ULTRA HIGH STRENGTH CONCRETE

By

HAFFIZ BIN HUSSIN

FINAL PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved:

A.P Dr Nasir Shafiq
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

January 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Haffiz Bin Hussin

ABSTRACT

The strength of ultra high strength concrete (UHSC) with axial compressive strength more than 100 MPa is presented in this paper. There are mixes have been cast in this project. Based on the slump test, the compression tests with twelve cubical specimens (150mm) at 3 days, 7 days, 28 days and 90 days, split cylinder tests with six cylinder specimens (100mm x 200mm) at 28 days and 90 days; and porosity test with two slabs (200mm x 300mm) for twelve coring specimens at 3 days, days, 28 days and 90 days, the compressive strength of UHSC with ratio of cement on fine and coarse aggregates are to 1:1.5:2.5, 2.5%, 3% and 4% of superplasticiser, 10% of silica fume and; 25% and 27% of water cement ratio are to be investigated. The observation of strength on each specimen with various percentage of superplasticiser will be made up to 90 days of strength. Graph of stresses vs. days will be plotted for further analysis as well as the calculation of modulus of elasticity (E).

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

UHSC	Ultra High Strength Concrete
OPC	Ordinary Portland Cement
SF	Silica Fume
Fagg	Fine aggregates
Cagg	Course aggregates
SP	Superplasticiser
ave	average
SCC	Self-Compacting Concrete

CHAPTER 1

INTRODUCTION

1.1 Background Study

Compressive strength, which have been influenced the used of high-performance concrete for economic reasons. While it is evident that a sample of this size cannot claim adequately to cover this subject (CEB 1994), these selected cases provide an insight as to why owners, designers, contractors and concrete producers have found their own particular reasons to use high-performance concrete.

In order to use a given structural material to its best economic advantage, it is important to understand its properties fully. According to Professor Jorg Schlaich (1987): 'one cannot design with and work with a material which one doesn't know and understand thoroughly. Therefore, design quality starts with education'.

1.2 Problem Statement

Structures nowadays are getting huge and beautiful in sequence with present technology and growing population. Thus huge structures such as tall buildings, longer bridges and huge damps required higher performance or strength of concrete as well as economical in order to achieve any design that we desired since importing several materials from other countries are uneconomical.

1.3 Objective

The main objective is to do a trial and error for casting a concrete with axial compressive strength more than 100 MPa by using 100% local cement.

1.4 Scope of Study

With the mixes of Portland cement, water, silica fume, fine and course aggregates and superplasticiser at 2.5%, 3% and 4%, make several tests to cast an Ultra High Strength Concrete (UHSC) which is more than 100MPa of compressive strength. The tests are slump test for properties of fresh concrete and while for properties of hardened concrete are cube crushing strength, split cylinder and porosity test. The materials requirements for this project are 250kg or 5 bags of cement, 25kg of silica fume and 10kg of superplacticiser.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Ultra High Strength Concrete (UHSC)

2.1.1 Background study of Ultra High Strength Concrete

In previous experiments, it stated that ultra high strength concrete (UHSC) is characterized by extraordinary mechanical properties (high compressive and tensile strength, large E-modulus) and has excellent durability properties regarding corrosion of concrete and reinforcement (low permeability against liquids and gases, thus high resistance against the penetration of ions, very good freeze-thaw-resistance with or without de-icing salts and a high abrasion resistance) (Dirk Weiße, Jianxin Ma, June 2004). Nevertheless, the deformation behavior of the UHSC-Matrix in comparison to normal strength concrete is a contrary matter. Until the peak load the behavior is predominantly linear-elastic, large deformations at peak can not be observed, and the reached post-peak strain is nearly zero. These facts point out the very brittle material behavior. The mentioned changes influence certainly design-relevant properties like bending, shear, torsion and punching bearing capacity as well as the bond of reinforcement (Weiße, D., 2003) and the behavior under concentrated loading (Klotz, S.; Holschemacher, K., 2003). At the beginning of the development a central focus was only given to the concrete technology aspects in order to increase compressive and tensile strength, so experimental results for design relevant properties were of secondary interest. However, before ultra high strength concrete can be used in the practice on site and therefore it can be taken advantage of the outstanding mechanical and durability properties, adequate models to describe the bearing behavior and design concepts must be provided. The fundamentals are wide experimental investigations in order to examine the influence of changed material properties and behavior.

Base on the test program that they conducted, 3 different mixes were designed as shown in Table 1 below.

Table 1 Mix designs (Dirk Weiße, Jianxin Ma, June 2004)

		Reference 1	Reference 2	UHSC 1	UHSC 2	UHSC 3
Sand	Content of Cement	1,86	2,42	0,92	-	-
Gravel		3,46	-	-	-	-
Crushed aggregates		-	0,49	1,68	-	2,06
Crushed aggregates		-	2,15	-	-	-
Cement CEM I 42,5 R	Content of Cement	1,00	1,00	1,00	1,00	1,00
Fly ash		0,21	0,27	0,20	-	-
Silica-slurry		-	-	0,13 (solids)	-	-
Silica-fume		-	-	-	0,30	0,18
Quartz sand	Content of Cement	-	-	0,30	1,53	0,88
Quartz powder		-	-	-	0,43	0,54
Water	Content of Cement	0,53	0,52	0,30	0,25	0,27
Superplasticizer		0,01	0,02	0,04	0,03	0,04

2.1.2 Compressive strength of UHSC

They also added that the compressive strength was determined on cylinders (Ø 100/*h* = 200 mm) and on cubes (100 × 100 mm^3). The used smaller dimensions of the specimens compared to those used in DIN 1048 (DIN 1048, Teil 5, 1991) are necessary, because of available testing machines. The same specimens were also used for the Reference mixes. In order to find answers concerning the dependency of the compressive strength on the slenderness, also cylinders with different heights were cast. The time development was measured for all concrete types at 7, 28 and 56 days, for some of it also after 3 and 90 days. All specimens were water cured at 20°C until the test.

Dirk Weiße and Jianxin Ma in June 2004, also determined that UHSC are not only the high compressive strengths after 28 days but its high early age strength is also quite remarkable. So, 80 - 120 N/mm² after 3 days are easily possible according to Figure 1. Therefore this concrete type is fairly interesting for prestressed reinforced concrete members, because the pretensioning can be applied earlier. The aim of a similar strength development could be achieved according to Figure 1. The Reference mix 2 has a slightly lower increase, which can be explained with the lower binder content.

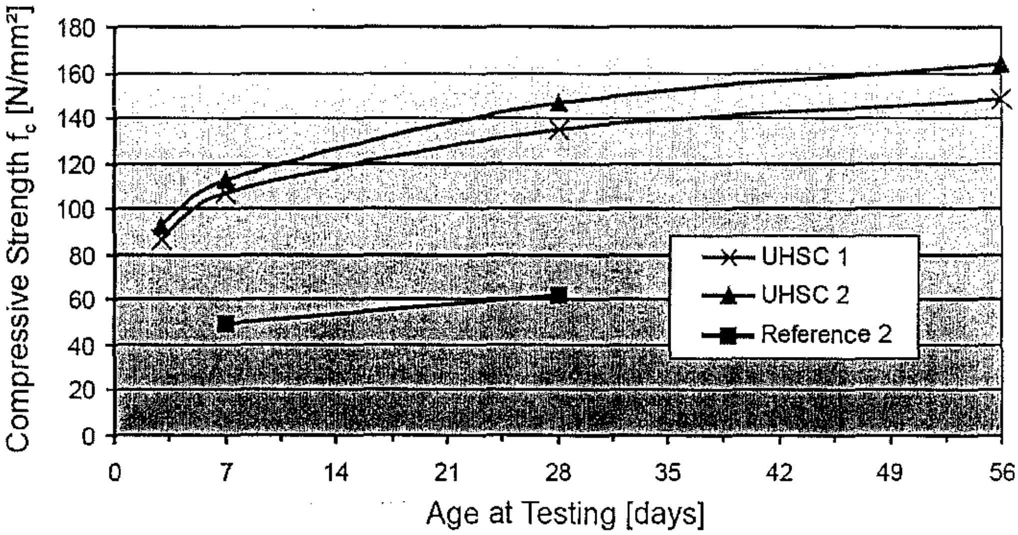

Figure 1 Time development of cylinder compressive strength (Dirk Weiße, Jianxin Ma, June 2004)

2.1.3 Tensile strength of UHSC

According to Remmel, G. 1994,

> The reachable tensile strength of UHSC depends very much on the mix composition, especially on type and amount of the used binder material. Generally accepted is the fact, that the tensile strength increases under proportionally, just asfor high strength concrete. Furthermore it has to be

distinguished between plain and fibre reinforced ultra high strength concrete. With a certain amount of fibres it is possible to augment the tensile strength drastically.

