THESIS

ON

"EFFECT OF SPECIMEN SHAPE AND SIZE ON THE STRENGTH PROPERTIES OF HIGH STRENGTH CONCRETE"

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Submitted By:

JASKARAN SINGH
(801222006)

Under the Guidance of

DR. RAFAT SIDDIQUE

SENIOR PROFESSOR

DEPARTMENT OF CIVIL ENGINEERING

THAPAR UNIVERSITY, PATIALA

DECLARATION

The author hereby declare that this dissertation entitled **"EFFECT OF SPECIMEN SHAPE AND SIZE ON THE STRENGTH PROPERTIES OF HIGH STRENGTH CONCRETE"**, in whole or part has not been used to obtain any degree in this, or any other, institute, except where references have been given in text, it is entirely the author own work. The author conform that the library may lend or copy this upon request for academic purposes.

JASKARAN SINGH
Roll no. - 801222006

CERTIFICATE

This is to certify that the work presented in dissertation entitled **"EFFECT OF SPECIMEN SHAPE AND SIZE ON THE STRENGTH PROPERTIES OF HIGH STRENGTH CONCRETE"** submitted by **Mr. Jaskaran Singh** in partial fulfillment of the requirements for the award of degree of **Master of Engineering** in Structural Engineering at **Thapar University, Patiala,** is a bonafide work carried out by the student under our supervision and guidance. The matter embodied in this report has not been submitted anywhere for the award of degree.

17/8/15

Dr. RAFAT SIDDIQUE
Senior Professor
Department of Civil Engineering
Thapar University, Patiala

COUNTERSIGNED

17/8/15

Dr. NAVEEN KWATRA
Professor & Head
Department of Civil Engineering
Thapar University, Patiala

Dr. S.S.BHATIA
Dean, Academic Affairs
Thapar University, Patiala

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JASKARAN SINGH
(ROLL NO. 801222006)

ABSTRACT

High strength concrete is currently a common construction material and its compressive strength is most basic and important material property in structural design. In this paper we investigate the influence of the shape and of the size of the specimens on the compressive strength of high strength concrete. We use cylinders and cubes of different sizes for performing stable stress-strain tests. This value was kept constant throughout the experimental program. Our results show that the post-peak behavior of the cubes is milder than that of the cylinders, which results in a strong energy consumption after the peak. This is constant with the observation of the crack pattern: the extent of micro-cracking throughout the specimen is denser in the cubes than in the cylinders. Indeed, a main inclined fracture surface is nucleated in cylinders, whereas in cubes we find that lateral sides get spalled and that there is a dense columnar cracking in the bulk of the specimen. Finally, we investigate the relationship between the compressive strength given by both types of specimen for several specimen sizes. The influence of specimen size and shape on the measured compressive strength was investigated for different high strength concrete mixes. Also, the compressive strength can also be determined to be insignificantly affected by changing l/d as the strength of concrete increases.

After testing of specimens at 7and 28 days, the results show that the cube specimen is generally stronger than the cylinder specimen and this effect will be gradually decreased when the concrete strength increased. For the effect of the specimen size the results show that the compressive strength increases as the specimen size decreases. This size effect might be ignored as the relationships showed that the effect is relatively small as compared to specimen shape effect.

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

As the use of high strength concrete has become a common practice in various applications for many decades, especially for high rise buildings, long span, bridges and repair and rehabilitation works. It is important to have confidence in the suitable and applicability of current testing practices. The 28 days compressive strength of concrete determined by a standard uniaxial compression test is accepted universally as a general index of concrete strength. Among several parameters, size and shape of test specimens are two of the most important parameters that influence the result of concrete compressive strength due to its fracture characteristics. There are basically two shapes of specimens used for testing, cube and cylinder, in the determination of compressive strength of concrete. In the British approach, 150mm cube is employed as standard specimen while Ø150x300mm cylinder is commonly used in the American approach.

The sizes and shapes of compressive strength test specimens of concrete varies from one country to another. Cylinders are used in the United States, Canada, France, Australia, etc. whereas cubes are the standard shapes in the United Kingdom, Germany, and many other European countries. There are several countries where tests are made on both cubes and cylinders. Commonly used standard sizes are 150mm and Ø150**x**300mm for cubes and cylinders, respectively. However, the advantages such as easy handling, necessitating lower capacity test machines, using less concrete, etc. offered by smaller specimens have caused them to be used more frequently.

Thailand is one of several countries that uses both cylinder and cube as standard test specimens to establish the characteristic compressive strength. Because of the differences in the shape, aspect ratio, and the associated end restraint provided by the machine platen, cube and cylinder strengths obtained from the same batch of concrete are different, the higher strength being given by the cubes (Mansur and Islam, 2002). Investigations conducted at various research centers around the globe have indicated that the factor that relates cube strength to cylinder strength does not remain constant for all grades of concrete.

In Saudi Arabia, concrete is the dominant construction material for all types of buildings and other structures. Most of the structural concrete elements are made with a compressive strength of 20 to 35MPa. Lately, there is an increase in use of high strength concrete (HSC) in major construction projects such as high-rise buildings and bridges. The advances in the quality control of concrete production are enabling ready mixed, pre-stressed, and pre-east concrete plants to achieve higher strength concretes. Locally, the characteristic compressive strength is usually measured based on 150 mm cubes. But in design practice, the design compressive strength is usually based on the standard Ø150x300mm cylinders. The use of Ø100x200mm cylinders gained more acceptance locally as the need to test high strength concrete increases. This is expected since most testing machines used locally have a full capacity of 1300MPa. Hence, to test a standard specimen having a compressive strength of 80MPa would require a test machine with a capacity greater than 1300MPa.

By far the most common test carried out on concrete is the compressive strength test. The main reason to understand this fact is that this kind of test is easy and relatively inexpensive to carry out (Mindess et al., 2003). Testing Standard requirements use different geometries of specimens to determine the compressive concrete strength. The most used geometries are cylinders with a slenderness equal to two and cubes. Shape effect on compression strength has been widely studied and different relationships between compression strength obtained for these geometries have been proposed, mainly from a technological standpoint. Such approach eludes the fact that there is a direct relation between the nucleation and propagation of fracture processes and the failure of the specimen. Indeed, experimental observations confirm that a localized micro-cracked area develops at peak stress (Shah and Sankar, 1987) or just prior to the peak stress (Torreti et al., 1993). For this reason compressive failure is suitable to be analyzed by means of Fracture Mechanics.

In the last decades concrete technology has made it easier to reach higher strengths and the so-called High-Strength Concrete (HSC) has appeared as a new construction material. This amount of the compressive strength provokes that the normalized specimens for normal strength concrete, e.g. Ø150x300mm cylinder, may surpass the capacity of standard laboratory equipment. To overcome this drawback HSC mixtures are often evaluated using Ø100x200mm cylinders, which also meet the requirements of ASTM C39. The strength obtained with this specimen is higher in average than that obtained with Ø150x300mm cylinders. This size effect on the compressive strength manifests that the specimen is not behaving as simply as it may look. Indeed, size effect is understood as the dependence of the nominal strength of a structure on its size (dimension) when compared to another geometrically similar structure (Baˇzant and Planas, 1998).

In this we are particularly interested in the influence of the shape and of the size of the specimens on the compressive strength, *fc*, of the material. According to our results we propose a new relationship between cylinder and cube specimens.

Several researchers have compared measured strengths achieved with different sizes of cubical and cylindrical specimens for high strength concrete. For cylindrical specimens comparisons were usually made between the compressive strength of Ø150x300mm cylinders and that of Ø100x200mm cylinders. Carrasquillo *et al.* (1981) reported that the average ratio of compressive strength of Ø150x300mm to Ø100x200mm cylinders was 0.9 regardless of strength and test age. A contradiction to this finding was later reported by Carrasquillo *et al.* (1988) which reported that compressive strength of Ø100x200mm cylinders were 7 percent lower than those of Ø150x300mm cylinders. French *et al.* (1993) observed in their study that on average Ø100x200mm cylinders tested showed 6 percent higher strength than that of their companion Ø150x300mm cylinders. Aitcin *et al.* (1994) reported that larger cylinder sizes gave rise to lower apparent compressive strength, and that compressive strength is not sensitive to cylinder size for very high strength concrete. A comparison of the compressive strength between 150mm cubes, Ø150x300mm cylinders was performed. These sizes were chosen because it represented the sizes that are most commonly used locally in the construction industry and research.

1.2 OBJECTIVES

The main objectives of this present research study are:

1. To experimentally investigate the characteristics of compressive strength and splitting tensile strength from different size and shape of specimens.

2. To compare the compressive strengths and splitting tensile strength obtained from the same concrete mix with varying size and shape of specimen.

3. To suggest the size and shape factors to convert the compressive strength of concrete determined from various types of specimen to standard Ø150x300mm cylinder and 150mm cube strength.

1.3 SCOPE OF RESEARCH

This research study will be performed with the scope listed below:

1. This study only deals with axial compressive strength and splitting tensile strength from test specimens at 7 and 28 days with limited variables to the specimen type and strength level of concrete.

2. Test specimens in this study are cylinders Ø150x300mm and cubes 150 mm. The concrete compressive strengths and spiltting tensile strength are expected to be between 550 and1000 kg/cm2 (standard cylindrical strength at 28 days). The specimens shall be tested by uniaxial load until ultimate load capacity is reached.

CHAPTER-2

LITERATURE REVIEW

2.1 INTRODUCTION

Testing of hardened concrete to determine its compressive strength is one of the most important and necessary experiments performed. High Strength Concrete (HSC) has been used and studied as a workable construction material for several decades. In U.S.A, HSC was applied to major prestressed girders in 1949. The first bridge reported to use HSC in its design and construction was Walnut Lane Bridge in Philadelphia (Russell, 1997). This bridge was constructed with a 160feet center main span with two 74 feet side spans with a strength of 37MPa in 14 to 17 days.

Zollman (1951) reported that the compressive strength at 28 days was usually high about 65MPa. ACI 363R-97 notes that concrete with a compressive strength of 34MPa was considered to be HSC in the 1950's. At that same time, the introduction of prestress design methods would have been considered to be more remarkable than the use of HSC. The possibilities for HSC production in the construction industry was increased by the development of high-range water reducing admixtures in the 1960's and further improvements of material technology.

Most common method of experiments is casting concrete samples and crushing them in laboratatory, using relevant testing machines. On the other hand, results of the experiment can be affected by various factors such as sizes, shapes and the moulds of specimen used for casting, curing conditions and rate of load application (Neville, 2002). Mostly two types of specimens used for testing hardened concrete are cubes and cylinders with different dimensions used across different nations. Cylindrical specimens Ø150mm×300mm are used mostly in Australia, Canada, France, New Zealand and the United States. While cube specimens Ø150mm×100mm are used mostly in European countries including great Britain and Germany (Elwet & Fu, 1995).

One of the differences between cylinder and cube specimens is that before being loaded, cylinder specimens need capping. The specimens have to be capped by Sulphur mortar or cement paste in order to have plain loading surfaces. Whereas cubes do not require capping as they are turned over on their sides, when being loaded.

On the other hand, cubes show higher compressive strength that requires higher capacity testing machine and about the cylinders they are tested in the direction of casting, which is considered as an advantage for them (Elwet and Fu, 1995).

Various researches conducted previously, to understand and clarify the so-called size and shape effect of concrete specimens on the compressive strength test results. According to (Bažant and Planas, 1998), size effect can be seen when by altering the size of a concrete member, its nominal strength also gets changed, even though their shape is similar to each other. The same definition can be proposed for shape effect as well, when nominal strength of concrete members is dependent on their shape. Apart from the parameter of nominal strength, some other properties also differ in their results, caused by using specimens with different shapes and sizes, properties like cracking or fracture pattern and trends of stress-strain curves.

One of the first investigations about size effect was carried out in 1925 by Gonnerman, using standard cubes of 6” and 8” and different sizes of cylinders. Testing different specimens at different ages, the average cylinder/cube ratio of 0.85 to 0.88 was obtained (Gonnerman, 1925; Elwet and Fu, 1995). Different curing condition’s effect on conversion factors (cylinder/cubes) was investigated by Plowman et al. (1974).

Another investigation about shape and size effect on compressive strength of high strength concrete has been carried out, proposing different conversion factors of 0.8 for cylinder Ø150×300mm/cube 150mm, 0.93 for cylinder Ø100×200mm/cube 150mm and 0.86 for cylinder Ø150×300mm/ cylinder Ø100×200mm. It was also found out that mix design parameters, also change the strength ratio of cylinder/ cubes (Malaikah, 2009).

Shape and size effect has been also investigated about high-strength concrete, showing that size effect is stronger in cubes than cylinders.

One of the factors, which change the conversion factors, is aggregates grading that shows itself through “wall effect”. This effect indicates that the amount of mortar required to fill the space between concrete’s aggregates is less than the amount of mortar needed to fill the space between aggregates and the mould’s wall (see Figure).

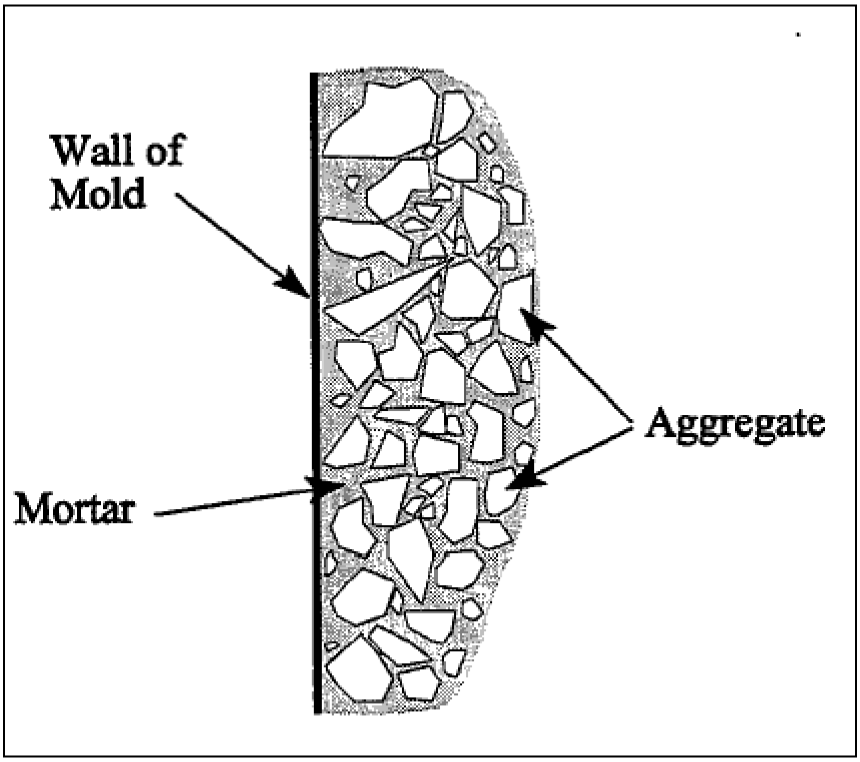


Figure 2.1: Wall effect (Neville, 2002)

The extra mortar between aggregates and wall of moulds causes an increase in compressive strength of specimens. It is also more remarkable in specimens which have larger ratio of surface/ volume and causes changes cylinder/cube conversion factor (Elwet and Fu, 1995; Tokyay and Ozdemir, 1997).

