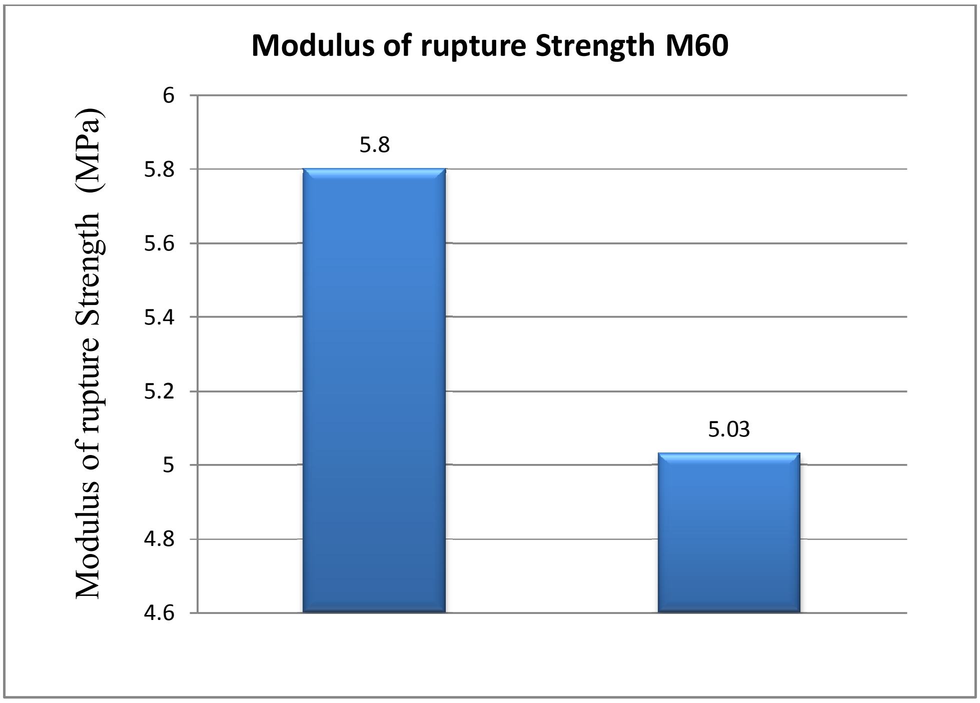


Fig. 6.6 Variation in modulus of rupture strength at 28 Days of M60 mixes.

At 28 days, modulus of rupture strength is decreased by 13.27% in 5% G.G.BS replacement compared to reference concrete.

From the above graph, we can see that mix with 0% G.G.BS replaced concrete is giving more modulus of rupture strength than other percentage replaced concrete and reference concrete at all ages of curing.

At 28 days, the maximum modulus of rupture strength achieved among M60 mixes is 5.80MPa and it is at 0% G.G.BS replacement.