For split tensile strength, base on experimental research from Dirk Weiße, Jianxin Ma, June 2004, splitting tensile strength was determined on cubes (100 × 100 × 100 mm^3) at all tested concrete ages. As for the compressive strength the time development of the splitting tensile strength is similar between UHSC and the Reference. Remarkable is the behavior at early ages. After 3 days UHSC 2 (the RPC) has a lower strength than UHSC 1, but going on to 7 days the values are now vice versa. The difference is at this point in time about 1.5 N/mm^2, which increases over the time to about 2.5 N/mm^2 as shown in Figure 2 below.

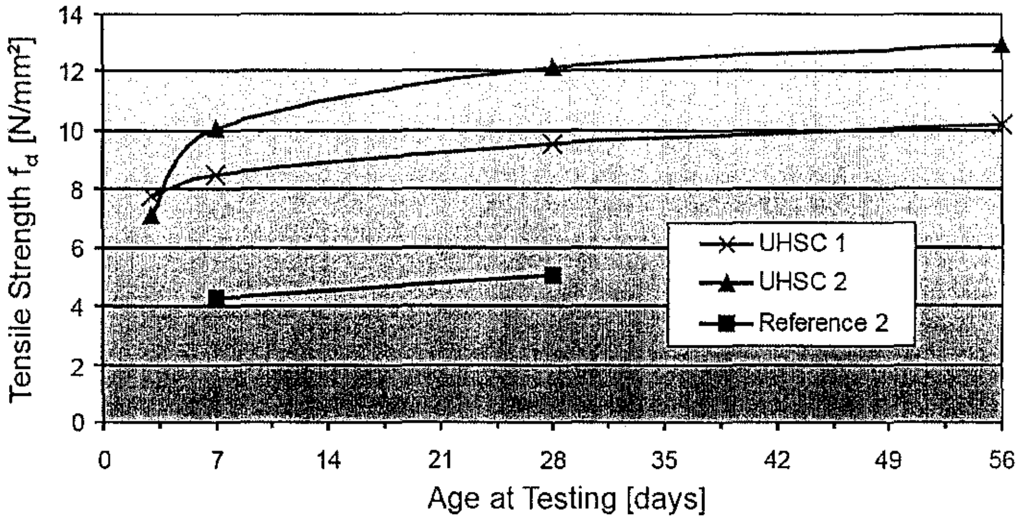

Figure 2 Time development of splitting tensile strength (Dirk Weiße and Jianxin Ma in June 2004)

2.1.4 *Modulus of Elasticity*

Generally from the development of ultra high strength concrete, only the compressive strength was the relevant factor. The deformation behavior, for example the modulus of elasticity was only a secondary interest. The stress-strain-relationship is important for calculating deflections of reinforced concrete members. Significant parameters for the E-modulus are the proportion of the matrix and its quality, type and portion of applied aggregates and certainly also the bond between the aggregates and the matrix. In the experimental program of modulus of elasticity was also measured on cylinders (Ø 100/*h* = 200 mm) at all tested concrete ages.

From the experimental value of Dirk Weiße and Jianxin Ma's findings in June 2004, it was stated that with the modulus of elasticity the trend of high early age strengths as known for the compressive and tensile strength is continued. Values above 40.000 N/mm^2, about 3 days are possible. Regarding the further increase over the time it is shown in Figure 3, that UHSC 2 has a lower increase after 7 days compared with UHSC 1 and Reference concrete 2. These two mixes contain fly ash (and microsilica for the UHSC 1) in the mix design, whereas UHSC 2 only silica fume as a pozzolanic additive. The second aspect is the type of aggregates as shown in Figure 4 on the relationship between the compressive strength and the E-modulus. In order to class the measured values, the possible range according to the CEB-FIP Model Code 90 (Structural Concrete, 1999) is given in this diagram (The curves for the MC 90 in Figure 4 are extrapolated, because the highest strength class is C100/115). The UHSC 1 has lower compressive strengths compared to UHSC 2, but the modulus of elasticity is higher. The use of aggregates with an own high strengths and E-modulus, in this case crushed basalt as coarse aggregates, improves the deformation behavior of ultra high strength concrete. Similar results were found with high strength concrete (Aulia, T. B., 2002 and Aulia, T. B., 1999).

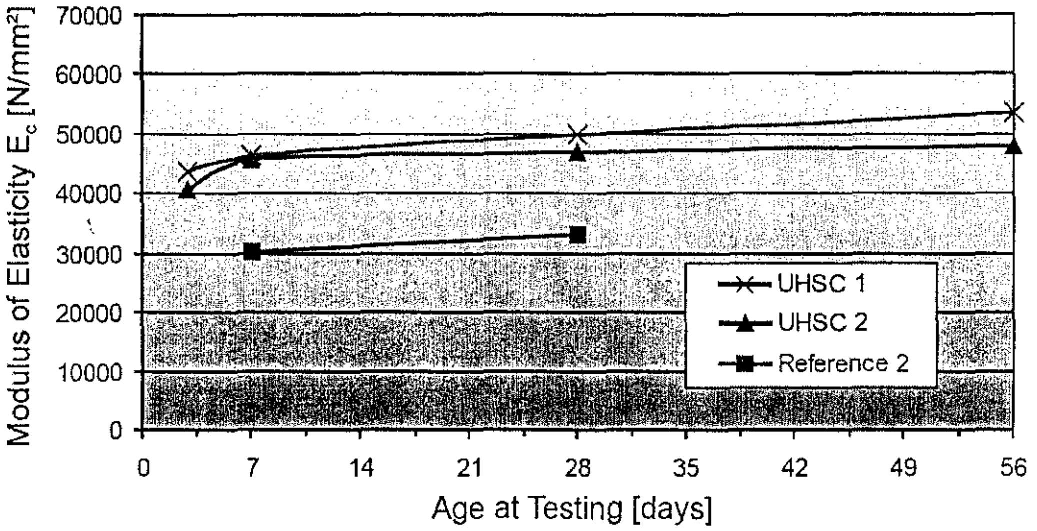

Figure 3 Time development of modulus of elasticity (Dirk Weiße and Jianxin Ma in June 2004)

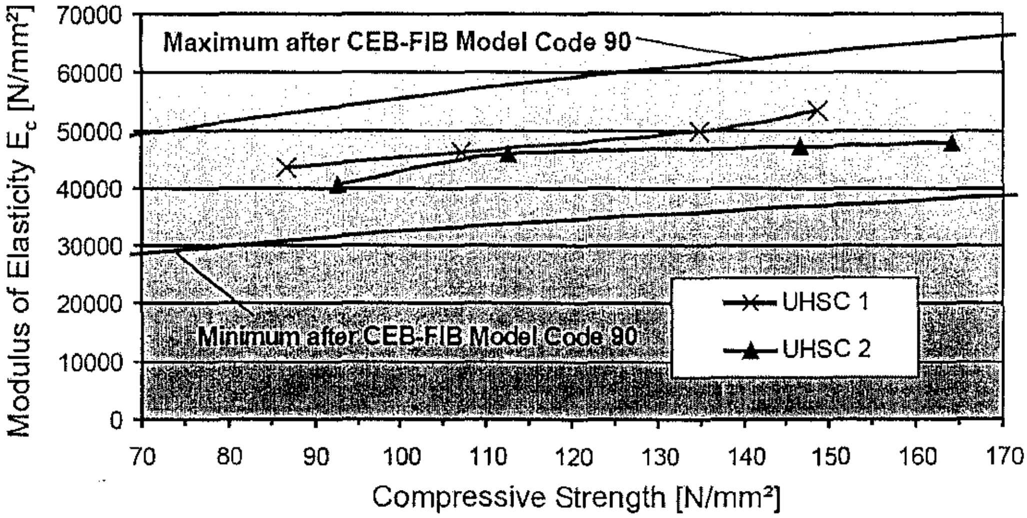

Figure 4 Relationship between modulus of elasticity and compressive strength (Dirk Weiße and Jianxin Ma in June 2004)

Formula used to calculate Modulus of Elasticity (E);

$$E = 4.73(f'c)^{0.5} \tag{1}$$

Where;
E = modulus of elasticity in GPa (Giga Pascal) and;
f'c = tensile strength of split cylinder test in MPa (Mega Pascal)

2.2 Cement (Ordinary Portland Cement)

Ordinary Portland Cement (OPC) which is manufactured by Lafarge Malayan Cement Berhad exceeds the quality requirements specified in the Malaysian Standard MS 522: Part 1: 1989.

It is the most common cement used in general concrete construction when there is no exposure to sulphates in the soil or groundwater. Specifications for Ordinary Portland Cement. Our OPC is manufactured under an effective system of testing, control and monitoring, conforming to requirements under SIRIM's product Certification License. Lafarge Malayan Cement Berhad bag OPC is sold under the "Rumah" brand - a leading brand in the construction industry and are extensively used in projects of all sizes. The raw materials required for the manufacture of OPC are calcareous material such as limestone or chalk and argilaceous materials such as shale or clay. A mixture of these materials is burnt at a high temperature of approximately 1400 ^{0}C in a rotary kiln to form clinker. The clinker is then cooled and grounded with a requisite amount of gypsum into fine powder known as Portland cement.