Wall effect has also been vastly investigated. One of the researches was carried out by (Zheng and Li (2002). In their research, a three-dimensional model was proposed in order to simulate aggregates density inside of concrete specimens.

The corresponding graph of the model is in a way that by moving from sides to inner zone of a concrete specimen, aggregate’s density, firstly has a growing trend up to a specific peak (which is a near-surface section), then after a slight decrease, the density reaches to a constant amount. Also, the peak point of the graphs rises by having more aggregates' fraction.

To eliminate the influence of wall effect, during an investigation, Turkel and Ozkul (2010), sawed concrete specimens from casted specimens. In the research, it was found that size effect is more pronounced in concrete samples of higher compressive strengths, which can be attributed to more brittle characteristics of these grades. Also, it was found that size effect depends on maximum aggregates size of concrete, for both medium and high compressive strengths, in the same manner.

With the increasing use of High Strength Concrete (HSC), it is important to have confidence in the suitable and applicability of current testing practices. Refinement and verification may be needed for the factors that may have an effect on compression test results. For normal strength concrete (NSC), the influence of the foregoing factors has been studied and reported. For HSC, however, very few investigations have been reported concerning these aspects. As the uniaxial test is used to monitor the compressive strength of concrete for quality control or acceptance purpose, the parameters that are used to establish the characteristic compressive strength need to be carefully controlled. Imam *et al.* (1995) investigated the important factors, i.e. specimen size, specimen shape and mould material, which may have an effect on compressive testing results of high-strength concrete. Compressive tests were performed on 6 different specimen types with a total of 360 specimens cast from 18 different high-strength concrete mixtures (fc' = 82 to 117MPa). From the results, they have concluded that the compressive strength decreases about 5% for each 50 mm increase of the cube size and the concrete compressive strength of 150 mm cube specimen is about 5.8% greater than that of Ø150x300 mm cylinder specimen. Also conversion factors were given, as shown in Table.

Table 2.1: Conversion factors between different specimen types

Conversion to	From	Cast iron moulds			
		Cylinder 150x300 mm	Cube 100 mm	Cube 150 mm	Cube 200 mm
Cast iron moulds	Cylinder 150x300mm	1.000	0.897	0.945	0.989
	Cube 100 mm	1.115	1.000	1.053	1.103
	Cube 150mm	1.058	0.950	1.000	1.046
	Cube 120mm	1.011	0.907	0.956	1.000
Plastic moulds	Cube 100mm	1.033	0.927	0.976	1.021
	Cube 150mm	0.953	0.855	0.901	0.942

Source: Inam et al. (1995)

Mansur and Islam (2002) performed an experimental study on the effects of different concrete specimen types on the compressive strength and established the inter-relationships between their strengths. Each of a total eleven test data sets generated in this study consists of five strength values for the five different types of test specimens. Each strength value was calculated by averaging the strength of at least three identical specimens. In the analysis, the 150 mm cube compressive strength was taken as the reference, and strength values determined for each type of specimen were converted to the corresponding standard cube strength by using suitable expressions obtained from linear regression analysis.

Tokyay and Özdemir (1997) investigated the specimen size and shape effects on the compressive strength of high-strength concrete. The experimental study was performed on different sizes of cylinder and cube specimens cast from three concrete mixtures having compressive strength levels of 40, 60 and 75MPa. The results show that strength values of 75 mm diameter cylinder and 75 and 100 mm cube specimens were lower than those of the larger specimens used.

Felekoglu and Turkel (2005) investigated the compressive strength values of cube and cylinder specimens at two strength levels with different sizes and proposed transformation coefficients. Concrete mix designs at two different strength grades (NSC and HSC) were prepared. A total of 144 specimens of 4 different types (150 mm and 200 mm cubes, Ø100x200mm and Ø150x300mm cylinders) from both NSC and HSC mixes used in groups of nine in compressive strength tests at 7 and 28 days were prepared. Standard curing was applied to these specimens until the time of test.

Test results showed that, the compressive strength values increase with the increase in size of the specimen. This behavior which is the opposite of literature was thought to be caused by the "wall effect". The maximum aggregate size of concrete mixtures is 25mm, which caused the wall effect and low compactness, particularly for Ø100x200mm cylinder specimens. At the same time, this situation puts forward the importance of the selection of the mold type which is proposed by the standards for a given maximum aggregate size.

Experimental study verified that cylindrical specimens always gave lower strength values when compared with cubic specimens. In order to convert the strength of different types of samples to standard cylinder (Ø150x300mm) and standard cube (150mm) strengths, coefficients were proposed and presented in Table

Table 2.2: Correction factors of different specimens

Compressive strength of concrete (MPa)	Correction factors for concrete strength			
	150x300mm Cylinder	**100x200mm Cylinder**	**100x100mm Cylinder**	**100mm Cube**
20	1.510	1.316	1.176	1.093
30	1.344	1.210	1.090	1.033
40	1.261	1.156	1.947	1.003
50	1.212	1.124	1.022	0.984
60	1.179	1.103	1.005	0.972
70	1.155	1.088	0.992	0.964
80	1.137	1.076	0.983	0.957
90	1.123	1.067	0.976	0.952
100	1.112	1.060	0.970	0.948

Source: Felekoglu and Turkel (2005)

Yazıcı and Sezer (2007) investigated the influence of size and capping type of cylindrical specimens on compressive strength of concrete. For this purpose, three hundred and eighty-four cylindrical specimens having dimensions of Ø150x300mm and Ø100x200mm were cast from eight concrete mixtures. Linear and nonlinear regression analyses were employed between compressive strength of Ø100x200mm cylinder (fc'100x200) and Ø150x300mm cylinder (fc'150x300). The results showed that the average compressive strength of Ø100x200mm cylinders is generally higher than Ø150x300mm cylinder specimens for the average compressive strength of concretes varies between 14 and 47MPa.

Reasons for this phenomenon were expressed as:

1. In the uniaxial compression test, smaller contact area between the specimen surface and steel platen of test machine resulting in lower friction-based shear forces in small specimens.

2. By means of statistical approach, the number of micro cracks and defects in smaller specimens are fewer than bigger specimens, resulting in a rise in density.

CHAPTER-3

EXPERIMENTAL PROCEDURE

3.1 MATERIALS

The use of locally available materials from different sources was emphasized in this study. For the cases where locally available materials were not attainable, commercially available materials were used. Following are the details of materials used.

3.1.1 Ordinary Portland Cement: Although all materials that go into concrete mix are essential, cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand and stone together and second to fill up the voids in between sand and stone particles to form a compact mass. It constitutes only about 20 percent of the total volume of concrete mix; it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Any variation in its quantity affects the compressive strength of the concrete mix. Portland cement referred as Ordinary Portland Cement is the most important type of cement and is fine powder produced by grinding Portland Cement clinker. The OPC is classified into 3 grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, maintaining better particle size distribution, finer grinding and better packing.

Ordinary Portland Cement of 43 Grade (JK cement) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement as determined from various tests conforming to Indian Standard IS: 8112:1989 are listed in table. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. The various tests conducted on cement are initial and final setting time, specific gravity, fineness and compressive strength. The results of above tests are given below in table.

Table 3.1: Properties of OPC 43 Grade Concrete

Sr. No.	Characteristics	Values Obtained Experimentally	Values Specified by IS 8112:1989
1.	Specific Gravity	3.12	-
2.	Standard consistency	29 %	-
3.	Initial Setting Time	147 minutes	30 minutes (minimum)
4.	Final Setting Time	305 minutes	600 minutes (maximum)
5.	Compressive Strength 7 Days 28 Days	 37.5 MPa 47.6 MPa	 33 MPa 43 MPa

3.1.2 Fine Aggregates: The aggregates most of which pass through 4.75mm IS Sieve are termed as fine aggregates. The fine aggregates may be Natural Sand, Crushed Stone Sand and Crushed Gravel sand. According to size, the fine aggregates may be described as coarse, medium and fine sands. Depending upon the particle size distribution IS: 383-1970 has divided the grading zones (Grade 1 to 4). The grading zones become finer from grading zones 1 to 4. The grading of the sand is compatible with zone (2).

In this experimental program, fine aggregates was locally procured and conformed to IS: 383-1970. The sand was sieved through 4.75mm sieve to remove any particles greater than 4.75mm and conforming to grading zone. Properties are shown below in table

Table 3.2: Properties of Fine Aggregates

Characteristics	Value
Color	Brown
Specific Gravity	2.61
Fineness Modulus	2.63
Water Absorption	0.89 %

3.1.3 Coarse Aggregates:

The aggregate which is retained over IS Sieve 4.75mm is termed as coarse aggregate. Crushed aggregate is used gradually of size 10-20mm. However particle sizes up to 40mm or more are used in Self-Compacting Concrete. Locally available coarse aggregate having the maximum size of 20mm was used in this work. The aggregates were washed to remove dust and dirt and were dried to dry surface condition. The aggregates were tested as per IS:383-1970. Specific gravity and other properties of coarse aggregates are given in table.

Table 3.3: Properties of Coarse Aggregates

Characteristics	Value/Specifications
Color	Greyish
Shape	Angular
Maximum Size	20mm
Specific Gravity	2.69

3.1.4 Admixture: The use of superplasticizer (high range water reducer) has become a quite common practice. This class of water reducers was originally developed in Japan and Germany in the early 1960's; they were introduced in th United States in the mid 1970's. In this experimental study, Superplasticizer (SP 905) is used which is a super plasticing concrete admixture based on synthetic polymer. It has advantage of producing high early strength and higher workability concrete.

Table 3.4: Properties of Polycarboxylate Superplasticizer

Characteristics	Value/Specifications
Appearance	Yellow brown liquid
pH	5.2 - 5.3
Specific Gravity	Approx. 1.06
Solubility	Excellent
Solid Content	Approx. 98.0

3.1.5 Silica Fume: Silica fume is the name given to the very fine grained dust given off as a by-product of high temperature furnaces which reduce silica to silicon or silicon alloys. It is essentially amorphous silica, with small amounts of quartz, cristobalite and other phases. Commercially available powder silica fume was used in the study. The silica fume had a specific gravity of 2.3.

Table 3.5: Properties of Silica Fume

Characteristics	Value/Specifications
Specific Gravity	2.3
SiO_2 Content (%)	98
CaO Content (%)	0.3
Al_2O_3 (%)	0.4
Fe_2O_3 (%)	0.10

3.1.6 Water: Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting. The potable water is generally considered satisfactory for mixing and curing of concrete.

3.2 CONCRETE

In this experimental study, four different high-strength concrete mixtures were used. The expected cylinder compressive strengths of concrete mixes are 550, 700, 850 and 1000 kg/cm2. Concrete mixes were designed, treated, and controlled under the same conditions. The cement used in all mixes is Portland cement type I, when natural river sand and crushed limestone are used as fine and coarse aggregates, respectively. The silica fume is used as mineral admixture. To achieve workable mixes with the desired quality and strength, a superplasticizer in the form of an aqueous solution is also used.

Six trial mixtures of high strength concrete were performed, based on the same materials with four different water-binder ratios (w/b), in order to get enough information in designing the final mix proportions. The design of trial mixes are expected to produce a range of strengths that encompass the target strengths. Three test cylinders per trial mixture are made and tested at 7 days. From trial mix test results, the high strength concrete mix proportions are adjusted with the assumption of compressive strength at 7 days is 80% of the strength at 28 days. The w/b, water and super plasticizer contents of each mix are adjusted to make compressive strength close to the expected strength and also to improve workability of fresh concrete. The slump values for all mixes in this study are expected to be more than 20 cm to facilitate the compaction of concrete.

Table 3.6: High-strength concrete mix proportions

Expected fc at 28 days	**Mix 1** **550 MPa**	**Mix 2** **700 MPa**	**Mix 3** **850 MPa**
Ordinary Portland cement (kg/m^3)	350	412	464
Silica fume (kg/m^3)	21	37	56
Water (kg/m^3)	140	140	130
Superplasticizer (kg/m^3)	7.42	8.98	15.60
Coarse aggregate (kg/m^3)	1.161	1,107	1,080
Fine aggregate (kg/m^3)	801	775	734
w/b ratio	0.38	0.31	0.25

NOTE:- Maximum size of coarse aggregate is 20 mm with cleaned and saturated surface dry condition.

- Fineness Modulus of fine aggregate (sand) is approximately equal to 3.0 with oven dry status.

- For ordinary Portland cement

- For Polycarboxylic base superplasticizer.

3.3 EQUIPMENTS

1. Standard Moulds

- Cube 100 mm

- Cube 150 mm

- Cylinder Ø100x200mm

- Cylinder Ø150x300mm

2. Weighing Scales

3. Concrete Vibrator

4. Compression Testing Machine

3.4 EXPERIMENTAL METHODS

The uniaxial compression tests were performed on specimens cast from 3 different high strength concrete mixtures. In order to determine shape and size effects, 4 different specimen types with the dimensions shown in figure are used.

All specimens were tested at 2 ages, i.e. 7 and 28 days. The determination of the strength for each concrete mixture, specimen age and specimen type are based on the average of 6 specimens. List of specimens, with different mould types and concrete strengths, are shown in Table.

Figure 3.1: Cube 150mm and Cylinder Ø150x300mm

Figure 3.1(a): 100mm Cube

Figure 3.1(b): Ø100x200mm Cylinder

Table 3.7: Number of specimen with different mould types and concrete mixes

Specimen Shape	**Dimension (mm)**	**Number of Specimens**		
		Mix 1	**Mix 2**	**Mix 3**
Cylinder	**Ø 100x200**	18	18	18
Cylinder	**Ø 150x300**	18	18	18
Cube	**100x100x100**	18	18	18
Cube	**150x150x150**	18	18	18

3.4.1 Specimen Preparation

Concrete mixing and casting for all batches were controlled under the same conditions as follow.

1. Concrete mixtures were batched using a pan mixer. Due to the limit of concrete mixer, each mixture is divided into four batches. Cement, silica fume and aggregates were mixed in the dry state for about 1 minute to ensure their uniformity.

Mixing water and superplasticizer were added gradually and simultaneously during mixing. All contents are mechanically mixed for 2 min. The consistency of the fresh concrete is measured by the conventional slump test.

2. Seventy two specimens were cast from each concrete mixture. Concrete is consolidated by internal vibrator during placing of concrete to ensure full compaction.

3. All test specimens were demoulded after 24 hours and then exposed to continuous curing in water pond until the time of specimen preparation and testing.

3.4.2 Testing

After the specimens have been cured for 7 and 28 days, the uniaxial testing is performed with the test procedures. The concrete specimens were tested for cylindrical compressive strength and splitting tensile strength in accordance with ASTM C39, while cubical compressive strength and splitting tensile strength in accordance with BS EN 12390-3.

CHAPTER-4

EXPERIMENTAL WORK

4.1 INTRODUCTION

The main goal of this study is to find out the effect of different factors, on conversion ratios for different concrete specimens' compressive strength. During the experimental study, different concrete specimens of different concrete mix designs were tested at different ages, with different curing conditions.

For casting concrete specimens, OPC cement was used. Crushed limestone aggregates (both fine and coarse), potable water and for one concrete mix design, superplasticizer was also utilized.

Before beginning of casting, sieve analysis was done and moisture conditions for all the aggregates were determined.