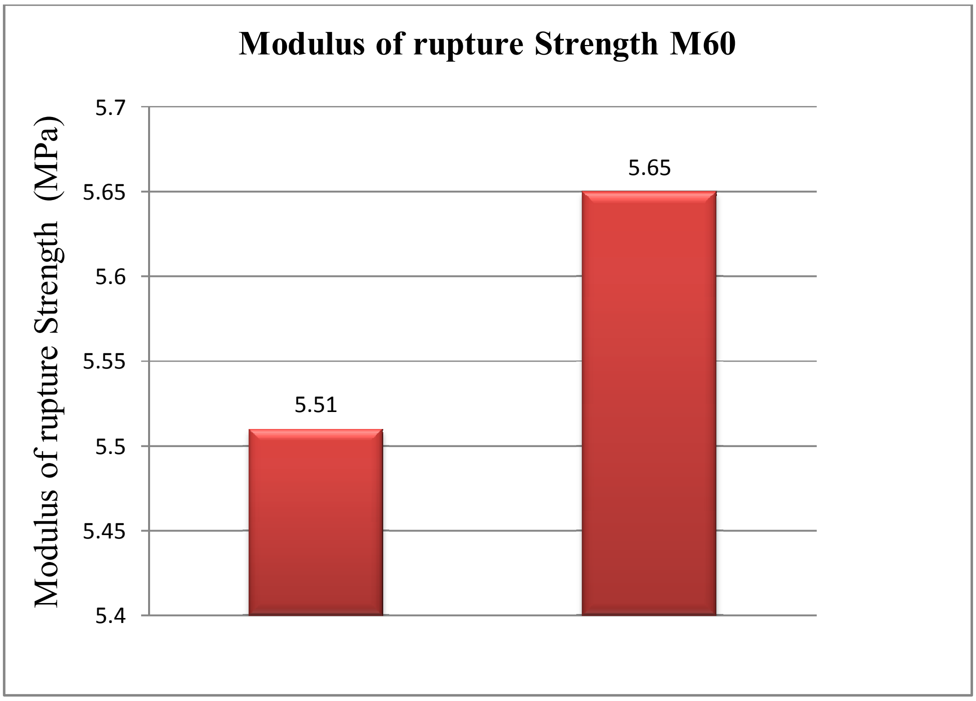


Fig. 6.7 Variation in Modulus of Rupture Strength at 28 Days of M80 mixes

At 28 days, modulus of rupture strength is increased by 2.54% in 5% G.G.BS replacement compared to reference concrete .

From the above graph, we can see that mix with 5% G.G.BS replaced concrete is giving more modulus of rupture strength than other percentage replaced concrete and reference concrete at all ages of curing.

At 28 days, the maximum modulus of rupture strength achieved among M80 mixes is 5.65 MPa and it is at 5% G.G.BS replacement.

6.4.1 Relationship between split tensile strength and modulus of rupture

For the present investigation, the average ratio between the modulus of rupture and split tensile strengths has been obtained as 1.6 as shown in Fig 6.16. The ratio between flexure and split tensile, as per ACI ranges from 1.4 to 1.6.

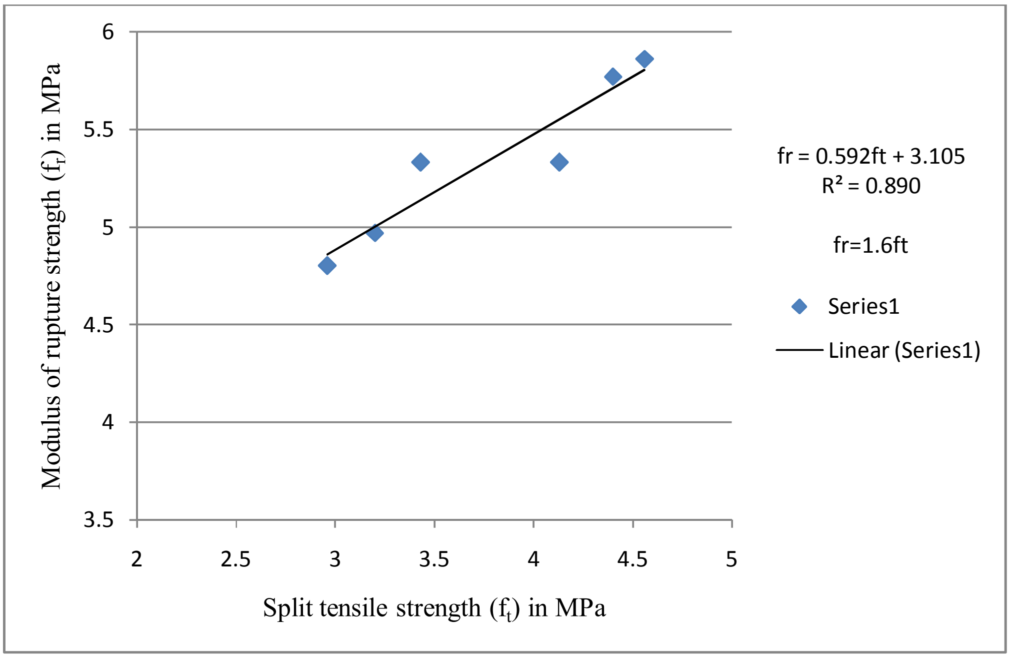


Fig. 6.8 Relationship between split tensile strength and modulus of rupture strength

6.5 Stress Strain curves

The complete stress-strain curve of 60 and 80MPa concrete under uniaxial compression were carried out. As a result, the specimens could be loaded so as to maintain a constant rate of strain increase and avoid unstable failure. Fig. 6.9 to 6.10 show the complete stress-strain curves of various grade concrete obtained from the experiment.

It can be seen from the figures that for high strength concrete, the shape of the ascending part of the stress-strain curve is more linear and steeper, that results in the increase of elastic modulus. The strain at peak stress is slightly higher, and the slope of the descending part is steeper as compared to lower strength concrete. That was due to the decrease in the extent of internal microcracking in higher strength concrete. The stress strength ratio at which microcracks begins to form continuous crack pattern is higher for higher strength concrete, therefore, the stress strength ratio at which the stress strain curve begin to curve more sharply to the horizontal is higher for high strength concrete.