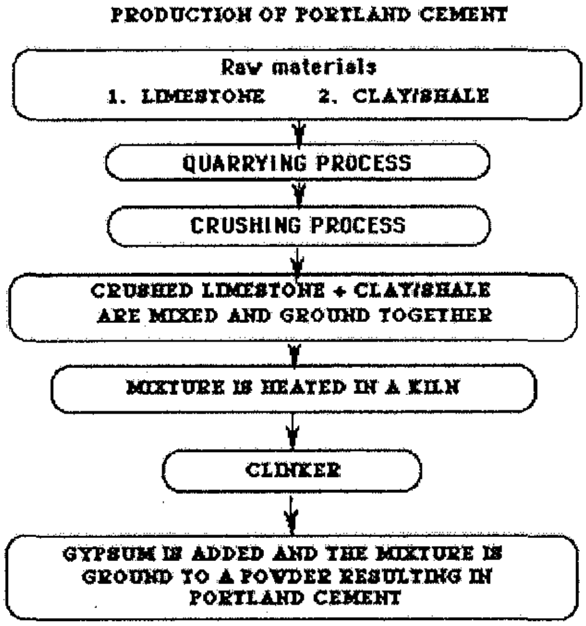

Figure 5 Flow of Portland cement production (Bye, G. C., 1983).

According to Bye, G.C., 1983, OPC is a gray colored powder which could create bonding mineral fragments into a compact whole when mixed with water. This hydration process results in a progressive stiffening, hardening and strength development. OPC manufactured by Lafarge Malayan Cement Berhad is compatible with admixtures meeting BS 5075 Part 1, for normal dosages and conditions. It can be blended for use with other Portland cement. In the manufacture of OPC, the proportioning of raw materials is strictly controlled at all stages to ensure that the quality of the finished product well exceeds the quality requirements stipulated in the relevant standard specifications.

Lafarge Malayan Cement Berhad OPC is available in 50kg bags and bulk. The OPC drawn from the silos is fed to rotary packers for bagging and then loaded into trucks and rail wagons for delivery. Bulk tankers are loaded directly from silos. Bulk OPC is also loaded into rail wagons for delivery to the company's depots located throughout Peninsular Malaysia. In addition to that, our Langkawi Works provides a strategic location to load bulk OPC into ships berthing alongside the wharf next to the works for export market. These are often available as inter-ground mixtures from cement manufacturers, but similar formulations are often also mixed from the ground components at the concrete mixing plant.

- *Portland Blastfurnace Cement* (Kosmatka, S.H.; Panarese, W.C., 1988)

It contains up to 70% ground granulated blast furnace slag, with the rest Portland clinker and a little gypsum. All compositions produce high ultimate strength, but as slag content is increased, early strength is reduced, while sulfate resistance increases and heat evolution diminishes. Used as an economic alternative to Portland sulfate-resisting and low-heat cements.

- *Portland Flyash Cement* (U.S. Federal Highway Administration, 2007)

It contains up to 30% fly ash. The flyash is pozzolanic, so that ultimate strength is maintained. Because flyash addition allows lower concrete water content, early strength can also be maintained. Where good quality cheap flyash is available, this can be an economic alternative to ordinary Portland cement.

- *Portland Pozzolan Cement*

It includes fly ash cement, since fly ash is a pozzolan, but also includes cements made from other natural or artificial pozzolans. In countries where volcanic ashes are available such as Italy, Chile, Mexico and Philippines, these cements are often the most common form in use.

- *Portland Silica Fume cement* (U.S. Federal Highway Administration, 2007)

An addition of silica fume can yield exceptionally high strengths, and cements containing 5-20% silica fume are occasionally produced. However, silica fume is more usually added to Portland cement at the concrete mixer.

- *Masonry Cements*

Are used for preparing bricklaying mortars and stuccos, and must not be used in concrete. They are usually complex proprietary formulations containing Portland clinker and a number of other ingredients that may include limestone, hydrated lime, air entrainers, retarders, waterproofers and coloring agents. They are formulated to yield workable mortars that allow rapid and consistent masonry work. Subtle variations of Masonry cement in the US are Plastic Cements and Stucco Cements. These are designed to produce controlled bond with masonry blocks.

- *Expansive Cements*

An addition to Portland clinker, expansive clinkers, and designed to offset the effects of drying shrinkage that is normally encountered with hydraulic cements. This allows large floor slabs (up to 60 m square) to be prepared without contraction joints.

- *White blended cements*

It may be made using white clinker and white supplementary materials such as high-purity metakaolin.

- *Colored cements*

Used for decorative purposes. In some standards, the addition of pigments to produce "colored Portland cement" is allowed. In other standards ASTM for example, pigments are not allowed constituents of Portland cement, and colored cements are sold as "blended hydraulic cements".

2.3 Silica fume

It is a byproduct from producing silicon metal or ferrosilicon alloys. Concrete that uses silica fume will benefit the most due to its chemical and physical properties. It is a very reactive pozzolan, thus can have very high strength and high in durability. Silica fume is available from suppliers of concrete admixtures and, when specified, is simply added during concrete production. Placing, finishing, and curing silica-fume concrete require special attention on the part of the concrete contractor. Also known as microsilica, byproduct of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. Also collected as a byproduct in the production of other silicon alloys such as ferrochromium, ferromanganese, ferromagnesium, and calcium silicon (ACI Comm. 226 1987b).

As quoted from ACI Comm. 226 1987b; Luther 1990, almost all Silica Fume was discharged into the atmosphere. After environmental concerns necessitated the collection and land filling of Silica Fume, it became economically justified to use Silica Fume in various applications. It consists of very fine vitreous particles with a surface area on the order of 215,280 ft2/lb (20,000 m2/kg) when measured by nitrogen absorption techniques, with particles approximately 100 times smaller than the average cement particle. Because of its extreme fineness and high silica content, Silica Fume is a highly effective pozzolanic material. Silica Fume is used in concrete to improve its properties. It has been found that Silica Fume improves compressive strength, bond strength, and abrasion resistance; reduces permeability; and therefore helps in protecting reinforcing steel from corrosion.

Determined by ACI committee 363 (1993) that since the 1950s, high strength concrete is widely as substitute for normal strength concrete (NSC).

Moreover, ACI committee 363 (1994) stated that the lower water cement ratio (w/c) and higher content of binder are needed to produce HSC. Consequently, high-range water-reducing admixtures (HRWRA) are used to achieve the required workability. Investigation of the performance of silica fume (SF) in concrete began since the 1950s. Nowadays, it has been well known that the use of SF can extensively improve the mechanical properties and durability of HSC. The huge amount of amorphous silicon dioxide and finest spherical particles are the main reasons for its high pozzolanic activity. The advantages of SF caused it for being the most well-known admixture material for HSC in recent years.

- *Effects on Air Entrainment and Air-void System of Fresh Concrete* (Admixtures and ground slag 1990; Carette and Malhotra 1983). .

  The dosage of air-entraining agent needed to maintain the required air content when using Silica Fume is slightly higher than that for conventional concrete because of high surface area and the presence of carbon. This dosage is increased with increasing amounts of Silica Fume content in concrete.

- *Effects on Water Requirements of Fresh Concrete* (Admixtures and ground slag 1990).

  Silica Fume added to concrete by itself increases water demands, often requiring one additional pound of water for every pound of added Silica Fume. This problem can be easily compensated for by using HRWR.

- *Effects on Consistency and Bleeding of Fresh Concrete* (Luther 1989).

Concrete incorporating more than 10% Silica Fume becomes sticky; in order to enhance workability, the initial slump should be increased. It has been found that Silica Fume reduces bleeding because of its effect on rheologic properties.

- *Effects on Strength of Hardened Concrete.*

Silica Fume has been successfully used to produce very high-strength, low-permeability, and chemically resistant concrete (Wolseifer 1984). Addition of Silica Fume by itself, with other factors being constant, increases the concrete strength. Incorporation of Silica Fume into a mixture with HRWR also enables the use of a lower water-to-cementitious-materials ratio than may have been possible otherwise (Luther 1990). The modulus of rupture of Silica Fume concrete is usually either about the same as or somewhat higher than that of conventional concrete at the same level of compressive strength (Carette and Malhotra 1983; Luther and Hansen 1989).

- *Effects on Freeze-thaw Durability of Hardened Concrete.*

Air-void stability of concrete incorporating Silica Fume was studied by Pigeon, Aitcin, and LaPlante (1987) and Pigeon and Plante (1989). Their test results indicated that the use of Silica Fume has no significant influence on the production and stability of the air-void system. Freeze-thaw testing (ASTM C 666) on Silica Fume concrete showed acceptable results; the average durability factor was greater than 99% (Luther and Hansen 1989; Ozyildirim 1986).