Table 4.1: Sieve analysis of aggregate with 20 mm maximum size

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
28	0.00	0.00	0.00	100.00
20	0.75	19.04	19.04	80.96
14	2.69	68.27	87.31	12.69
10	0.40	10.15	97.46	2.54
6.3	0.10	2.54	100.00	0.00
5	0.00	0.00	100.00	0.00
3.35	0.00	0.00	100.00	0.00
Pan		0.00	100.00	0.00
	3.94			

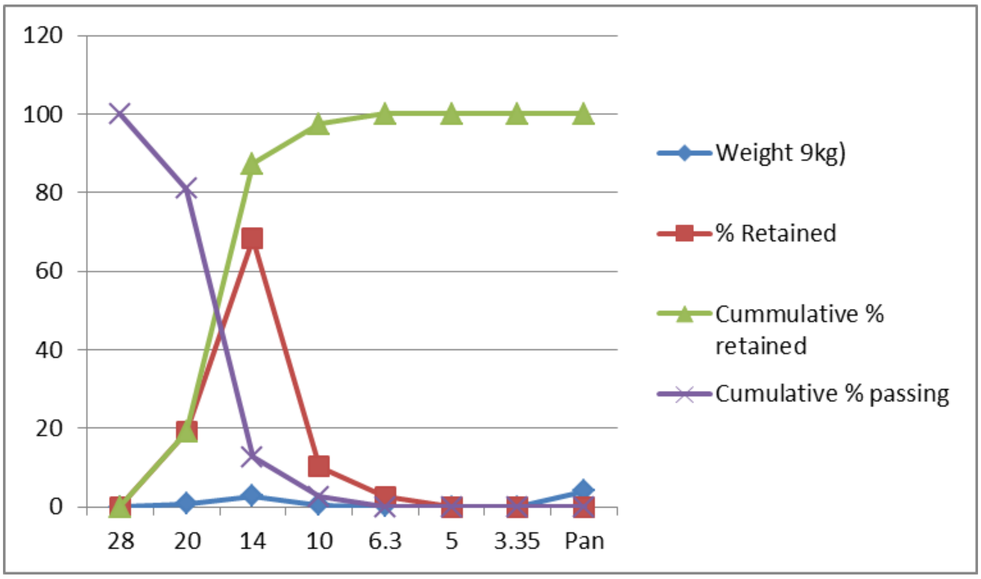


Figure 4.1: Graph showing results of sieve analysis aggregate with 20 mm maximum size

Table 4.2: Sieve analysis of aggregate with 14 mm maximum size

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
28	0.00	0.00	0.00	100.00
20	0.05	1.26	1.26	98.74
14	0.30	7.57	8.83	91.17
10	2.39	60.15	68.98	31.02
6.3	1.17	29.51	98.49	1.51
5	0.04	0.88	99.37	0.63
3.35	0.03	0.63	100.00	0.00
Pan		0.00	100.00	0.00
	3.97			

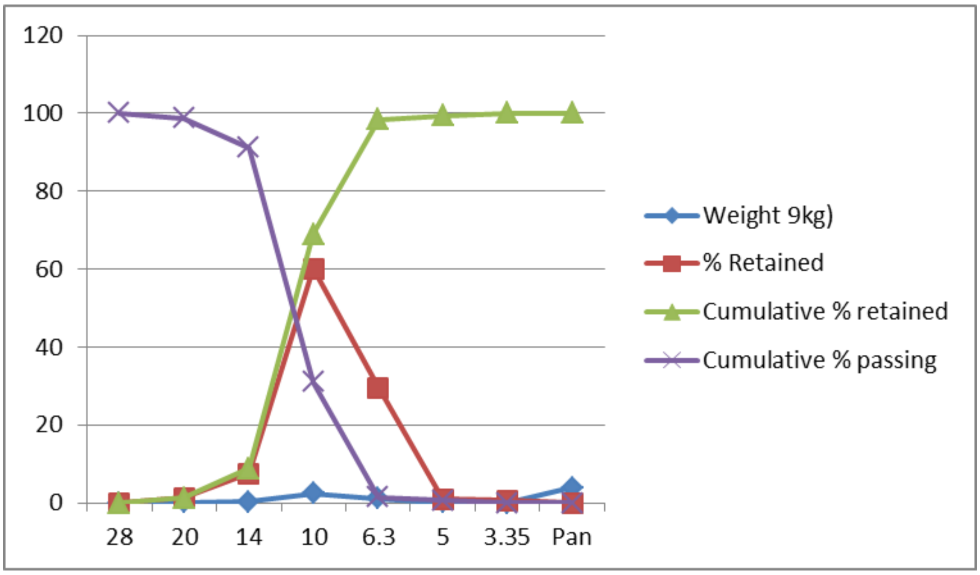


Figure 4.2: Graph showing results of sieve analysis aggregate with 14mm maximum size

Table 4.3: Sieve analysis of aggregate with 10 mm maximum size

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
28	0.00	0.00	0.00	100.00
20	0.00	0.00	0.00	100.00
14	0.00	0.00	0.00	100.00
10	0.05	2.01	2.01	97.99
6.3	1.17	47.08	49.09	50.91
5	0.54	21.53	70.62	29.38
3.35	0.49	19.72	90.34	9.66
Pan	0.24	9.66	100.00	0.00
	2.49			

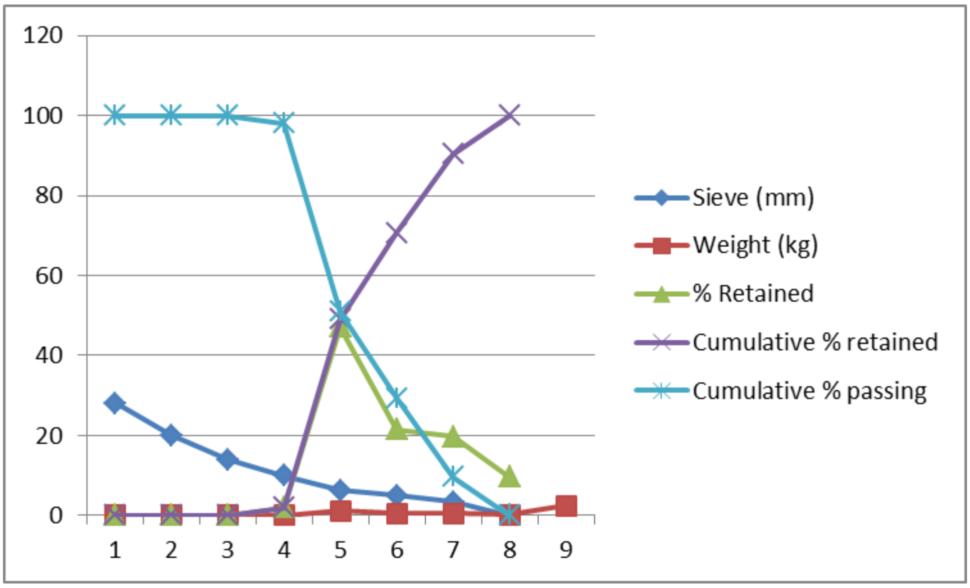


Figure 4.3: Graph showing results of sieve analysis of aggregate with 10 mm maximum size

Table 4.4: Sieve analysis of fine aggregates

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
4.75	0.00	0.00	0.00	100.00
2.36	140	14.00	14.00	86.00
1.19	310	30.50	44.50	55.50
0.59	220	21.50	66.00	34.00
0.297	130	12.50	78.50	21.50
0.149	90	8.50	87.00	13.00
Pan	130	13.00	100.00	0.00
	1000			

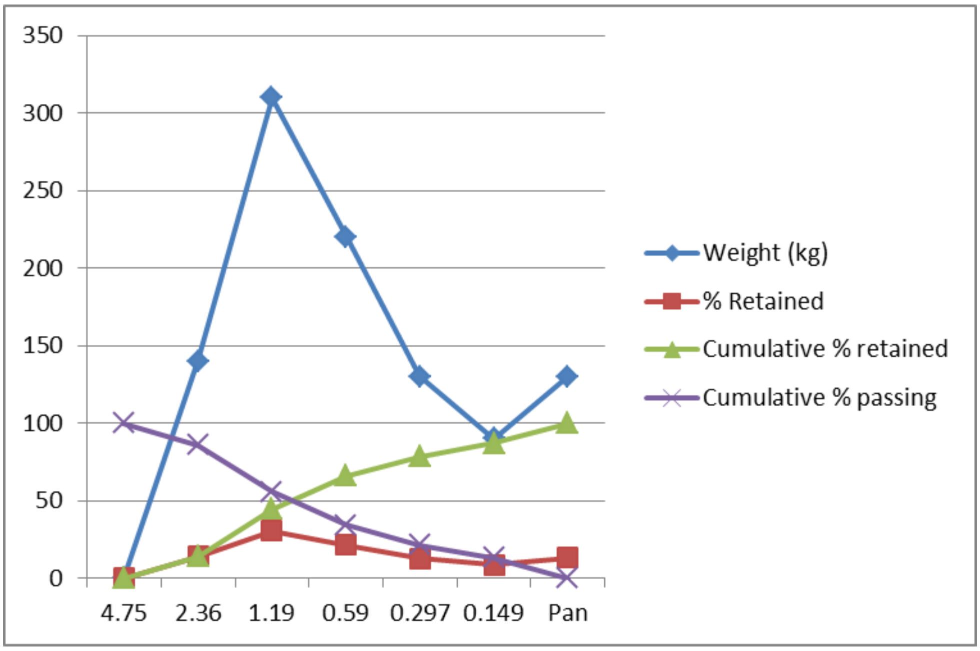


Figure 4.4: Graph showing results of sieve analysis of fine aggregates

Three mix designs were chosen for this study. The mix designs were decided to be different in water/cement ratio and superplasticizer percentage respectively.

For each mix design, before casting, trial mix-designs were done in order to make sure that each mix satisfies the requirements. Table show the proportioning of materials and results of trial mixes for each concrete mix.

Table 4.5: Mix design A

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregates (kg/m^3)	10mm aggregates (kg/m^3)	14mm aggregates (kg/m^3)	20mm aggregates (kg/m^3)
357	225	808	180	270	539

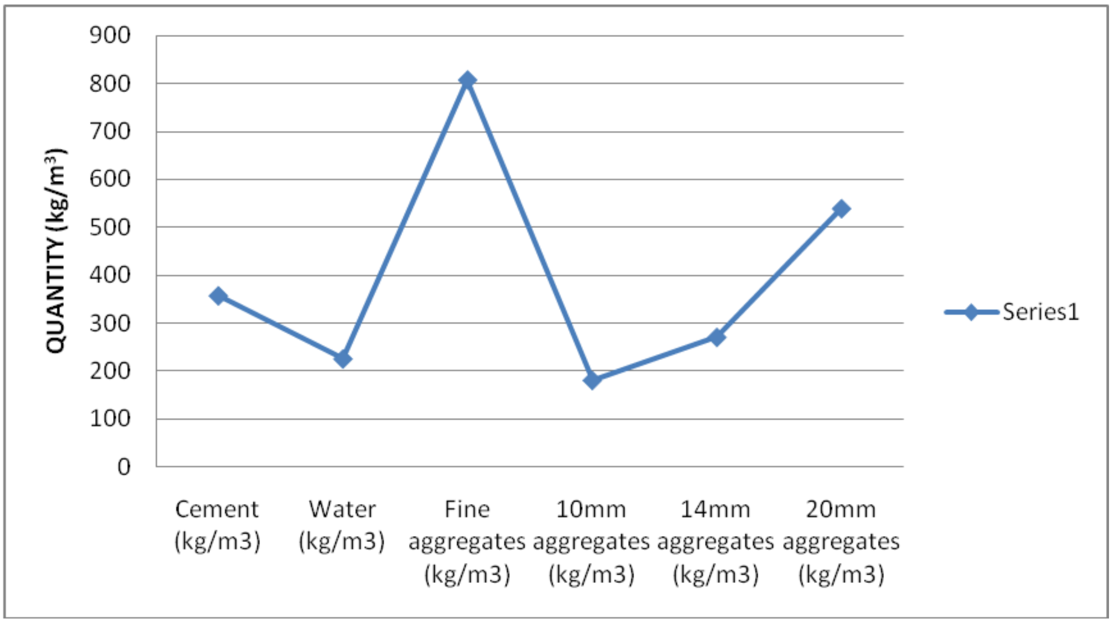


Figure 4.5: Graph showing mix design values for mix A

Table 4.6: Mix design B

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregates (kg/m^3)	10mm aggregates (kg/m^3)	14 mm aggregates (kg/m^3)	20 mm aggregates (kg/m^3)
402	225	815	167	251	501

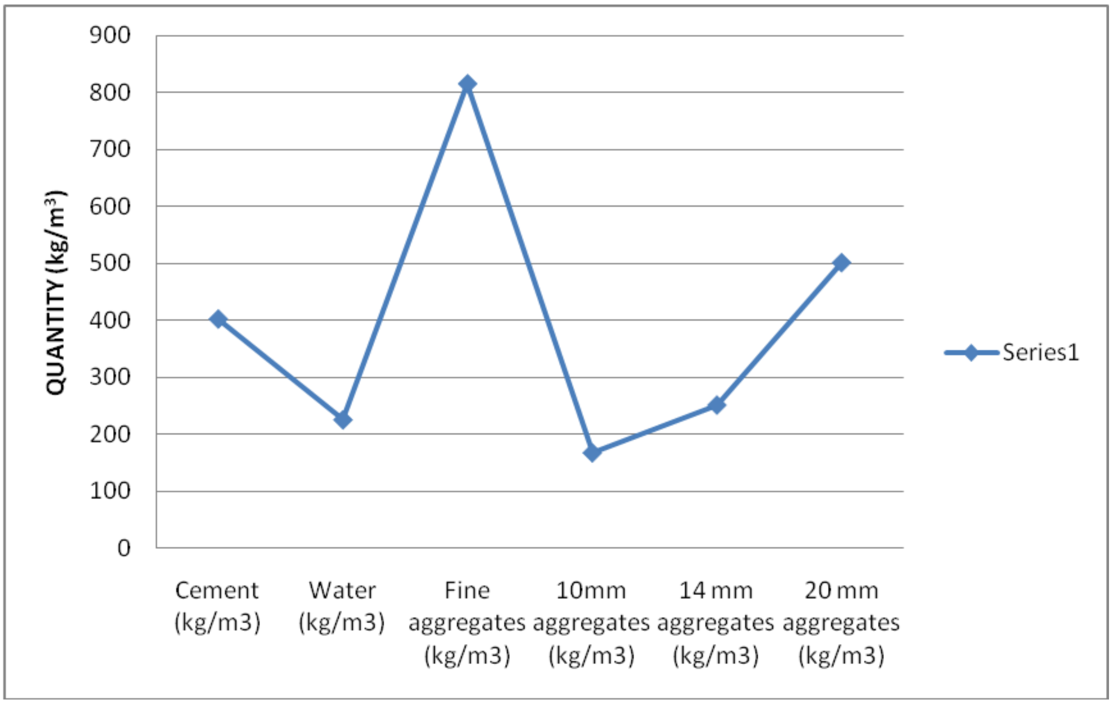


Figure 4.6: Graph showing mix design values for mix B

Table 4.7: Mix design C

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregates (kg/m^3)	10 mm aggregates (kg/m^3)	14 mm aggregates (kg/m^3)	20 mm aggregates (kg/m^3)
486	170	628	212	318	630
Superplasticizer 9.6% by weight of cement					

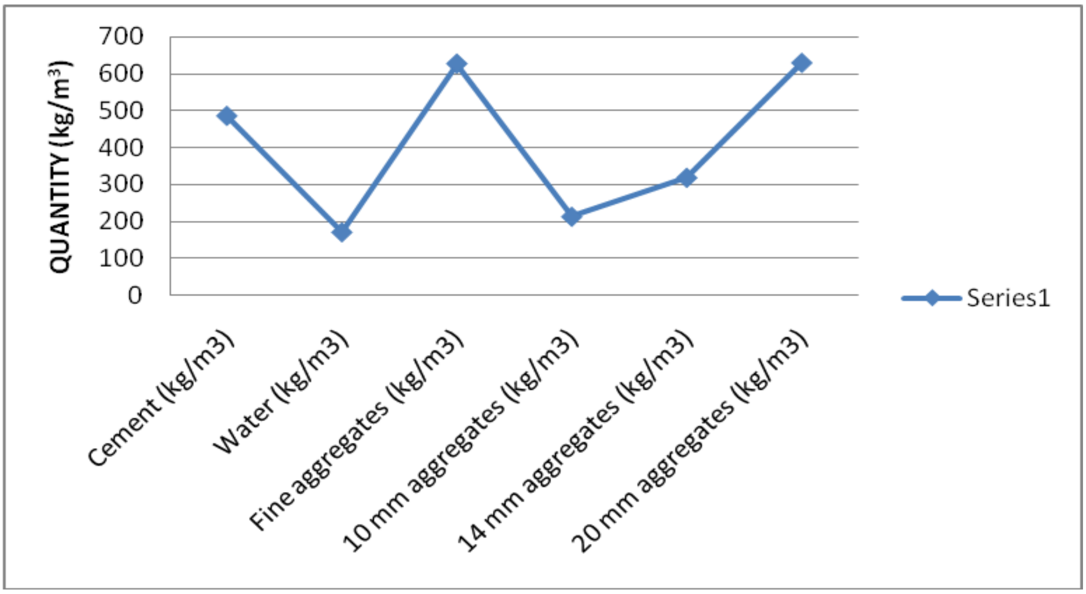


Figure 4.7: Graph showing mix design values for mix C

Water to cement ratio of mix design A, B and C are kept constant to be equal to 0.63, 0.56 and 0.35, respectively.