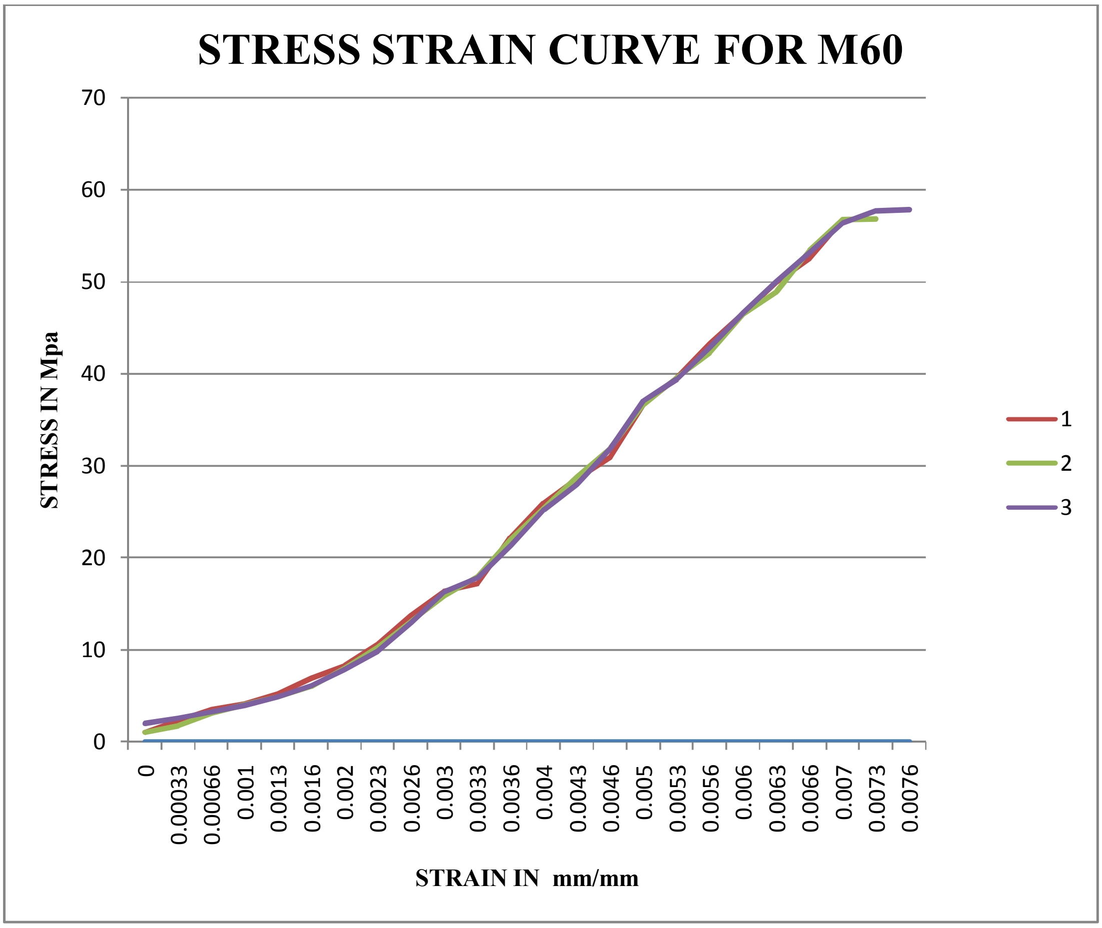


Fig. 6.9 Stress Strain curves for 5% G.G.B.S M60 Grade concrete

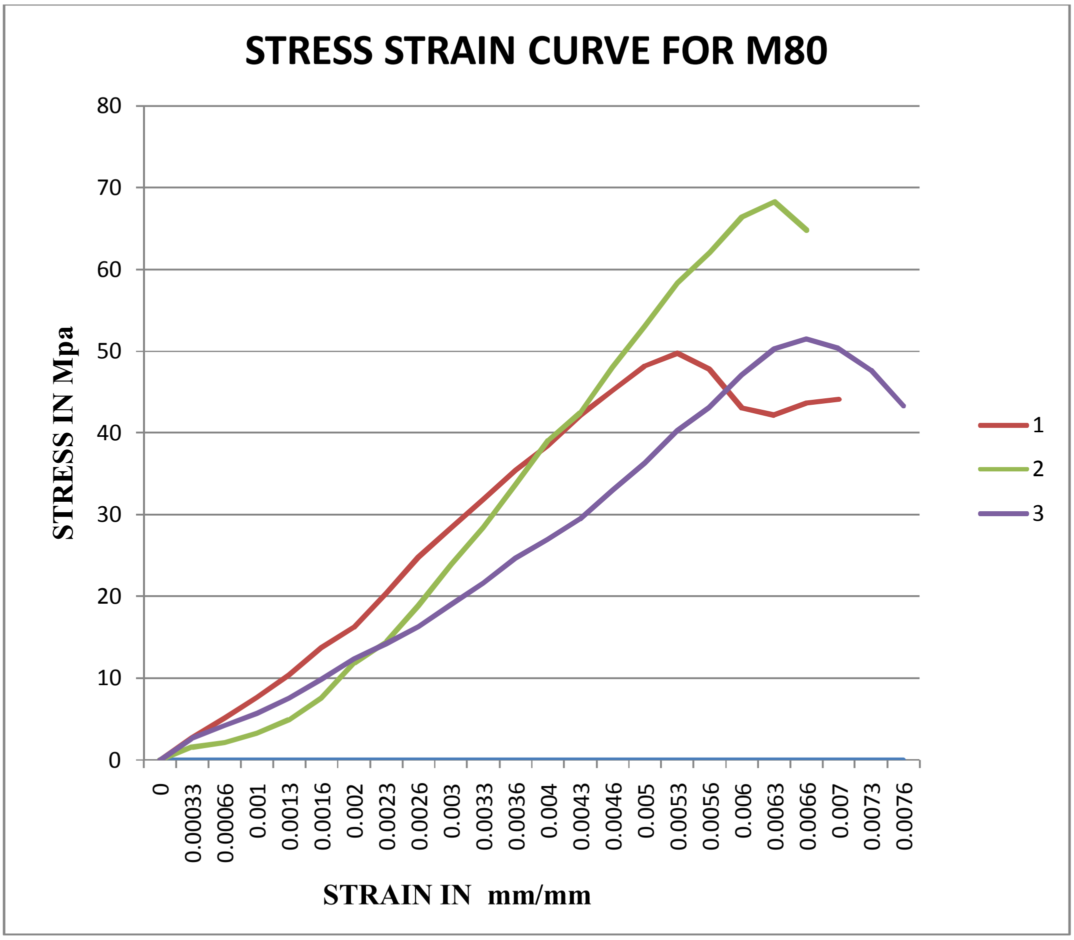


Fig. 6.10 Stress Strain curves for 5 % G.G.B.S M80 Grade concrete

"THE MODULUS OF ELASTICITY TEST FOR CONCRETE WAS PERFORMED BUT FAILED".

CHAPTER 8

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Chapter 7

Conclusion

In the present study the use of pozzolanic material, GGBS in production of HPC has been investigated.

1). With the use of super plasticizer it possible to get a mix with low water to cement ratios of the range 0.35, 0.30, 0.25 to get the desired strength.

2). The Compressive strength of concrete increases as compared to reference concrete. It is higher at 10% replacement of Cement with GGBS among M60 and 5% replacement among M80. At 28 days maximum strength achieved are 69.63 MPa which is higher than 0% and 5%. At 28 days the maximum strength achieved for M80 concrete is 80.21 MPa which is higher than 0% and 10%.

3). The Gain of strength is slow in 5% and 10% GGBS replacement than 0% replacement in M60 and M80.

4). The spilt tensile strength and modulus of rupture of GGBS are increasing in M80 as compared to reference concrete but decreasing in M60 concrete by the replacement of cement with GGBS. The nature of decrease of split tensile strength in M60 concrete can be due to Man handling error. Nevertheless, equation is been proposed in present study between spilt tensile strength and cube compressive strength. The proposed equation of present study has a good match with the equation proposed by ACI 363R-84.

The crack surfaces of lower strength concrete generally develop between the interface of aggregate and the cement paste. On the other hand, cracking in higher strength concrete is more localized, and the number and length of continuous crack patterns developed at failure are smaller than those of lower strength concrete. For this reason, the failure mode of high strength concrete is typical of that of nearly homogeneous material. In addition, the strength of the coarse aggregate was found to be the controlling factor for the ultimate strength of high performance concrete. The influence of coarse aggregate is found to be less important for lower strength concrete.

Split tensile strength, modulus of rupture strength and modulus of elasticity are related to the compressive strength of concrete and are in good agreement with some of the equation proposed in literature.

The percentage decrease in compressive strength was observed in 5% GGBS concrete for 3 days of curing, 1% increase in compressive strength was observed and 10.89% increase in compressive strength for 28 days of curing with respect to reference concrete. This is due to the fact that gain of early strength in pozzolonic concrete is less as compared to non pozzolonic concrete and later strength is more in pozzolonic concrete as compared to non pozzolonic concrete.