- *Effects on Permeability of Hardened Concrete.*

It has been shown by several researchers that addition of Silica Fume to concrete reduces its permeability (Admixtures and ground slag 1990; ACI Comm. 226 1987b). Rapid chloride permeability testing (AASHTO 277) conducted on Silica Fume concrete showed that addition of Silica Fume (8% Silica Fume) significantly reduces the chloride permeability. This reduction is primarily the result of the increased density of the matrix due to the presence of Silica Fume (Ozyildirim 1986; Plante and Bilodeau 1989).

- *Effects on ASR of Hardened Concrete.*

Silica Fume, like other pozzolans, can reduce ASR and prevent deletrious expansion due to ASR (Tenoutasse and Marion 1987).

Available in two conditions: dry and wet. Dry silica can be provided as produced or densified with or without dry admixtures and can be stored in silos and hoppers. Silica Fume slurry with low or high dosages of chemical admixtures are available. Slurried products are stored in tanks with capacities ranging from a few thousand to 400,000 gallons (1,510 m3) (Admixtures and ground slag 1990; Holland 1988).

2.4 Superplasticiser

A hindering material which consist of sodium salt of high molecular weight sulphonic polymer. It is specially formulated for production of high quality, early and crucial strength water-tight concrete that possesses excellent workability retention. It may reduce the required mixing water between 15 to 20 percent while maintaining the required workability and hence expedites early strength development and improves ultimate strength of the concrete. The advent of these materials made it possible for the first time to economically batch workable concretes with water/cement ratios of less or equal to 0.35, batch Silica Fume concrete at low water/cement ratios, achieve super-fluid, highly workable concretes without excessive set extension and produce self compacting concretes. While the safety procedures are avoid ingestion and prolonged contact with skin, wash skin or affected area with clean water.

The properties of superplasticiser are as listed below:

1. Enables the production of high strength concrete by reducing the water: cement ratio.
2. Possesses excellent slump retention.
3. Improves substantially the concrete workability at given water: cements ratio sand therefore aids flow and compaction around reinforcements.
4. Enables the production of self-compacting concrete which eases placing in difficult situations and alleviates the need for vibration.

5. Facilitates the production of fair-faced concrete.
6. Enables rapid pumping of concrete and therefore reduces the pumping pressure required.
7. Enables the reduction in cement content used for given strength requirements.
8. Reduces the shrinkage and crazing cracks in mass concrete.

2.5 Water

The most essential ingredient to achieve solid, strong and durable concrete rely on the careful proportioning and mixing of other ingredients. A concrete mixture that does not have enough paste to fill all the voids between the aggregates will be difficult to place and will produce rough, honeycombed surfaces and porous concrete. A mixture with the correct amount of cement paste will ease the placing and producing a smooth surface; however, the resulting concrete is likely to shrink more and be uneconomical. A properly designed concrete mixture will possess the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, a mix is about 10 to 15 percent cement, 60 to 75 percent aggregate and 15 to 20 percent water. Entrained air in many concrete mixes may also take up another 5 to 8 percent. Portland cement's chemistry comes to life in the presence of water. Cement and water form a paste that coats each particle of stone and sand. Through a chemical reaction called hydration, the cement paste hardens and gains strength. The character of the concrete is determined by quality of the paste. The strength of the paste, in turn, depends on the ratio of water to cement. The water-cement ratio is the weight of the mixing water divided by the weight of the cement. High-quality concrete is produced by lowering the water-cement ratio as much as possible without sacrificing the workability of fresh concrete. Generally, using less water produces a higher quality concrete provided the concrete is properly placed, consolidated, and cured.

Although most drinking water is suitable for use in concrete, aggregates are chosen carefully. Aggregates comprise 60 to 75 percent of the total volume of concrete. The type and size of the aggregate mixture depends on the thickness and purpose of the final concrete product. Almost any natural water that is drinkable and has no pronounced taste or odor may be used as mixing water for concrete. However, some waters that are not fit for drinking may be suitable for concrete. Excessive impurities in mixing water not only may affect setting time and concrete strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. Specifications usually set limits on chlorides, sulfates, alkalis, and solids in mixing water unless tests can be performed to determine the effect the impurity has on various properties. Relatively thin building sections call for small coarse aggregate, though aggregates up to six inches (150 mm) in diameter have been used in large dams. A continuous gradation of particle sizes is desirable for efficient use of the paste. In addition, aggregates should be clean and free from any matter that might affect the quality of the concrete. Soon after the aggregates, water, and the cement are combined, the mixture starts to harden. All portland cements are hydraulic cements that set and harden through a chemical reaction with water. During this reaction, called hydration, a node forms on the surface of each cement particle. The node grows and expands until it links up with nodes from other cement particles or adheres to adjacent aggregates. The building up process results in progressive stiffening, hardening, and strength development. Once the concrete is thoroughly mixed and workable it should be placed in forms before the mixture becomes too stiff. During placement, the concrete is consolidated to compact it within the forms and to eliminate potential flaws, such as honeycombs and air pockets. For slabs, concrete is left to stand until the surface moisture film disappears. After the film disappears from the surface, a wood or metal handfloat is used to smooth off the concrete. Floating produces a relatively even, but slightly rough, texture that has good slip resistance and is frequently used as a final finish for exterior slabs. If a smooth, hard, dense surface is required, floating is followed by steel troweling.

Curing begins after the exposed surfaces of the concrete have hardened sufficiently to resist marring. Curing ensures the continued hydration of the cement and the strength gain of the concrete. Concrete surfaces are cured by sprinkling with water fog, or by using moisture-retaining fabrics such as burlap or cotton mats. Other curing methods prevent evaporation of the water by sealing the surface with plastic or special sprays (curing compounds). Special techniques are used for curing concrete during extremely cold or hot weather to protect the concrete. The longer the concrete is kept moist, the stronger and more durable it will become. The rate of hardening depends upon the composition and fineness of the cement, the mix proportions, and the moisture and temperature conditions. Most of the hydration and strength gain take place within the first month of concrete's life cycle, but hydration continues at a slower rate for many years. Concrete continues to get stronger as it gets older.

2.6 Aggregates

Generally, aggregates are sand and gravel categorized by its particles size by using the method of sieving. Scientifically, aggregates are chemically inert, solid bodies held together by the cement. Aggregates come in various shapes, sizes, and materials ranging from fine particles of sand to large, coarse rocks. Because cement is the most expensive ingredient in making concrete, it is desirable to minimize the amount of cement used. 70 to 80 percent of the volume of concrete is aggregate keeping the cost of the concrete low. The selection of an aggregate is determined, in part, by the desired characteristics of the concrete. For example, the density of concrete is determined by the density of the aggregate. Soft, porous aggregates can result in weak concrete with low wear resistance, while using hard aggregates can make strong concrete with a high resistance to abrasion. Aggregates should be clean, hard, and strong. The aggregate is usually washed to remove any dust, silt, clay, organic matter, or other impurities that would interfere with the bonding reaction with the cement paste. It is then separated into various sizes by passing the material through a series of screens with different size openings.

Table 2 Classes of aggregate

class	aggregates used	uses
ultra-lightweight	vermiculite ceramic spheres perlite	lightweight concrete which can be sawed or nailed, also for its insulating properties
lightweight	expanded clay shale or slate crushed brick	Used primarily for making lightweight concrete for structures, also used for its insulating properties.
normal weight	crushed limestone sand river gravel crushed recycled concrete	used for normal concrete projects
heavyweight	steel or iron shot steel or iron pellets	used for making high density concrete for shielding against nuclear radiation

The choice of aggregate is determined by the proposed use of the concrete. Normally sand, gravel, and crushed stone are used as aggregates to make concrete. The aggregate should be well-graded to improve packing efficiency and minimize the amount of cement paste needed. Also, this makes the concrete more workable.

CHAPTER 3
METHODOLOGY

3.1 Project identification

The methodologies that I have been followed through finishing this project are as shown below:

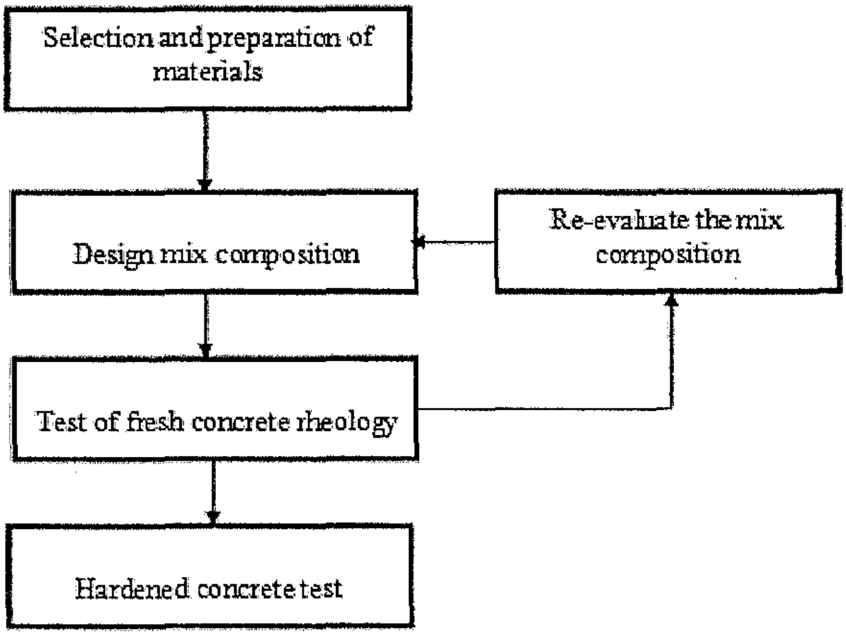

Figure 6 Flow chart of activities

3.1.1 Literature review

Literature review was conducted to expose to the previous studies that has been done on the topic of the project. Literature review is a research based on the journals, publications and also reference books from the library. The idea on how to conduct the project was planned from the knowledge gained from the literature review.