On fresh concrete, for each mix design, test of workability and on hardened concrete, compressive strength tests and splitting tensile strength test were performed. Also, non-destructive tests, including rebound hammer tests, were executed.

Two types of curing conditions (water and air) and testing ages (7 and 28 days) were considered for the test specimens.

4.2 MATERIALS USED

4.2.1 Cement

For casting all the specimens, OPC cement was used. Chemical compositions and physical properties of the cement are shown in previous chapter.

Both coarse and fine aggregates used for this study were crushed limestone. As mentioned before, prior to casting, tests were done to determine the aggregates properties. Sieve analysis results were shown in previous section.

Table 4.8: Water absorption of aggregates

Aggregates	Water absorption %
Fine	1.00
10mm	1.60
14mm	0.94
20mm	0.64

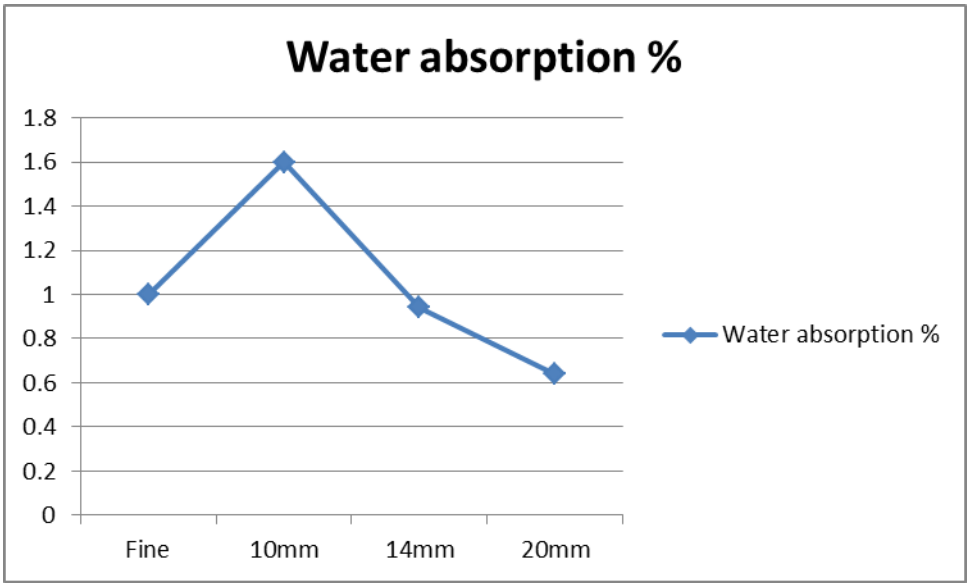


Figure 4.8: Graph showing water absorption percentage for different size aggregates

Table 4.9: Results of aggregates' specific gravity

Aggregates	Specific gravity
Fine	2.78
10mm	2.60
14mm	2.67
20mm	2.71

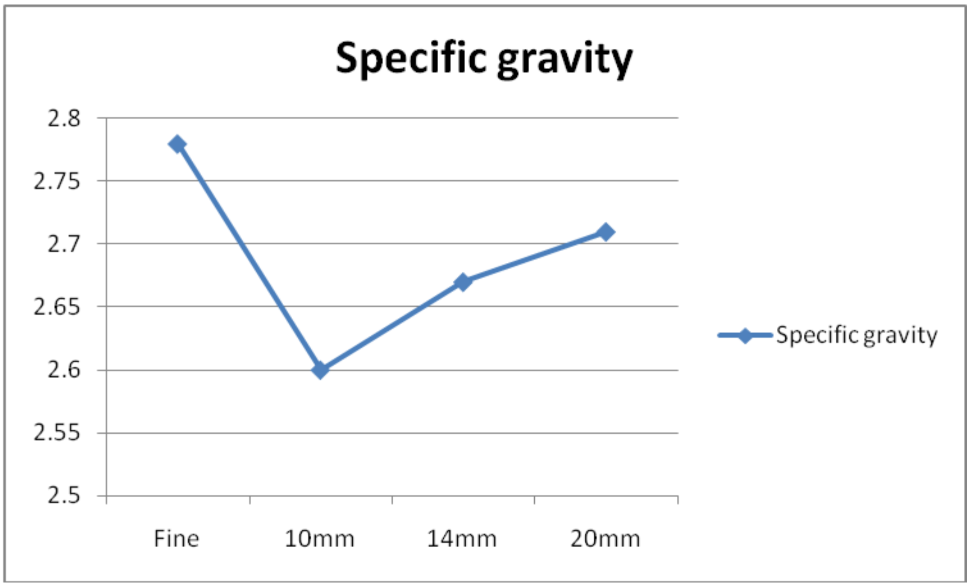


Figure 4.9: Graph showing specific gravity results for different size aggregates

4.2.2 Silica Fume

For casting all the specimens, OPC cement was used with admixture(silica fume) and superplasticizer. Chemical compositions and physical properties of silica fume are shown in previous chapter.

As mentioned before, prior to casting, XRD and SEM tests were done to determine the silica fume properties

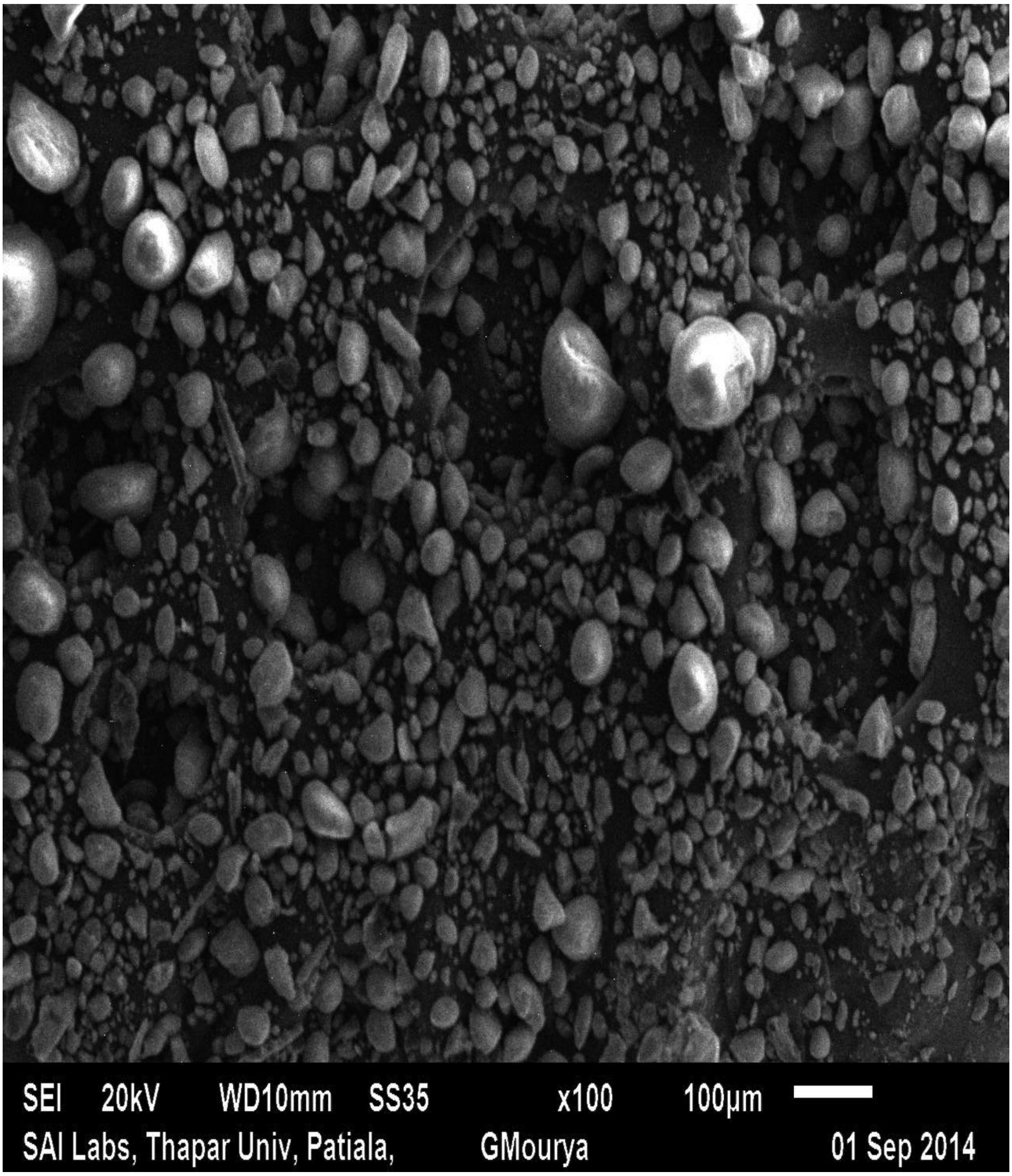


Figure 4.10: Micro view of Silica Fume

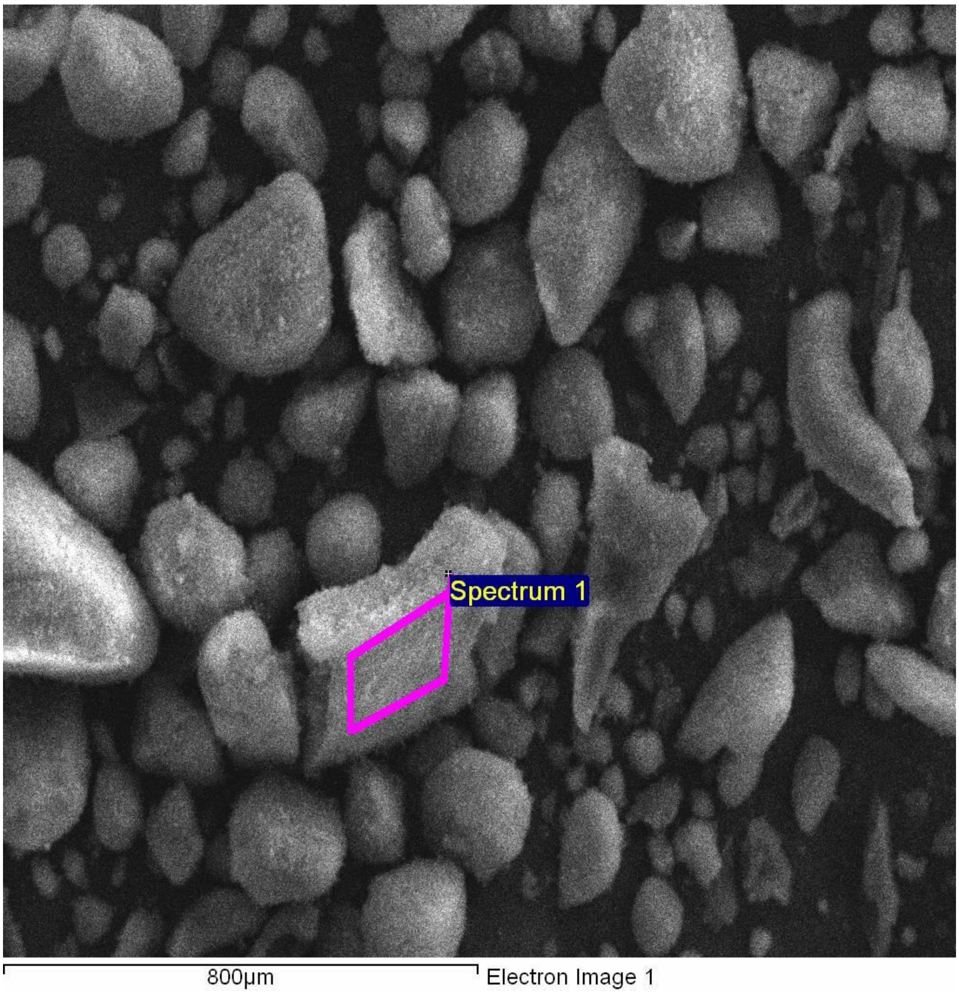


Figure 4.11: Micro Image of Silica Fume Particles (spectrum 1)