3.1.2 Discussion

Weekly meeting with the supervisor was conducted to ensure that the project is going on the right path. The meetings lead to a better understanding besides in depth researches. Ideas were exchange at the meetings.

3.2 Mix Design Proportion

This project includes six types of mixes in order to achieve the compressive strength of more than 100MPa. Material used are Portland cement, Silica fume, sand as fine aggregates, Crushed Bassalt or Gravel of 20 mm maximum size for crushed aggregates and Superplasticiser. Table below shows each type of mixes that are going to be cast in 3, 7, 28 and 90 days for cubical crushing strength test and porosity observation and as well as for split cylinder test in 28 and 90 days.

Table 3 Mix proportion (Quantities are in kg/m3 of concrete)

Mix Type	OPC	SF	FA	CA	Water	Superplasticiser
M500a	500	50	690	1150	148	15
M500b	500	50	690	1150	148	20
M550a	550	55	670	1120	163	16.5
M550b	550	55	670	1120	163	22
M600a	600	60	650	1090	178	18
M600b	600	60	650	1090	178	24

All mixes shown above are water based of 0.27 fixed. For cubical concrete, its dimension is 150mm^3, 100mm in diameter x 200mm in length for cylinder concrete and 400mm x 200mm x 40mm of plank concrete to be cast in order to achieve compressive strength more than 100MPa.

3.3 Concrete Mixing

The physical properties of density and strength of concrete are determined, in part, by the proportions of the three key ingredients, water, cement, and aggregate. You have your choice of proportioning ingredients by volume or by weight. Proportioning by volume is less accurate, however due to the time constraints of a class time period this may be the preferred method.

A basic mixture of mortar can be made using the volume proportions of 1 water : 2 cement : 3 sand. Most of the student activities can be conducted using this basic mixture. Another "old rule of thumb" for mixing concrete is 1 cement : 2 sand : 3 gravel by volume. Mix the dry ingredients and slowly add water until the concrete is workable. This mixture may need to be modified depending on the aggregate used to provide a concrete of the right workability. The mix should not be too stiff or too sloppy. It is difficult to form good test specimens if it is too stiff. If it is too sloppy, water may separate (bleed) from the mixture [6].

Remember that water is the key ingredient. Too much water results in weak concrete. Too little water results in a concrete that is unworkable.

1. If predetermined quantities are used, the method used to make concrete is to dry blend solids and then slowly add water (with admixtures, if used).

2. It is usual to dissolve admixtures in the mix water before adding it to the concrete. Superplasticizer is an exception.

3. Forms can be made from many materials. Cylindrical forms can be plastic or paper tubes, pipe insulation, cups, etc. The concrete needs to be easily removed from the forms. Pipe insulation from a hardware store was used for lab trials. This foam-like material was easy to work with and is reusable with the addition of tape. The bottom of the forms can be taped, corked, set on glass plates, etc. Small plastic weighing trays or Dairy Queen banana split dishes can be used as forms for boats or canoes.

4. If compression tests are done, it may be of interest to spread universal indicator over the broken face and note any color changes from inside to

outside. You may see a yellowish surface due to carbonation from CO_2 in the atmosphere. The inside may be blue due to calcium hydroxide.

5. To answer the proverbial question, "Is this right?" a slump test may be performed. A slump test involves filling an inverted, bottomless cone with the concrete mixture. A Styrofoam or paper cup with the bottom removed makes a good bottomless cone. Make sure to pack the concrete several times while filling the cone. Carefully remove the cone by lifting it straight upward. Place the cone beside the pile of concrete. The pile should be about 1/2 to 3/4 the height of the cone for a concrete mixture with good workability.

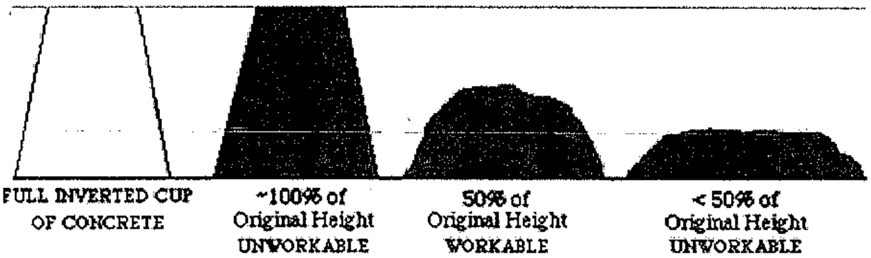

Figure 7 Slump test to determine workability (Kosmatka, Steven H., and Panarese)

6. To strengthen samples and to promote hydration, soak concrete in water (after it is set).

7. Wet sand may carry considerable water, so the amount of mix water should be reduced to compensate.

8. Air bubbles in the molds will become weak points during strength tests. They can be eliminated by:

    - i. packing the concrete.
    - ii. Tapping the sides of the mold while filling the mold.
    - iii. "rodding" the concrete inside the mold with a thin spatula.

9. Special chemicals called "water reducing agents" are used to improve workability at low water to cement ratios and thus produce higher strengths. Most ready-mix companies use these chemicals, which are known

commercially as superplasticizers. They will probably be willing to give you some at no charge.

10. You can buy a bag of cement from your local hardware store. A bag contains 94 lb. (40kg) of cement. Once the bag has been opened, place it inside a garbage bag (or two) that is well sealed from air. This will keep the cement fresh during the semester. An open bag will pick up moisture and the resulting concrete may be weaker. Once cement develops lumps, it must be discarded. The ready mix company in your area may give you cement free of charge in a plastic pail.

3.4 Concrete casting

Fresh concrete will then poured into cube, slab and cylinder. The purpose is to cure the concrete and perform several tests on the concrete. After pouring the fresh concrete in the mould, it will be vibrated in order to prevent from honey comb or void spaces of air in the concrete to exist. This is because honey comb could affect the strength or characteristics of the specimens.

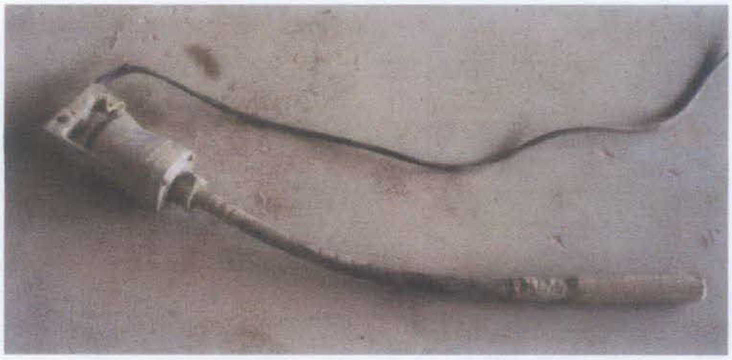

Figure 8 Vibrator

Table 4 Samples of test

Test	Item per mix	Age (day)				Total Sample
		3	7	28	90	
Compression Stress	3	√	√	√	√	12
Porosity	3	√	√	√	√	12
Split Cylinder Test	3			√	√	6

Size of cube and slab are as stated below:

Cube = 150mm x 150mm x 150mm

Slab = 200mm x 300mm x 40mm

Cylinder = 200mm (dia) x 100mm

3.5 Concrete curing

After removal of mould on the second day, the cylinder must be placed inside the curing tank until the day of testing. The purpose of curing is to avoid shrinkage cracking due to temperature fluctuation and also to gain the maximum strength of the concrete.

3.6 Hardened concrete tests

Once concrete has hardened it can be subjected to a wide range of tests to prove its ability to perform as planned or to discover its characteristics if its history is unknown.

For new concrete this usually involves casting specimens from fresh concrete and testing them for various properties as the concrete matures. The 'concrete cube test' is the most familiar test and is used as the standard method of measuring compressive strength for quality control purposes. Concrete beam specimens are cast to test for flexural strength and cast cylinders can be used for tensile strength. Specimens for many other tests can be made at the same time to assess other properties.

3.6.1 Compression test

Comparative performance of hardened concrete is investigated by measuring the development of compressive strength with curing age of 3, 7, 28 and 90. The compressive strength was taken as the maximum compressive load it could carry per unit area.

Figure 9 Compression machine (ADR 1500)

3.6.2 Porosity test

Porosity of concrete is an important factor is classifying its durability. Generally, concrete of a low porosity will afford better protection to reinforcement within it than concrete of high porosity.

There are no vacuum absorption tests in the British Standards, although an earlier version of BS 3921 did contain such a test. There are a number of variations on vacuum absorption in the RILEM tests in which various reduced and soaking times are recommended.

The porosity test for this project is using vacuum saturation method. Vacuum saturation is a method of assessing the total water absorption porosity of a material. Porosity can be determined by measuring its weight gain and expressing this as a percentage of the mass of the sample.

The porosity measurements were conducted on slices of cylinders cores that have been casted into (0.048 x 0.315 x 0.205) m slabs. The cored slices were put inside vacuumed desiccator for 30 minutes, and then the decisssator is filled with water for 6 hours. After 24-hours soaked in water, the samples were dried at 100 ±5°C.

The vacuum saturation porosity, P is calculated from:

$$P = \frac{\text{Volume of water absorbed}}{\text{Volume of sample}} \times 100$$

$$P = \frac{W_{sat} - W_{oven}}{W_{sat} - W_{water}} \times 100$$

Where P is the vacuum saturation porosity (%), W_{sat} the weight in air of saturated sample, W_{water} the weight in water of saturated sample, and W_{dry} the weight of oven-dried sample.

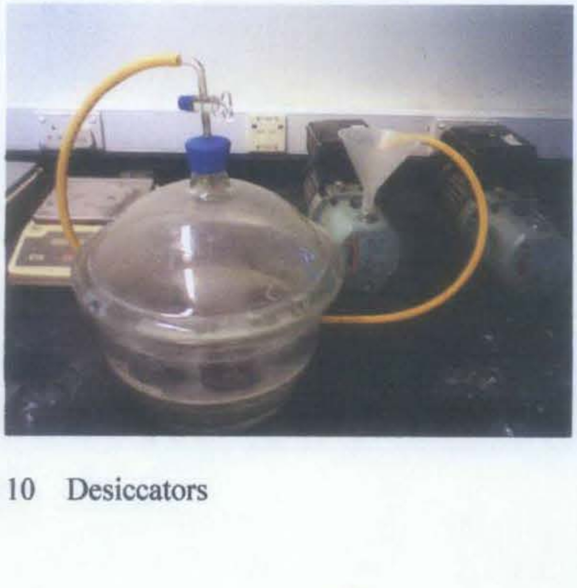

Figure 10 Desiccators

3.6.3 *Split cylinder test*

Comparative performance of hardened concrete is investigated by measuring the development of its split cylinder test with curing age of 3, 7, 28 and 90. This test is similar to the compression test in order to obtain its maximum tensional strength by using the compression machine (ADR 1500). It differs to the compression test by locating the cylinder into its holder then only places it into the machine.

The tensile strength of a material is the maximum amount of tensile stress that it can be subjected to before failure. The definition of failure can vary according to material type and design methodology. This is an important concept in engineering, especially in the fields of material science, mechanical engineering and structural engineering [10].

There are three typical definitions of tensile strength:

- Yield strength: The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently.
- Ultimate strength: The maximum stress a material can withstand.
- Breaking strength: The stress coordinate on the stress-strain curve at the point of rupture.

Figure 11 Cylinder holder

CHAPTER 4

DATA ANALYSIS

4.1 Compressive strength

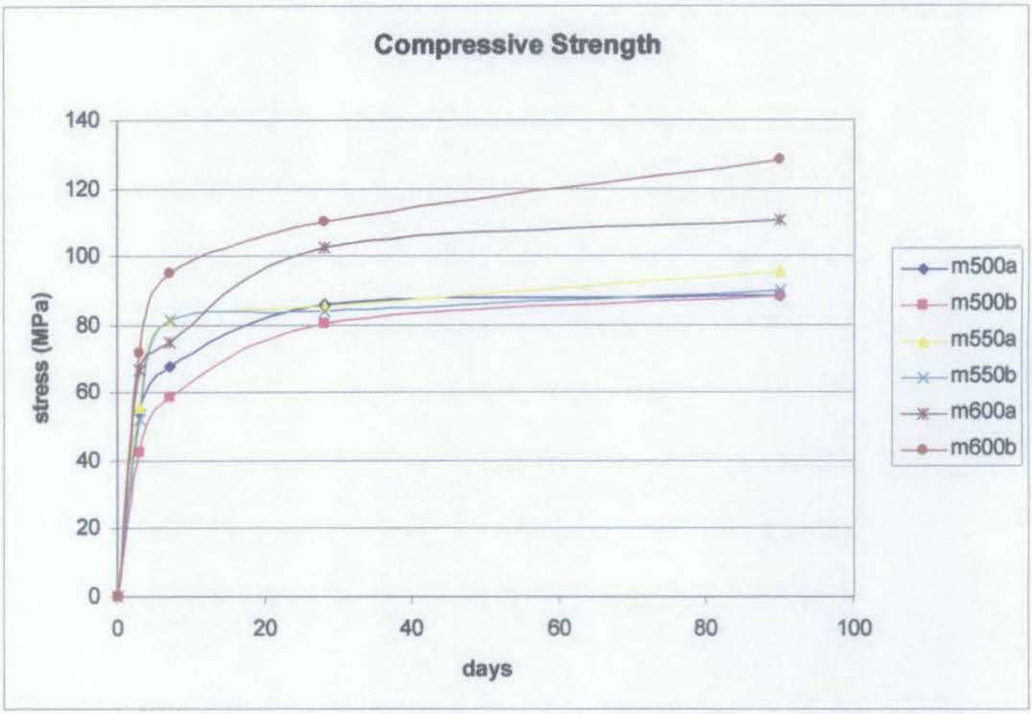

Figure 12 Compressive strength for all mix designs

According to the graph above, all compressive strengths achieved by each mix design from three specimens are maximum values. For mix designs m500a and m500b; 150mm cube mould, 3% and 4% of superplasticiser respectively and 0.27 water cement ratio were used. The compressive strength of these mixes at 90th day was 88.32MPa and 88.41MPa respectively. While the other four mixes use 100mm cube mould, 2.5% and 3% of superplasticiser alternately and 0.25 water cement ratio were used. Thus, these mixes obtained compressive strength of 95.77MPa for m550a, 90.11MPa for m550b, 110.9MPa for m600a and 128.5MPa for m600b which is the highest strength achieved among all mixes at 90th day. For complete table of compressive strength of all mix designs from age 3 to 90 days, refer to Appendix A.

As observed from figure above, between m500a and m500b, m500a obtained higher compressive strength at early age compared to m500b but going towards 90th day, the compressive strength of m500b was getting higher than m500a. Same goes to mix design of m550a and m550b. This pattern occurs due to the percentage of superplasticiser used in each mix designs where the one with higher percentage of superplasticiser would obtain greater strength at early age compared to the lower ones. This is because of having the exact amount of superplasticiser needed to reduce the required mixing water. Besides that, Silica fume also plays an important role in contributing high strength at early age where it consists of very fine vitreous particles approximately 100 times smaller than the average cement particle. Furthermore, improves compressive strength, bond strength, and abrasion resistance. While comparison between mix design m600a and m600b, m600b has greater compressive strength starting at the early age until the 90th day and from the graph pattern, it indicates that its strength is still increasing.

Table 5 Slump for each mix designs

Mix Type	SP (%)	Slump (mm)
M500a	3	130
M500b	4	255
M550a	3	150
M550b	2.5	110
M600a	3	155
M600b	2.5	90

Table above indicates the results of slump test for every mix designs. Since 4% of superplasticiser resulted in 255mm of slump, m500b has the highest workability where its characteristic is as similar to self-compacting concrete. Thus, 4% of superplasticiser was reduced to 2.5%. Hence, m600b has the lowest workability among the other mixes which is 90mm. Although low in workability, m600b achieved the strongest compressive strength as mentioned before.

The use of superplasticizer contributes to producing high strength concrete. Superplasticizer acts as a water reducer that improves the workability with low water to binder content. It performs their function by deflocculating the agglomerations or lumps of cement grains. In the normal stage the surface of cement grains contain a combination of positive and negative chargers. As they are agitated and bump into each other, they repelled to each other if the charger are alike and non-alike respectively. On the other hand, superplasticizer consist of very large molecules (colloidal size), which dissolve in water to give ions with a very high negative chargers (anions). These anions adsorbed on the surface of cement particles in sufficient number to form a complete monolayer around them to become predominantly negatively charged. Thus they repeal each other and flocs in released and can then contribute to the mobility of cement paste and hence to the workability of concrete [11].