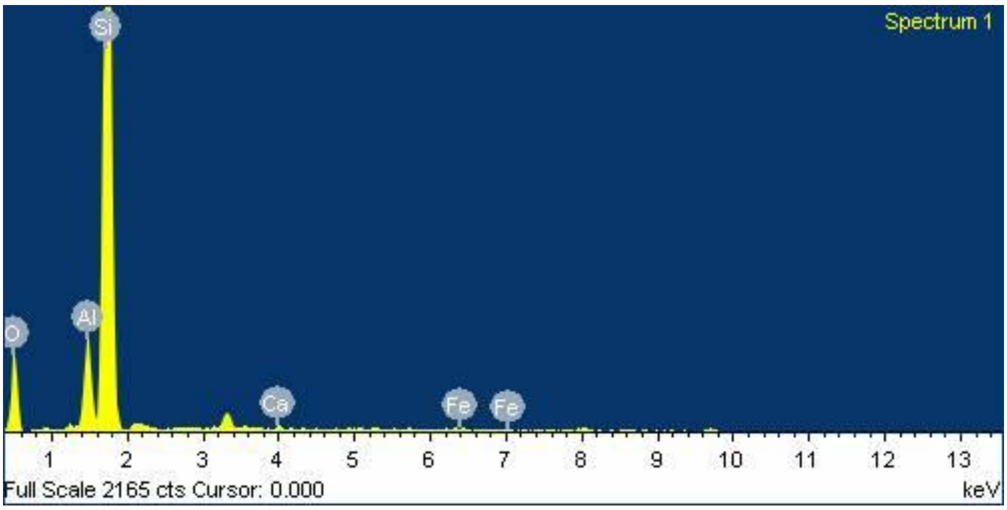


Figure 4.12: Chemical composition for Spectrum 1

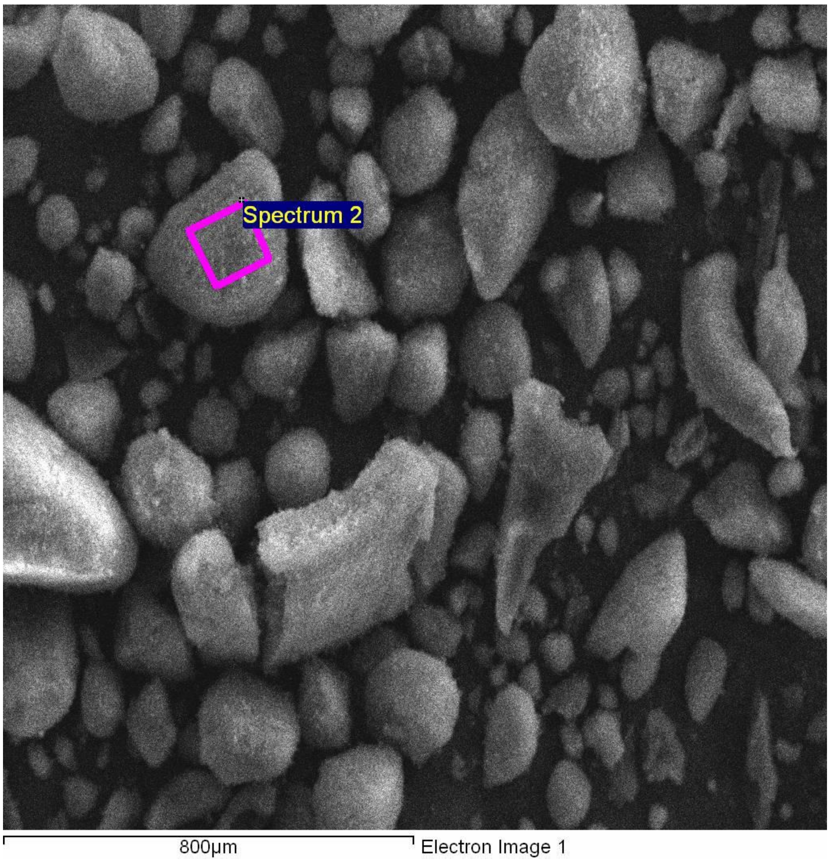


Figure 4.13: Showing Micro Image of Silica Fume Particles (spectrum 2)

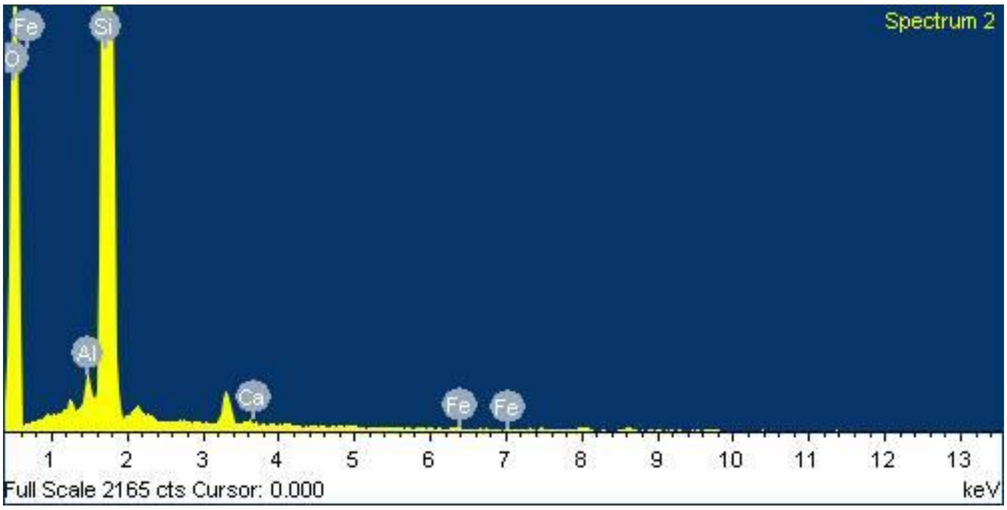


Figure 4.14: Chemical Compostion For Spectrum 2

4.3 CASTING CONCRETE

The process of batching, weighting and mixing of necessary materials were performed manually. By using a plate mixer, first aggregates and cement were mixed for 30 seconds, then water was added to the blended materials and mixed for approximately few minutes. When a test on fresh concrete (i.e. slump or vebe time test) had to be performed, necessary sample was taken from fresh concrete, test was executed and then, the utilized amount of concrete was poured back to the source, blended once again to make homogeneous mix and then concrete was poured into the moulds (BS 1881 : Part 125: 1986, 2009).

4.4 COMPACTING AND CURING

Usually two types of vibration tables are used in order to vibrate and compact the filled concrete moulds. One was an ordinary vibrating table and another one was the vibrating table on which the concrete moulds could be fixed.

Concrete specimens, were carried to curing room after being casted and compacted, in which the humidity percentage is over 90% and the temperature was kept equal to 21°C. After being kept for approximately 24 hours, the specimens were taken to water tank or air room, regarding to their specified curing conditions, and kept there until their testing age.

Figure 4.15: Vibrating table

4.5 TESTS ON FRESH CONCRETE

4.5.1 Workability test

The only test, performed on fresh concrete mixes was slump test. The experiment was performed in the laboratory. Figure show performance of slump.

Figure 4.16: Slump test

4.6 TESTS ON HARDENED CONCRETE

Few experiments were carried out on hardened concrete specimens,namely compressive strength, splitting tensile strength, rebound hammer and density.

4.6.1 Compressive Strength Test

In this research, concrete specimens of different sizes and shapes for compressive strength tests.

In Figure, samples of cylinder and cube are shown before testing. In this, loading speed was 0.4MPa/s for all specimens during compressive strength test.

Figure 4.17: Cylinder specimen under compression

Figure 4.18: Cube Specimen under compression

4.6.2 Splitting Tensile Strength Test

Splitting test was also carried out on both cubes and cylinders at the age of 28 days. At the time of testing, specimens were removed from curing tank and a line was drawn on specimens to make sure that load was axially applied.

Figure 4.19: Cylinder specimen under splitting tension

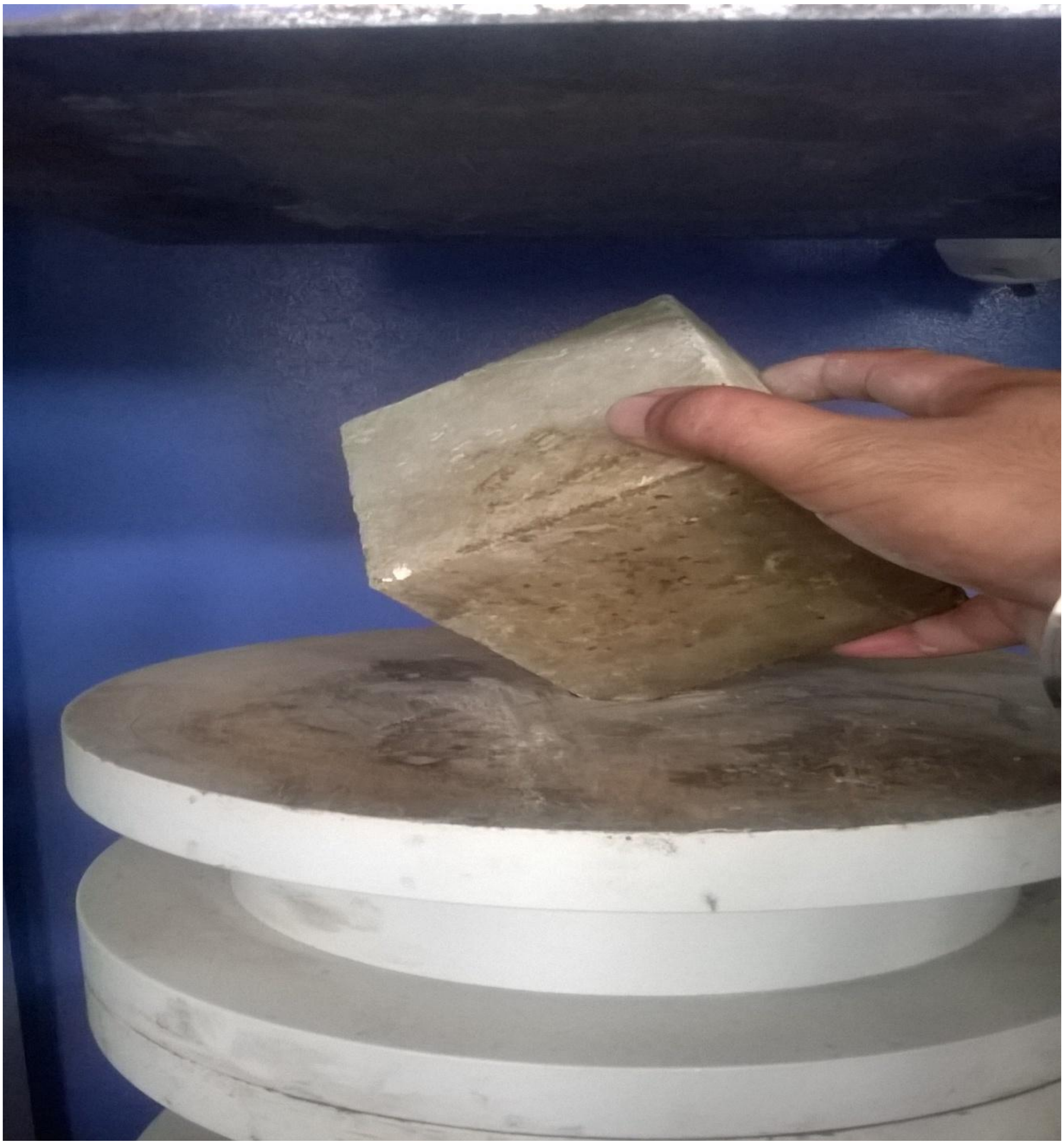


Figure 4.20: Cube specimen under splitting tension

4.6.3 Rebound Hammer Test

Rebound hammer or Schmidt hammer test is known for surface hardness test. It is performed for estimating concrete specimen’s compressive strength. During this process of experiment, 10 impacts are stroke to the surface of specimen. The test should be repeated about 10 times on the same side for each specimen. Result of this test can be affected by factors like moisture conditions and cement type.

Figure 4.21: Rebound hammer test

For calculating the true number of rebound hammer through approximately 10 replicates, first the average of all 10 results is calculated, then those replicates, which have more than 6 units of difference with the average amount are discarded. Then average of the remained replicates is calculated and reported as the specimen's rebound number.

CHAPTER-5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

In the previous chapter, explanation of performed experiments was briefly explained. Now in this, results of mentioned experiments will be presented through graphs and findings from analysis followed by discussions of every result.

The experiments carried out were slump test, rebound hammer test, compressive strength and splitting tensile strength. For each test, results will be presented and discussed.

5.2 TEST ON FRESH CONCRETE (Slump Test)

For each mix design, slump test was performed. The results are shown in table below.

Table 5.1: Slump test results

Mix Design	Workability Slump (mm)
A	75
B	100
C	120

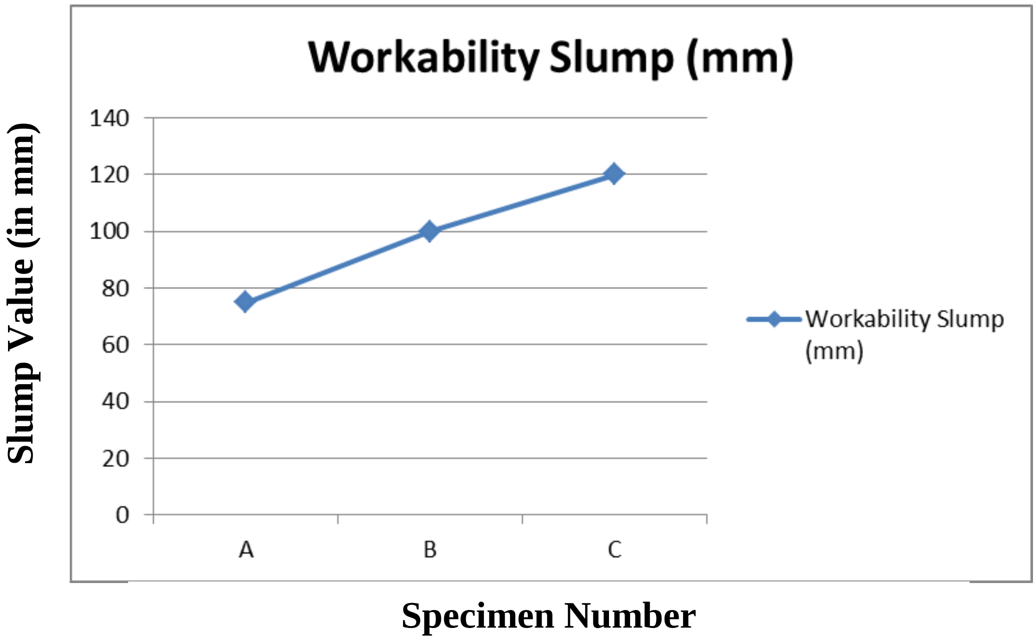


Figure 5.1: Slump test results

The results show that by decreasing water to cement ratio of mix designs, there is a decrease for slump.

Despite the fact that for mix design C, superplaticizer was used, the level of workability was still low, which was caused by low water/cement ratio.i.e-0.35.

For the mix design A, high slump value is in fact due to high water/cement ratio. This was probably as a result of the utilized cement's strength grade.

5.3 TESTS ON HARDENED CONRETE

5.3.1 Compressive Strength

On each mix design, hardened concrete density test was performed according to BS EN 12390-7, 2009. Table shows the average hardened density for each experiment's condition.