Lowest porosity percentage obtained at age of 3 days was 1.424% while at 90th day was 1.189% by mix design of m600b. Refer to Appendix B for complete porosity percentage obtained at each specified day as in Figure 9 for each and every mix design.

4.3 Split Cylinder

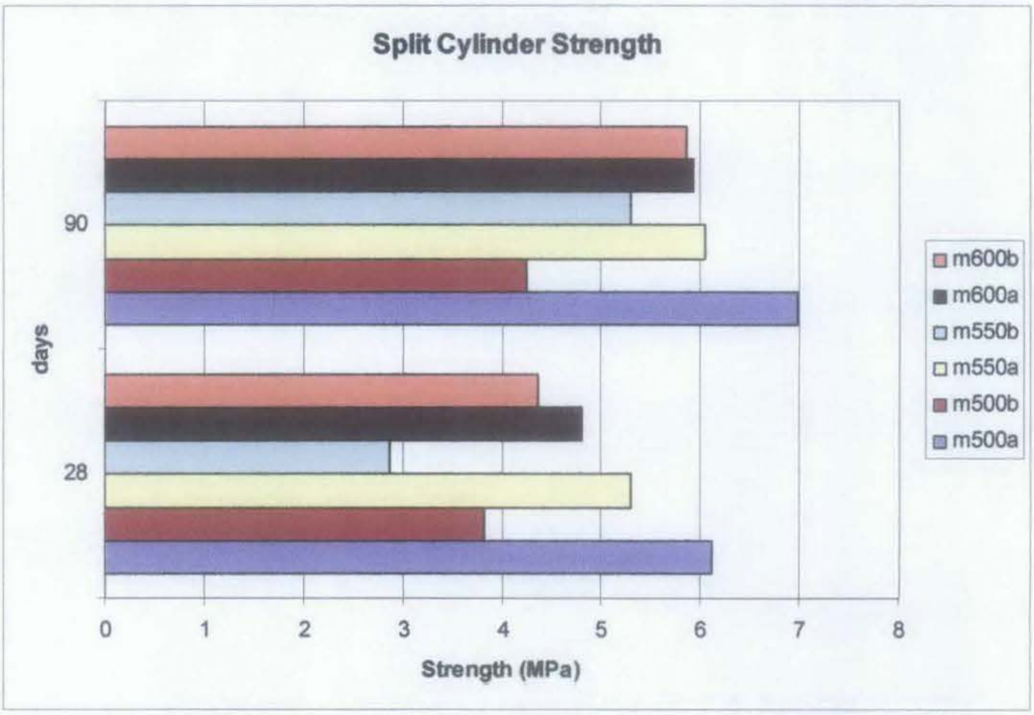

Figure 14 Strength of cylinders obtained from split cylinder test

The strength of cylinders of each mix was measured at 28th and 90th day of age only. The method used was split cylinder test. From Figure 10 above, we observed that all mix designs in category "b" have lower strain compared to category "a" which consists of 3% of superplasticiser. They have higher tensional strength because of obtaining optimum amount of superplasticiser unlike category "b" where they're having too low or too high percentage of superplasticer that made them weak in tensional strength.

Highest tensional strength obtained was made by m500a which is 6.9852MPa at age

4.2 Porosity

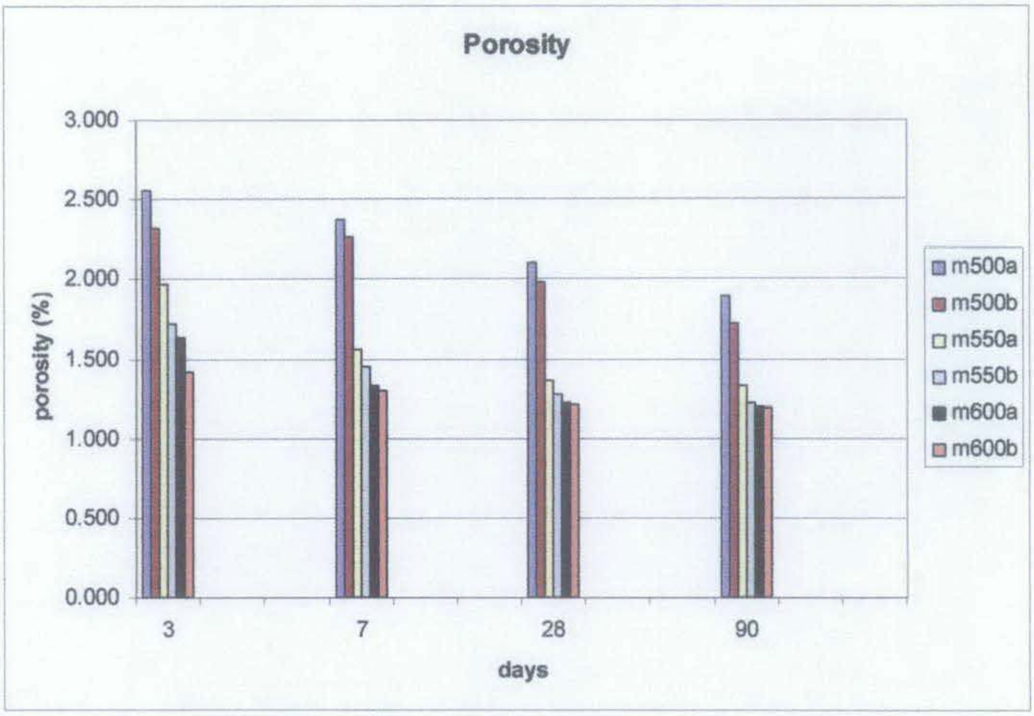

Figure 13 Percentage of porosity for all mix designs

Porosity of each mix was measured at the age 3, 7, 28 and 90 days and the result is shown as in Figure 9 above. Both m500a and m500b have high percentage of porosity which is 2.558% and 2.319% respectively at age of 3 days. As they cured through age of 90 days, their porosity were still decreasing where the porosity are 1.892% and 1.719%. The percentage porosity of other four mixes was still decreasing but they obtained much lower percentage compared to those two mixes. This happens because of the size of mould used for designing the cube which is 150mm cube mould. Due to that, the total volume calculated was a lot, hence more mix proportion needed for mixing as well as water. Since volume of water has increased, therefore during dehydration of specimens, pores or voids were created in between aggregates. Thus leads to higher percentage of porosity and lower in compressive strength.

Unlike the other four mix designs, 100mm cube mould was being used. Since the mould was smaller, the volume was lessening too. Thus, low water volume used, few pores or voids were being created and so higher compressive strength achieved.

90 days with modulus of elasticity (E) of 12.5GPa while the lowest strain is 2.874MPa from mix m550b at 28 days of age with E = 7.019GPa. For all tensional strength and modulus of elasticity of every mix design obtained, refer to Appendix C.

CHAPTER 5
CONCLUSION
&
RECOMMENDATION

5.1 Conclusion

Considering all results in chapter 4, data analysis, each mix design have high strength of compression where until today their strength are still increasing. The highest strength that I have achieved for this experiment is 128.5PMa from m600b at the age of 90th day. These increasing strengths have reached the objective of this paper which is obtaining maximum strength of more than 100MPa. For the lowest porosity obtained is 1.189% also by mix design of m600b while the highest tensional strength is 6.9852MPa with modulus of elasticity of 12.5GPa. As a conclusion, mix design of m600a and m600b which consist of OPC, SF, Fagg, Cagg, SP and Water have already achieved the objective of this experiment at the age of 28 days. Comparing this result with normal concrete where it reaches its maximum strength at age of 28th day, UHSC could obtained higher compressive strength within 28 days.

5.2 Recommendation

Observation made from this experiment is that mixing concrete in high volume for its mixing proportion could affect the characteristics of the hardened concrete. Thus, casting cubes, cylinders and slabs separately would be appropriate in order to obtain more accurate results. Moreover, mixing the mix design according to the flow of mixing concrete is essential where water is to be mix at the most end of the procedure for these mixes. Vibration needs to be done in a short period of time in order to avoid from honey comb because if it takes too long to vibrate, most of its course aggregates will be at the bottom part of the mould and resulted with inaccurate value of testing.

REFERENCES

ACI Committee 226. 1987b. Silica fume in concrete: Preliminary report. ACI Materials Journal March-April: 158-66.

ACI committee 363. State-of-the-art report on high strength concrete. Detroit: American Concrete Institute; 1993.

ACI committee 363. Guide for the use of silica fume in concrete. Detroit: American Concrete Institute; 1994.

Admixtures and ground slag for concrete. 1990. Transportation research circular no. 365 (December). Washington: Transportation Research Board, National Research Council.

Aulia, T. B.: Effects of Polypropylene Fibers on the Properties of High- Strength Concretes. Leipzig Annual Civil Engineering Report No. 7 (2002), pp. 43 - 59.

Aulia, T. B., Deutschmann, K.: Effect of Mechanical Properties of Aggregate on the Ductility of High Performance Concrete. Leipzig Annual Civil Engineering Report No. 4 (1999), pp.133 - 148.