Table 5.2: Compressive strength of HSC mix A

Specimen Type	Compressive Strength (MPa)							
	100mm Cube		150mm Cube		Cylinder 100x200mm		Cylinder 150x300mm	
Sr. No.	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
1	59.6	68.4	61.8	70.9	47.5	59.5	50.6	55.5
2	68.9	72.7	62.0	71.1	49.1	57.8	46.7	58.7
3	66.3	73.3	65.1	71.5	50.8	61.7	49.0	57.5
4	71.9	73.7	64.7	75.2	48.5	63.0	50.1	56.9
5	64.7	73.7	64.3	68.9	51.5	65.9	47.5	61.5
6	69.1	80.2	64.5	76.6	51.7	63.8	48.2	60.3
Average	66.75	73.7	63.7	72.4	49.9	62.0	48.6	58.4

Table 5.3: Compressive strength of HSC mix B

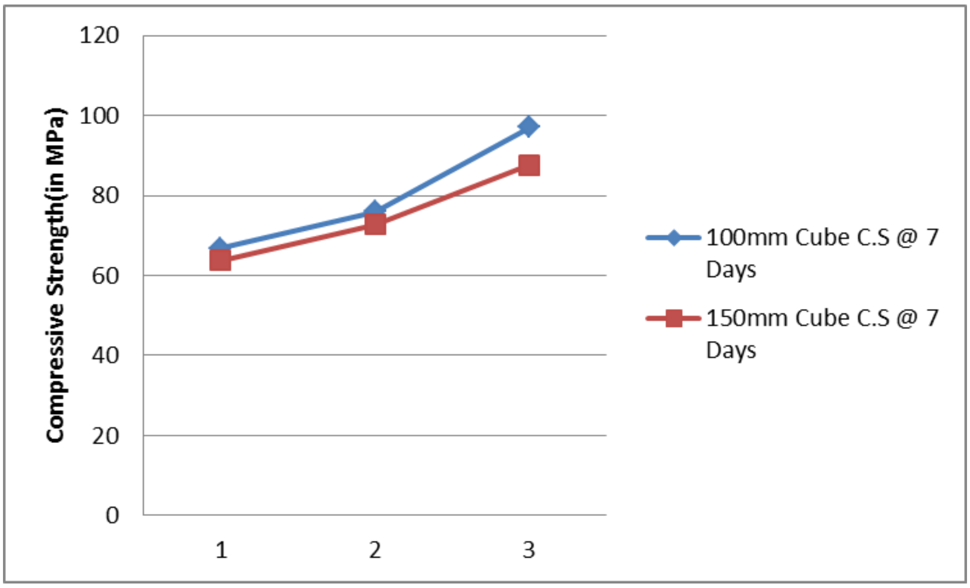
Specimen Type	Compressive Strength (MPa)							
	100mm Cube		150mm Cube		Cylinder 100x200mm		Cylinder 150x300mm	
Sr. No.	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
1	79.7	89.8	75.3	88.7	68.2	74.5	60.7	67.0
2	76.3	88.5	67.5	87.3	67.6	75.6	65.5	69.9
3	74.2	87.5	73.7	86.1	68.9	73.7	65.4	72.3
4	78.2	88.1	74.7	90.7	70.7	76.2	65.7	71.5
5	73.3	89.6	76.7	85.1	71.5	73.4	61.9	71.0
6	74.7	91.2	68.1	84.6	70.2	74.8	66.2	70.4
Average	76.0	89.1	72.7	87.0	69.5	74.7	64.2	70.3

Table 5.4: Compressive strength of HSC mix C

Specimen Type	Compressive Strength (MPa)							
	100mm Cube		150mm Cube		Cylinder 100x200mm		Cylinder 150x300mm	
Sr. No.	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
1	93.6	97.3	86.4	104.0	78.5	86.2	76.6	86.3
2	89.0	99.8	85.8	98.4	85.3	90.6	82.3	87.9
3	95.9	95.0	85.3	99.3	84.5	88.7	79.7	85.6
4	98.8	115.5	87.6	100.8	85.9	84.3	82.9	88.2
5	100.7	110.2	92.5	101.0	78.2	93.1	74.1	89.0
6	103.8	107.4	89.3	103.9	79.0	93.8	81.3	92.2
Average	97.0	104.2	87.6	101.2	81.9	89.4	79.5	88.2

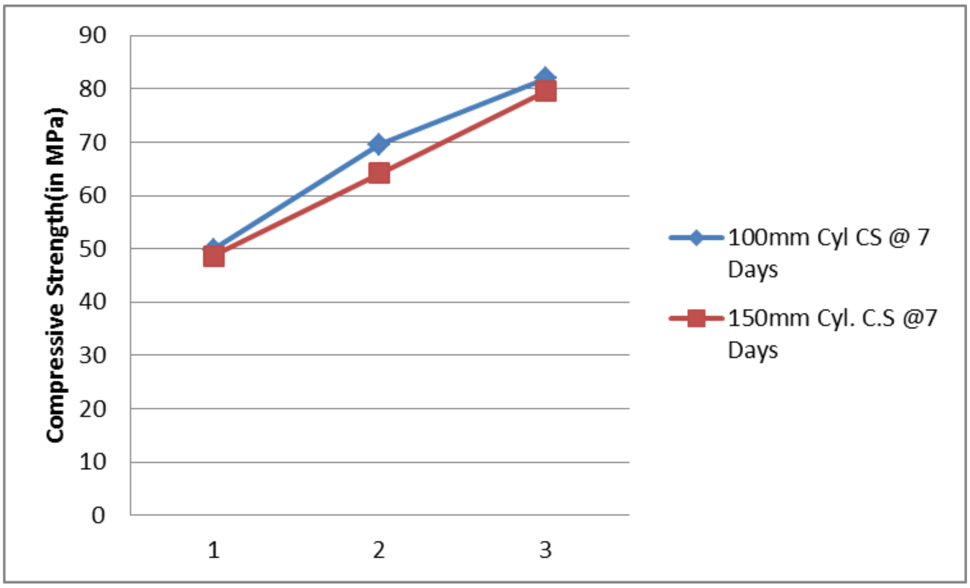
5.3.2 Specimen Size Effect on Compressive Strength

Linear regression analysis is employed to find the relations between concrete strength values from different sizes of specimen. The relationships of average compressive strengths are shown in tables below with figures respectively. The results show that the compressive strength of the bigger size specimen is generally lower than the same shape of specimen obtained from the same concrete mix. This is due to the probability of having large defects, such as voids and cracks in the test specimen, which increases with size. Thus smaller size specimen can give higher strength and the test results for small size specimen may need to be modified.



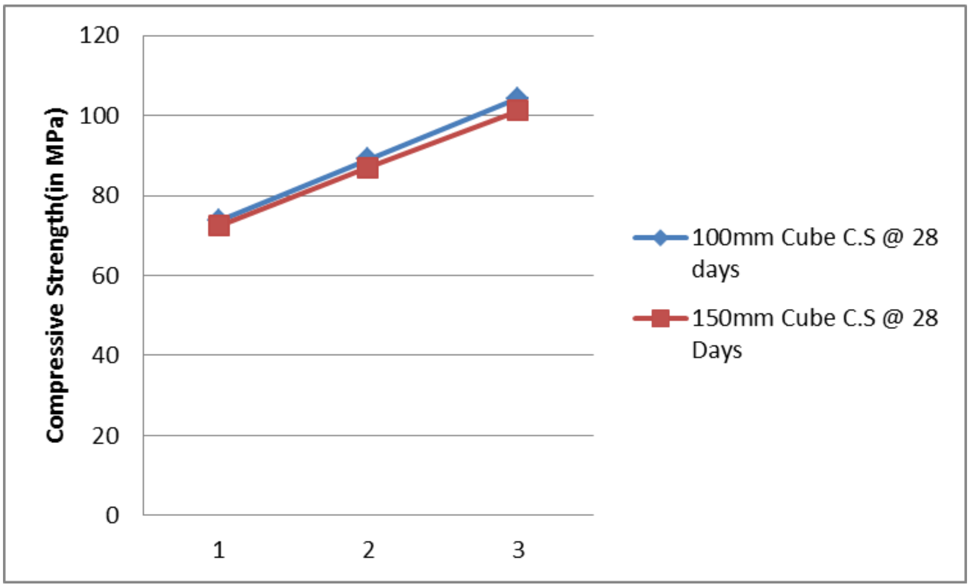
Specimen of different mix design

Figure 5.2: Comparison between compressive strength (average) at 7 days of 100mm cube and 150mm cube



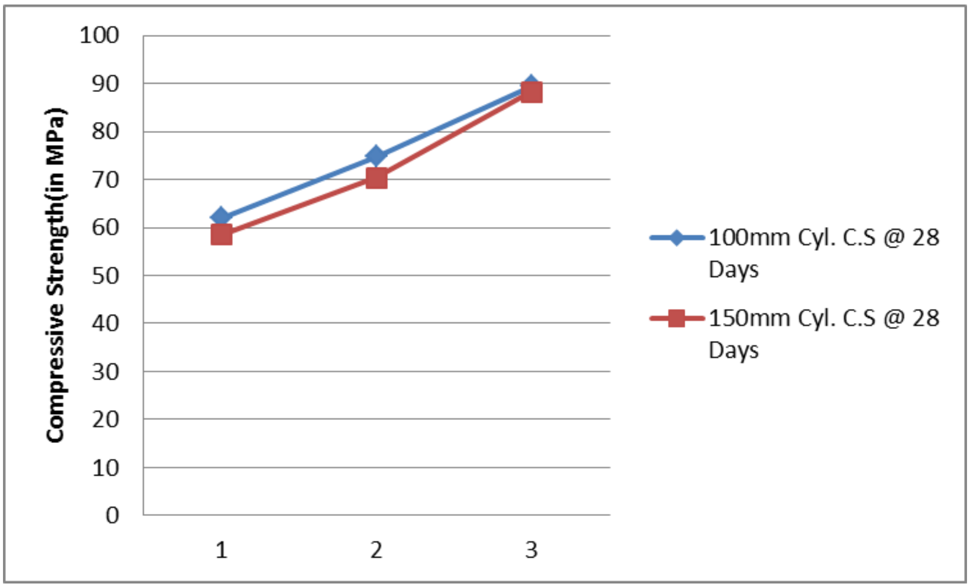
Specimen of different mix design

Figure 5.3: Comparison between compressive strength (average) at 7 days of Ø100×200mm cylinder and Ø150×300mm cylinder



Specimen of different mix design

Figure 5.4: Comparison between compressive strength (average) at 28 days of 100mm cube and 150mm cube



Specimen of different mix design

Figure 5.5: Comparison between compressive strength (average) at 28 days of Ø 100×200mm cylinder and Ø150 × 300 mm cylinders

The proposed expressions, for specimen size effect, from previous research are summarized and shown in Tables. In order to compare the results from present study with other research, the relations from Figures are also included in the tables. From the relationships, however, it seems to be valid to assume that the compressive strength obtained from cube 100 mm and cylinder Ø100x200 mm specimens can give the same results with standard cube 150 mm and cylinder Ø150x300 mm, respectively. Although the standard specimen for testing compressive strength is Ø150x300 cylinder as specified in ASTM, Ø100x200 cylinder has been used successfully in the United State without any transformation factors required. American Concrete Institute has also recommended that smaller test cylinders are acceptable provided the strength is determined in accordance with ASTM C 39 and the same size cylinder is used for both trial mixtures and acceptance testing (ACI 363.2-98).

Table 5.5: Relations between concrete strength values from different cylindrical specimen size

Researcher(s)	Proposed Expression	Range of Concrete strength (MPa)
Mansur and Islam (2002)	$F_{c,cy150} = 0.98\ F_{c,cy100} - 3.49$	20-100
Felekoglu and Turkel (2005)	$F_{c,cy150} = 1.16\ F_{c,cy100}$	50-55
Yi et al (2006)	$F_{c,cy150} = 0.968\ F_{c,cy100}$	20-80
Yazici and Sezer (2007)	$F_{c,cy150} = 0.97\ F_{c,cy100}$	14-47
Present study - for 7 days strength - for 28 days strength	 $F_{c,cy150} = 0.99\ F_{c,cy100}$ $F_{c,cy150} = 0.97\ F_{c,cy100}$	55-100

Note: $F_{c,cy150}$ = 150x300mm cylindrical compressive strength (MPa),

$F_{c,cy100}$ = 100x200mm cylindrical compressive strength (MPa),

Table 5.6: Relations between concrete strength values from different cube specimen size

Researcher(s)	Proposed Expression	Range of Concrete strength (MPa)
Mansur and Islam (2002)	$F_{c,cy150} = 0.91\ F_{c,cy100} + 3.62$	20-100
Yi et al (2006)	$F_{c,cy150} = 0.929\ F_{c,cy100}$	20-80
Present study - for 7 days strength - for 28 days strength	$F_{c,cy150} = 0.97\ F_{c,cy100}$ $F_{c,cy150} = 0.96\ F_{c,cy100}$	55-100

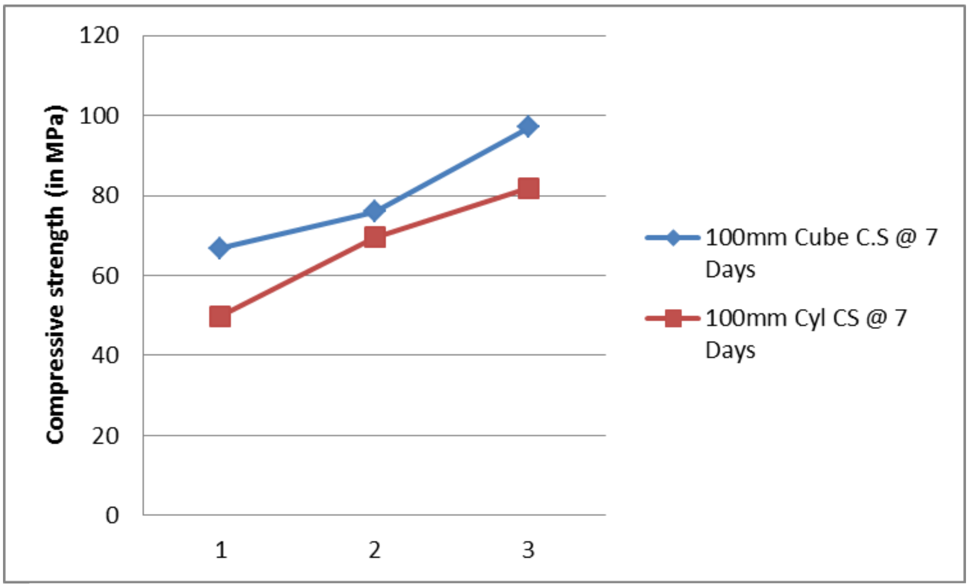
Note: $F_{c,cy150}$ = 150x300mm cylindrical compressive strength (MPa),

$F_{c,cy100}$ = 100x200mm cylindrical compressive strength (MPa),

5.3.3 Specimen Shape Effect on Compressive Strength

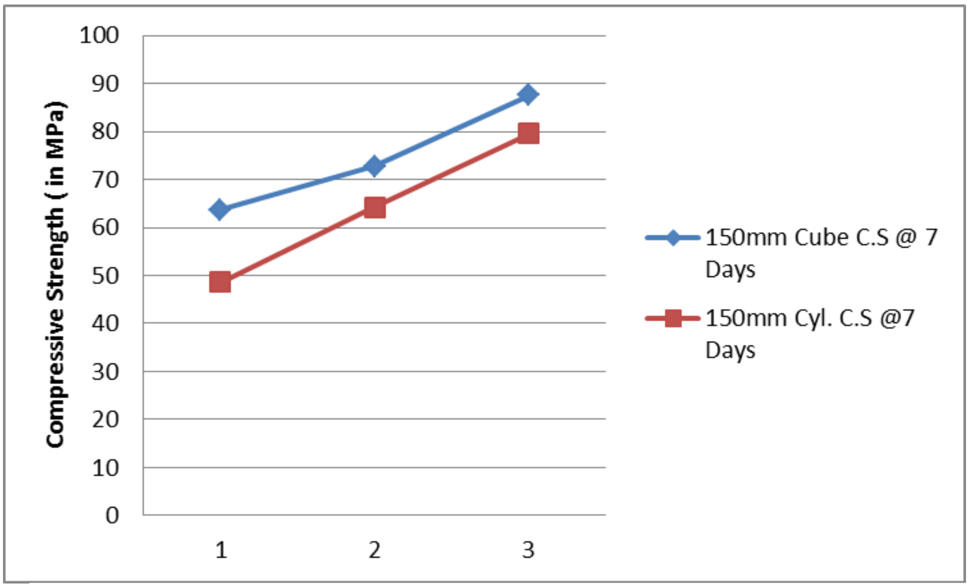
It can be seen from the results shown in Tables that the cube strengths are consistently higher than the corresponding cylinder strength for the range of concrete strength considered in this study. The ratio of the compressive strength at 28 days of Ø150x300 mm cylinder to the 150 mm cube is varied from 0.78 to 0.86 for the designed cylinder strength of 550 to 1,000 kg/cm^2. The transformation factor proposed in CEB-FIP (1990) Model Code, in terms of the ratio of cylinder to cube strength, is 0.80 for cylinder strength of 40MPa and the factor increases progressively to 0.89 when the cylinder compressive strength reaches a value of 80MPa.

Fig. show plots of cube against cylinder compressive strengths. The lines of relations shown on the figures indicate the best-fit lines obtained from the linear regression analysis with test data points. The relations are also shown in Table in order to compare with the proposed expressions from previous research.



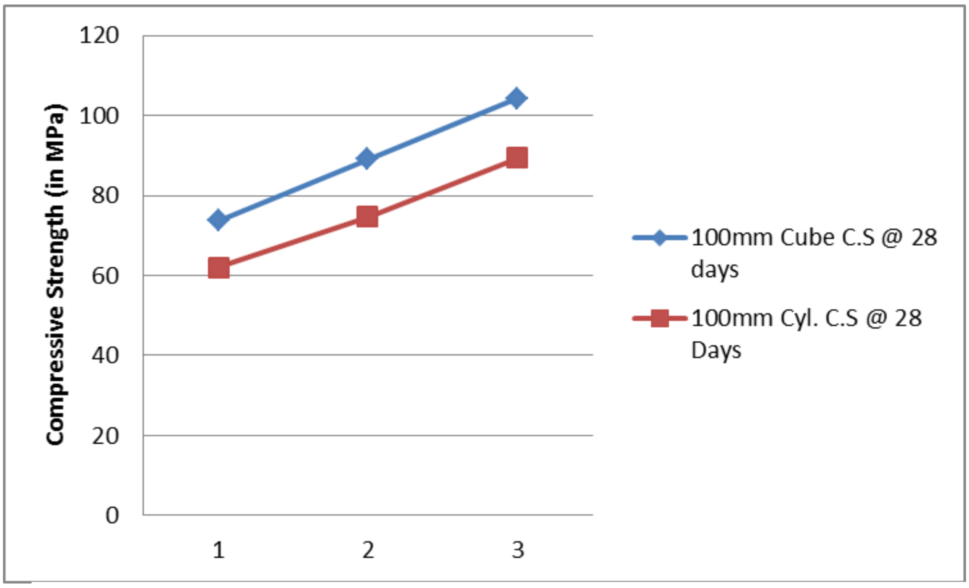
Specimen of different mix design

Figure 5.6: Comparison between compressive strength at 7 days of 100mm cube and Ø100x200mm cylinder



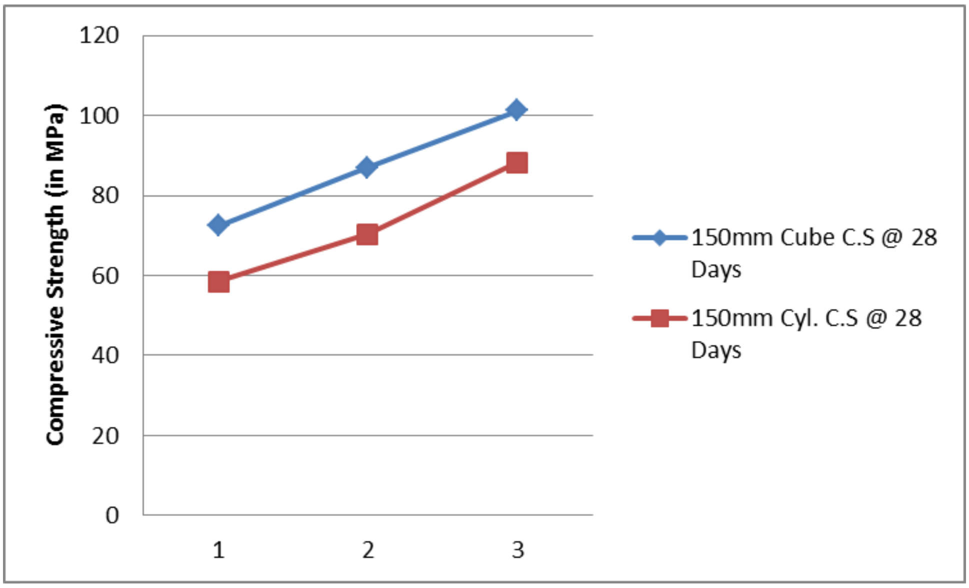
Specimen of different mix design

Figure 5.7: Comparison between compressive strength at 7 days of 150mm cube and Ø150x300mm cylinder



Specimen of different mix design

Figure 5.8: Comparison between compressive strength at 28 days of 100mm cube and Ø100x200mm cylinder



Specimen of different mix design

Figure 5.9: Comparison between compressive strength at 28 days of 150mm cube and Ø150x300mm cylinder

5.4 Splitting Tensile Strength

In this experiment, splitting tensile strength test was performed on both cubical and cylindrical specimens cured in water at the age of 28 days. Results are shown in the table given below.

Table 5.7: 28 Days Splitting Tensile Strength of Mix Design A

Samples	Splitting Tensile Strength (MPa)
Cyl.100X200mm (1)	4.28
Cyl.100X200mm (2)	4.47
Cyl.100X200mm (3)	3.95
Cyl.150X300mm (1)	3.72
Cyl.150X300mm (2)	3.83
Cyl.150X300mm (3)	3.65
Cube 100mm (1)	3.75
Cube 100mm (2)	3.47
Cube 100mm (3)	3.53
Cube 150mm (1)	3.38
Cube 150mm (2)	3.15
Cube 150mm (3)	3.40

Table 5.8: 28 Days Splitting Tensile Strength of Mix Design B

Samples	Splitting Tensile Strength (MPa)
Cyl.100X200mm (1)	4.41
Cyl.100X200mm (2)	4.47
Cyl.100X200mm (3)	3.81
Cyl.150X300mm (1)	6.67
Cyl.150X300mm (2)	6.60
Cyl.150X300mm (3)	6.35
Cube 100mm (1)	1.69
Cube 100mm (2)	1.55
Cube 100mm (3)	1.60
Cube 150mm (1)	3.59
Cube 150mm (2)	3.59
Cube 150mm (3)	3.52

Table 5.9: 28 Days Splitting Tensile Strength of Mix Design C

Samples	Splitting Tensile Strength (MPa)
Cyl.100X200mm (1)	6.04
Cyl.100X200mm (2)	6.31
Cyl.100X200mm (3)	6.91
Cyl.150X300mm (1)	5.84
Cyl.150X300mm (2)	5.60
Cyl.150X300mm (3)	6.08
Cube 100mm (1)	1.59
Cube 100mm (2)	1.45
Cube 100mm (3)	2.09
Cube 150mm (1)	5.48
Cube 150mm (2)	5.48
Cube 150mm (3)	4.93

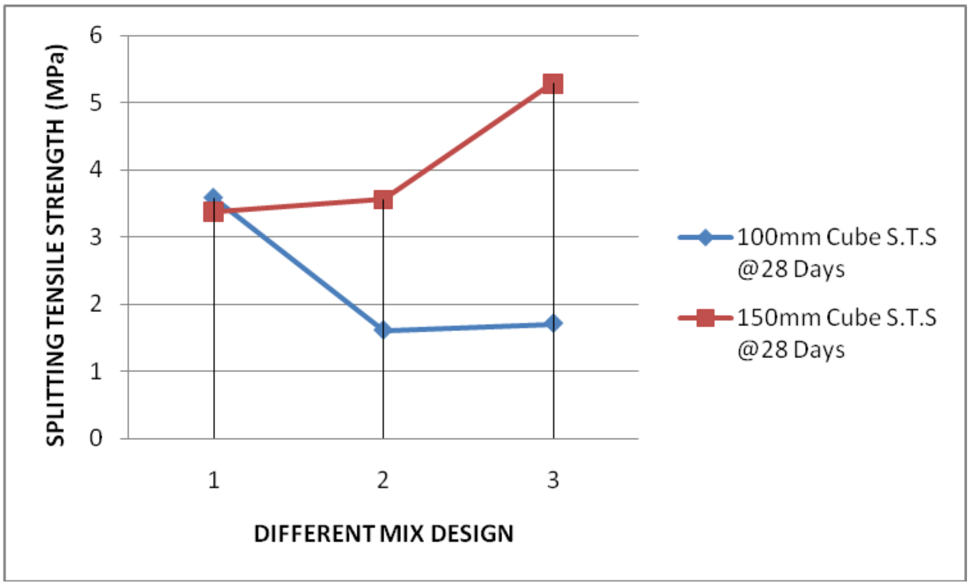


Figure 5.10: Comparison between splitting tensile strength (average) at 28 days of 100mm cube and 150mm cube

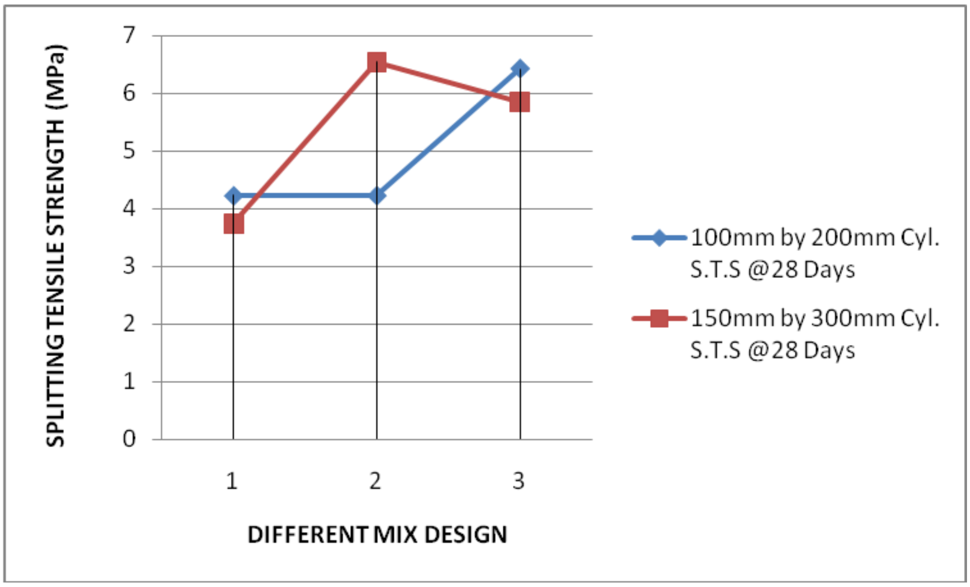


Figure 5.11: Comparison between splitting tensile strength (average) at 28 days of Ø 100×200mm cylinder and Ø150×300mm cylinder

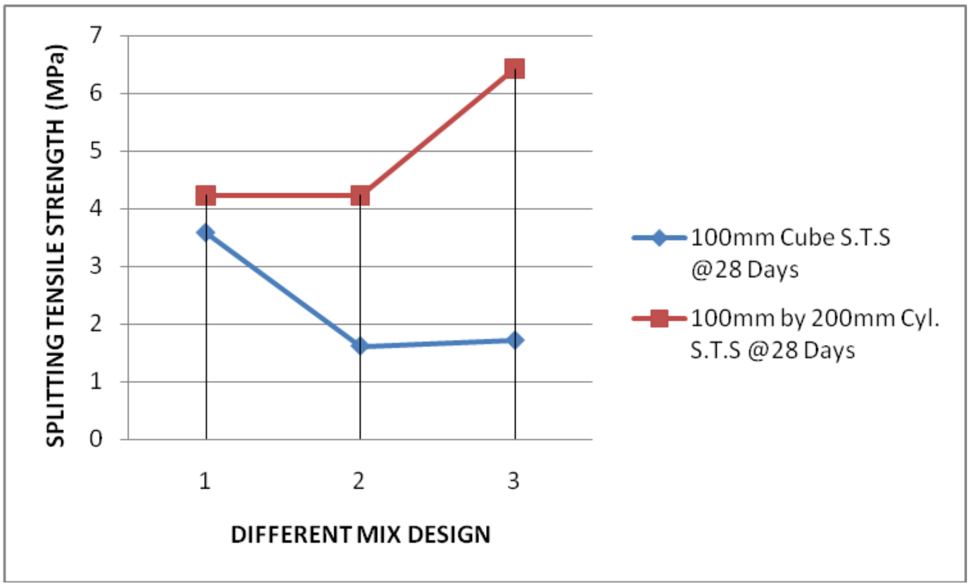


Figure 5.12: Comparison between splitting tensile strength at 28 days of 100mm cube and Ø100x200mm cylinder

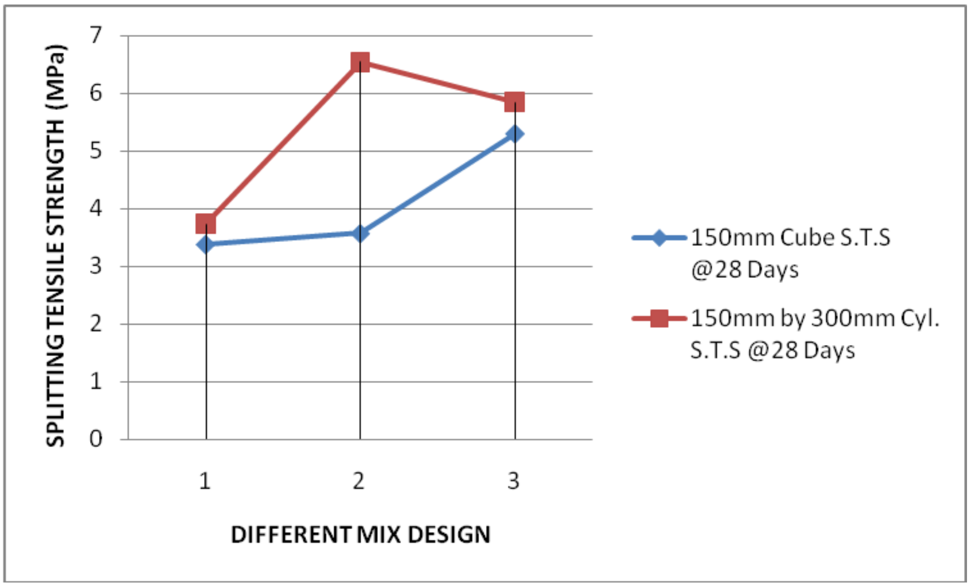


Figure 5.13: Comparison between splitting tensile strength at 28 days of 150mm cube and Ø150x300mm cylinder

CONCLUSIONS

Based on the results of the study, with particular test materials and test procedures employed, the following conclusions can be made.

1. The expressions for specimen Size effect based on two different specimen sizes are presented. The results show that compressive strength increases as the specimen size decreases. From the 28-days test results, the ratio of 150 mm to 100 mm cube strength and Ø150x300 mm to Ø100x200 mm cylinder strength are 0.96 and 0.97, respectively.

2. The expressions for specimen shape effect based on the result from cube and cylinder specimens are presented. The compressive cube strength is generally higher than cylindrical strength and this effect trend to be decreased as the concrete strength increases.

3. Splitting tensile strength (Shape effect) results shows that cylinder specimen has higher strength as compared to cube specimen.

4. At last in case of Size effect, splitting tensile strength increases with increasing size.

REFERENCES

AASHTO LRFD Bridge Design Specifications, Second Edition, American Association of State Highway and Transportation Officials, Washington DC, 2005.

ACI Committee 318-05, Building code requirements for structural concrete, American Concrete Institute, 2005.

ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (318R-02)", American Concrete Institute, Farmington Hills, MI, 2002, 443 pp.

ACI Committee 363, "State-of-the-Art Report on High-Strength Concrete (ACI 363R-2)", American Concrete Institute, Detroit, 1992 (Revised 1997), 55 pp.

ACI Committee 363, "Guide to Quality Control and Testing of High-Strength Concrete (ACI 363.2R-98)", American Concrete Institute, Detroit, 1998, 18 pp.

Ahmad, S. H. and Lue, D. M., "Flexure-Shear Interaction of Reinforced High-Strength Concrete Beams", ACI Structural Journal, Vol. 84, No.4, 1987, pp. 330-341.

Arias, A., Forquin, P., Zaera, R. and Navarro, C. "Relationship between static bending and compressive behaviour of particle-reinforced cement composites," Composites: Part B, 39, 2008, 1205-1215.

ASTM C 494. 1999. Standard Specification for Chemical Admixtures for Concrete. Annual Book of ASTM Standards, American Society for Testing and Materials.

Bae, S. and Bayrak, O., "Stress Block Parameters for High-Strength Concrete Members", ACI Structural Journal, Vol. 100, No. 5, 2003, pp. 626-636.

Bayrak, O. and Sheikh, S. A., “Confinement Reinforcement Design Considerations for Ductile HSC Columns”, Journal of Structural Engineering, Vol. 124, No. 9, 1998, pp. 999- 1010.

Bazant, Z. P. (1998). Size effect in tensile and compression fracture of concrete structures: Computational modeling and desing. In Fracture Mechanics of Concrete Structures, pages 1905–1922, Freiburg, Germany. F.H. Wittmann, Ed., Aedificatio Publishers.

Bazant, Z. P. and Planas, J. (1998). Fracture Size Effect in Concrete and Other Quasibrittle Materials. CRC Press, Boca Raton.

Bernhardt, C. J. and Fynboe, C. C., “High Strength Concrete Beams”, Nordic Concrete Research, No. 5, 1986, pp. 19-26.

BESHR, H., A. A. ALMUSALlAM and M. MAsLEHUDDIN. 2003. Effect of coarse aggregate quality on the mechanical properties of high strength concrete. Construction and Buikling Materials 17: 97-103.

Bhatia, S., “Continuous Prestressed Concrete Beams in the Inelastic Range”, M.Sc. Thesis, Department of Queen’s University, Kingston, Ontario, Canada, 1984.

Bing, L., Park, R. and Tanaka, H., “Stress Strain Behavior of High Strength Concrete Confined by Ultra-High- and Normal-Strength Transverse Reinforcement”, ACI Structural Journal, Vol. 98, No. 3, 2001, pp. 395-406.

Borges, J. U. A., Subramaniam, K. V., Weiss, W. J., Shah, S. P., and Bittencourt, T. (2004). Length effect on ductility of concrete in uniaxial and flexural compression. ACI Structural Journal, 101(6):765–772.

Burns N. H., Gross S. P. and Byle K.A., “Instrumentation and Measurements - Behavior of Long-Span Prestressed High Performance Concrete Bridges”, PCI/FHWA International Symposium on High Performance Concrete October 20-22, New Orleans, Louisiana, 1997.

Canadian Standards Association, “Design of Concrete Structures, CSA A23.3 1994”, Rexdale, Ontario, 1994, pp.199.

Carino, N. J., “Prediction of Potential Strength at Later Ages”, Concrete and Concrete- Making Materials, 1994, pp. 140.

Carpinteri, A., Chiaia, B., and Ferro, G. (1998). Size effect on nominal tensile strength of concrete structures: Multifractality of material ligaments and dimensional transition from order to disorder. Materials and Structures, 28:311–317.

CARRAsQUILLO, P.M. and RL. CARRAsQUILLO. 1998. Evaluation of the use of current concrete practice in the production of high-strength concrete. ACI Materials Journal 85(1): 49-54.

CARRAsQUILLO, R, A. NILSON and F. SLATE. 1981. Properties of high strength concrete subject to short-term loads. ACIJournal 78(3): 171-178.

Carrasquillo, R. L., Nilson, A. H. and Slate, F., “Properties of High Strength Concrete Subject to Short- Term Loads”, ACI Structural Journal, Vol. 78, No.3, 1981, pp. 171-178.

Carrasquillo, R. L., Slate, F. and Nilson, A. H., “Micro-Cracking and Behavior of High Strength Concrete Subject to Short- Term Loading”, ACI Structural Journal, Vol. 78, No.3, 1981, pp. 179-186.

Chin, M. S., Mansur, M. A. and Wee, T. H., “Effect of Shape, Size and Casting Direction of Specimens on Stress-Strain Curves of High-Strength Concrete”, ACI Materials Journal, Vol. 94, No. 3, 1997, pp. 209-219.

Choi, S., Thienel, K. C., and Shah, S. P. (1996). Strain softening of concrete in compression under different end constraints. Magazine of Concrete Reseach, 48(175):103–115.

Cohn, M. Z. and Lounis, Z., "Moment Redistribution in Structural Concrete Codes", Canadian Journal of Civil Engineering, Vol.18, No. 1, 1991, pp. 97-108.

Collins, T. M., "Proportioning High-Strength Concrete to Control Creep and Shrinkage" ACI Materials Journal, Vol. 86, No. 6, 1989, pp. 576-580.

Collins, M. P., Mitchell, D. and MacGregor, J. G., "Structural Design Considerations for High-Strength Concrete", Concrete International, Vol. 15, No. 5, 1993, pp. 27-34.

Comite Europeen de Normalisation (CEN), "Eurocode 2: Design of Concrete Structures, Part 1 – General Rules and Rules for Buildings", prEN 1992-1, 2002, pp. 211.

Cusson, D. and Paultre, P., "High-Strength Concrete Columns Confined by Rectangular Ties", Journal of Structural Engineering, Vol. 120, No. 3, 1994, pp. 783-804.

Del Viso, J.R., Carmona, J.R. and Ruiz, G. "Shape and size effects on the compressive strength of highstrength concrete," Cement and Concrete Research, 38, 2008, 386-395.

Elices, M., Guinea, G. V., and Planas, J. (1992). Measurement of the fracture energy using three-point bend tests. 3. Influence of the cutting the P ¡± tail. Materials and Structures, 25:327–334.

Guinea, G. V., Planas, J., and Elices, M. (1992). Measurement of the fracture energy using three-point bend tests. 1. Influence of experimental procedures. Materials and Structures, 25:121–128.

Hognestad, E., Hanson, N. W. and McHenry, D., "Concrete Stress Distribution in Ultimate Strength Design", ACI Journal, Vol. 52, No. 4, 1955, pp. 455-479.

Hueste, M. B. D. and Cuadros G. G., “Survey of Current Practice for Design of High Strength Concrete Prestressed Bridge Girders”, TRB Annual Meeting, Transportation Research Board, Washington, D.C., January 2004.

Ibrahim, H. H. H. and MacGregor, G., “Tests of Eccentrically Loaded High-Strength Concrete Columns”, ACI Structural Journal, Vol. 93, No. 5, 1996, pp. 585-594.

Ibrahim, H. H. H. and MacGregor, G., “Modification of the ACI Rectangular Stress Block for High-Strength Concrete”, ACI Structural Journal, Vol. 94, No. 1, 1997, pp. 40-48.

Imam, M., Vandewalle, L. and Mortelmans, F. “Are current concrete strength tests suitable for high strength concrete?,” Materials and Structures, 28, 1995, 384-391.

Iravani, S., “Mechanical Properties of High-Performance Concrete”, ACI Materials Journal, Vol. 93, No. 5, 1996, pp. 416-426.

Jansen, D. C. and Shah, S. P. (1997). Effect on length on compressive strain softening of concrete. Journal of Engineering Mechanics-ASCE, 123(1):25–35.

Khatri, R.P. and Sirivivatnanon, V. “Effect of different supplementary cementitious materials on mechanical properties of high performance concrete,” Cement and Concrete Research, 25, 1, 1995, 209-220.

Le Roy, R., “Instantaneous and Time Dependant Strains of High-Strength Concrete”, Laboratoire Central des Ponts et Chaussees, Paris, France, 1996, pp. 376.

Legeron, F. and Paultre, P., “Prediction of Modulus of Rupture of Concrete”, ACI Materials Journal, Vol. 97, No. 2, 2000, pp. 193-200.

Mansur, M. A., Chin, M. S. and Wee, T. H., “Flexural Behavior of High-Strength Concrete Beams”, ACI Structural Journal, Vol. 94, No. 6, 1997, pp. 663-674.

Miller, R. A., Castrodale, R., Mirmiran, A., and Hastak, M., “Connection between Simple Span Precast Concrete Girders Made Continuous”, Draft Final Report, NCHRP Project 12-53, University of Cincinnati, Cincinnati, OH, October 2003.

Mindess, S., Young, J. F., and Darwin, D. (2003). Concrete. Prentice Hall, Pearson Education, Inc. United States of America.

Mokhtarzadeh, A. and French, C. E., “Mechanical Properties of High-Strength Concrete”, Final Report No. 1998-11, Minnesota Department of Transportation, 1988.

Naaman, A. E. “Rectangular Stress Block and T-Section Behavior”, PCI Journal, Vol. 47, No.5, 2002, pp. 106-112.

Nagashima, T., Sugano, S., Kimura, H. and Ichikawa, A., “Monotonic Axial Compression Test on Ultra-High-Strength Concrete Tied Columns”, Earthquake Engineering Tenth World Conference, Balkema, Rotterdam, the Netherlands, 1992, pp. 2983-2988.

Nedderman, H., "Flexural Stress Distribution in Very-High Strength concrete”, M.Sc. Thesis, University of Texas at Arlington, 1973, 182 pp.

Neville, A. M., Properties of Concrete, Fourth and Final Edition, New York: J. Wiley, New York, 1996, pp. 884.

Neville, A.M. and Brooks, J.J., Concrete technology, Longman, United Kingdom, 1990.

Noguchi Laboratory Data, Department of Architecture, University of Tokyo, Japan, (http://bme.t.u-tokyo.ac.jp/index_e.html).

Park, R. and Paulay, T., “Reinforced Concrete Structures”, John Wiley and Sons, New York, N. Y., 1975.

Parrot, L. J., “The Properties of High-Strength Concrete”, Technical Report No. 42.417, Cement and Concrete Association, Wexham Springs, 1969, 12 pp.

Paultre, P. and Mitchell, D., “Code Provisions for High-Strength Concrete - An International Perspective”, Concrete International, 2003, pp. 76-90.

PCI Industry Handbook Committee, “PCI Design Handbook – Precast and Prestressed Concrete”, Precast/Prestressed Concrete Institute, Chicago, Illinois, 1999.

Pei, M., Wang, Z., Li, W., Zhang, J., Pan, Q. and Qin, X. “The properties of cementitious materials superplasticized with two superplasticizers, " Construction and Building Materials, 22, 2008, 2382-2385.

Razvi, S. R. and Saatcioglu, M., “Confinement Model for High Strength Concrete”, Journal of Structural Engineering, Vol. 125, No. 3, 1999, pp. 281-289.

Russell B. W. and Pang J. P., “Investigation of Allowable Compressive Stresses for High Strength, Prestressed Concrete Bridges”, PCI/FHWA International Symposium on High Performance Concrete October 20-22, New Orleans, Louisiana, 1997.

Russell, H. G., “ACI Defines High-Performance Concrete”, Concrete International, February, 1999, pp. 56-57.

Russell, H. G., Miller, R. A., Ozyildirim, H. C. and Tadros, M. K., “Compilation and Evaluation of Results from High Performance Concrete Bridge Projects, Volume 1”, Federal Highway Administration, 2003.

Russell, H. G., Miller, R. A., Ozyildirim, H. C. and Tadros, M. K., “Compilation and Evaluation of Results from High Performance Concrete Bridge Projects, Volume 2”, Federal Highway Administration, 2003.

Russell, H. G., Miller, R. A., Ozyildirim, H. C. and Tadros, M. K., “High Performance Concrete”, Compact Disc, Federal Highway Administration, Version 3.0, 2003.

Sarkar, S., Adwan, O. and Munday, J. G. L., "High Strength Concrete: An Investigation of the Flexural Behavior of High Strength RC Beams" Structural Engineer, Vol. 75, No. 7, 1997, pp. 115-121.

Schade, J. E., "Flexural Concrete Stress in High Strength Concrete Columns", M. S. Thesis in Civil Engineering, the University of Calgary, Calgary, Alberta, Canada, 1992.

Stanton, J. F., Barr, P. and Eberhard, M. O., "Behavior of High-Strength HPC Bridge Girders", Research Report, University of Washington, Seattle, WA, 2000.

Swartz, S. E., Nikaeen, A., Narayan Babu, H. D., Periyakaruppan, N. and Refai, T. M. E., "Structural Bending Properties of Higher Strength Concrete", ACI Special Publication-87, High-Strength Concrete, 1985, pp. 145-178.

Tadros, M., Al-Omaishi, N., Seguirant, J. S. and Galit, J. G., "Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders", NCHRP Report 496, Transportation Research Board, 2003.

Vasconcelos, G., Lourenco, P.B., Alves, C.A.S. and Pamplona, J. "Experimental characterization of the tensile behaviour of granites," International Journal of Rock Mechanics and Mining Sciences, 45, 2008, 268 - 277.

Zia, P., Ahmad, S., Leming, M. L., Schemmel, J. J. and Elliot, R. P., "Mechanical Behavior of High Performance Concrete, Vol. 3 - Very Early Strength Concrete", SHRP Report C-363, Strategic Highway Research Program, National Research Council, Washington, D. C., 1993.

Zia, P., Ahmad, S., Leming, M. L., Schemmel, J. J. and Elliot, R. P., "Mechanical Behavior of High Performance Concrete, Vol. 4 - High Early Strength Concrete", SHRP Report C-364, Strategic Highway Research Program, National Research Council, Washington, D. C., 1993.

Zia, P., Ahmad, S., Leming, M. L., Schemmel, J. J. and Elliot, R. P., "Mechanical Behavior of High Performance Concrete, Vol. 5 - Very High Strength Concrete", SHRP Report C-365, Strategic Highway Research Program, National Research Council, Washington, D. C., 1993.

Zia, P., "State-of-the-Art of HPC: An International Perspective", Proceedings of the PCI/FHWA International Symposium on High Strength Concrete, New Orleans, Luisiana, 1997, pp. 49-59.

Zi, G., Oh, H. and Park, S.K. "A novel indirect tensile method to measure the biaxial tensile strength of concretes and other quasibrittle materials," Cement and Concrete Research, 38, 2008, 751-756.

Zollman, C. C., "Prestressed Concrete Construction", The Military Engineer, No.291, 1951.