Bye, G. C. Portland Cement: Composition, Production and Properties. Pergamon Press, NY, 1983.

Carette, G. G., and V. M. Malhotra. 1983. Mechanical properties, durability and drying shrinkage of portland cement concrete incorporating silica fume. Cement, Concrete, and Aggregates 5 (1):3-13.

Ceriolo L, Tommaso AD. Fracture mechanics of brittle materials: a history point of view. 2nd Int. PhD Symposium in Civil Engineering. Budapest; 1998.

Dirk Weiße, Jianxin Ma, June 2004, Mechanical Properties of Ultra High Strength Concrete

Klotz, S.; Holschemacher, K.: Teilflächenpressung bei UHFB. In: König, G.; Holschemacher, K.; Dehn, F. (Hrsg.): Ultrahochfester Beton, pp. 215 - 226. Bauwerk Verlag Berlin, 2003.

Ko¨nig G, Dehn F, Faust T. Proceedings of 6th International Symposium on utilization of High Strength & High Performance Concrete, Vol. 1–2, Leipzig; 2002.

Kosmatka, S.H.; Panarese, W.C. (1988). *Design and Control of Concrete Mixtures*. Skokie, IL, USA: Portland Cement Association, pp. 17, 42, 70, 184.

Kosmatka, Steven H., and Panarese, William C. Design and Control of Concrete Mixtures, Thirteenth edition, Portland Cement Association, 1988.

Linsbaueer HN, Tschegg EK. Fracture energy determination of concrete with cube shaped specimens. Zement and Beton 1986;31:38 –40.

Luther, M. D. 1989. Silica fume (microsilica): Production, materials and action in concrete. In Advancements in Concrete Materials Seminar, 18.1-18.21. Peoria, Ill.: Bradley University

Luther, M. D. 1990. High-performance silica fume (microsilica)—Modified cementitious repair materials. 69th annual meeting of the Transportation Research Board, paper no. 890448.

Luther, M. D., and W. Hansen. 1989. Comparison of creep and shrinkage of high-strength silica fume concretes with fly ash concretes of similar strengths. In ACI special publication SP-114. Vol. 1, Fly ash, silica fume, slag and natural pozzolans in concrete. ed. V. M. Malhotra. 573-91. Detroit: American Concrete Institute

Ozyildirim, C. 1986. Investigation of concrete containing condensed silica fume: Final report. Report no. 86-R25 (January). Charlottesville: Virginia Highway & Transportation Research Council.

Pigeon, M., and M. Plante. 1989. Air-void stability part I: Influence of silica fume and other parameters. ACI Journal 86 (5):482-90.

Pigeon, M., P. C. Aitcin, and P. LaPlante. 1987. Comparative study of the air-void stability in a normal and a condensed silica fume field concrete. ACI Journal 84 (3):194-99 (May-June).

Remmel, G.: Zum Zug- und Schubtragverhalten von Bauteilen aus hochfestem Beton. Deutscher Ausschuß für Stahlbeton (German Committee of Reinforced Concrete), No. 444, 1994.

Structural Concrete. Textbook on Behaviour, Design and Performance. Updated knowledge of the CEB/FIP Model Code 1990. Volume 1: Introduction - Design process - Materials. fib-Bulletin No. 1, 1999.

U.S. Federal Highway Administration (2007). Ground Granulated Blast-Furnace Slag, Silica Fume and Fly Ash.

Weiße, D.: Verbundverhalten der Bewehrung in UHFB. In: König, G.; Holschemacher, K.; Dehn, F. (Hrsg.): Ultrahochfester Beton, pp. 199 - 214. Bauwerk Verlag Berlin, 2003.

Wolseifer, J. 1984. Ultra high-strength field placeable concrete with silica fume admixture. Concrete International: Design and Construction 6 (4):25-31 (April).

APPENDIX A

Table A-1 Compressive strength for mix design m500a

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	8.03	8.14	8.07	
3	1107kN	1098kN	1250kN	
	51.3	49.6	54.8	51.90
weight (kg)	8.11	8.12	8.09	
7	1447kN	1552kN	1455kN	
	64.31	67.63	64.66	65.53
weight (kg)	8.08	8.12	8.13	
28	1470kN	1935kN	1734kN	
	65.34	86	77	76.11
weight (kg)	8.1	8.05	8.15	
90	1871kN	1987kN	1843kN	
	83.15	88.32	81.91	84.46

Table A-2 Compressive strength for mix design m500b

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	8.06	8.06	8	
3	957.6kN	906.3kN	823.3kN	
	42.56	40.28	36.59	39.81
weight (kg)	8.1	8.08	8.09	
7	1251kN	1315kN	1279kN	
	55.62	58.46	57.1	57.06
weight (kg)	8.09	8.08	8.04	
28	1813kN	1746kN	1791kN	
	80.59	77.6	80.06	79.42
weight (kg)	8.06	8.05	8.03	
90	1830kN	1990kN	1852	
	81.33	88.41	82.13	83.96

Table A-3 Compressive strength for mix design m550a

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	8.05	8.12	8.13	
3	1156kN	1251kN	1213kN	
	51.96	55.62	53.24	53.61
weight (kg)	8.15	8.14	8.15	
7	1759kN	1826kN	1781kN	
	78.17	81.17	79.15	79.50
weight (kg)	8.11	8.16	8.15	
28	1920kN	1917kN	1871kN	
	85.32	85.18	83.15	84.55
weight (kg)	8.07	8.15	8.13	
90	2001kN	1993kN	2155kN	
	90.03	88.59	95.77	91.46

Table A-4 Compressive strength for mix design m550b

	Maximum Load (kN)/Stress (Mpa)			
days	1	2	3	ave
weight (kg)	2.44	2.39	2.43	2.42
3	506.9kN	519.7kN	457.5kN	
	50.69	51.97	45.75	49.47
weight (kg)	2.45	2.43	2.43	2.44
7	811.8kN	693.3kN	757.2kN	
	81.18	69.33	75.72	75.41
weight (kg)	2.44	2.43	2.43	2.43
28	794.8kN	776.7kN	841.3kN	
	79.48	77.67	84.13	80.43
weight (kg)	2.44	2.52	2.46	2.47
90	884.9kN	901.1kN	888.5kN	
	88.49	90.11	88.5	89.03

Table A-5 Compressive strength for mix design m600a

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	2.55	2.53	2.55	2.54
3	669.4kN	657kN	544.8kN	
	66.94	65.7	54.48	62.37
weight (kg)	2.51	2.52	2.56	2.53
7	694.7kN	750.2kN	669.6kN	
	69.47	75.02	66.96	70.48
weight (kg)	2.55	2.48	2.46	2.50
28	1026kN	1014kN	969kN	
	102.6	101.4	96.9	100.30
weight (kg)	2.55	2.56	2.58	2.56
90	1109kN	1046kN	1034kN	
	110.9	104.6	103.4	106.30

Table A-6 Compressive strength for mix design m600b

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	2.49	2.52	2.55	2.52
3	612.8kN	566.5kN	716.5kN	
	61.28	56.65	71.65	63.19
weight (kg)	2.6	2.54	2.57	2.57
7	949.5kN	743.7kN	722.9kN	
	94.95	74.37	72.29	80.54
weight (kg)	2.56	2.54	2.56	2.55
28	1102kN	1001kN	864.9kN	
	110.2	100.1	86.49	98.93
weight (kg)	2.54	2.54	2.5	2.53
90	1235kN	1285kN	1225kN	
	123.5	128.5	122.5	124.83

APPENDIX B

Table B-1 Porosity of mix design m500a

Weight in water, of saturated and in oven	days	weight (g)			ave	porosity (%)
		1	2	3		
W_{oven}	3	227.7	226.8	221.3	225.27	2.558
W_{water}		89.7	85.8	81.3	85.60	
W_{sat}		231.5	230.4	224.9	228.93	
W_{oven}	7	257.8	264.7	258	260.17	2.370
W_{water}		105.8	109.2	104.1	106.37	
W_{sat}		262.5	267.7	261.5	263.90	
W_{oven}	28	256.3	255.1	253.6	255.00	2.102
W_{water}		105.4	108.4	104.1	105.97	
W_{sat}		259.7	258.2	256.7	258.20	
W_{oven}	90	230.9	224.7	230.4	228.67	1.892
W_{water}		91.7	90.9	104.1	95.57	
W_{sat}		233.1	227.6	233	231.23	

Table B-2 Porosity of mix design m500b

Weight in water, of saturated and in oven	days	weight (g)			ave	porosity (%)
		1	2	3		
W_{oven}	3	272.5	266.1	265.5	268.03	2.319
W_{water}		119.6	114.6	115	116.40	
W_{sat}		277.3	269.6	268	271.63	
W_{oven}	7	278.9	286.1	279.6	281.53	2.261
W_{water}		117.6	123.9	119	120.17	
W_{sat}		283.8	290	282	285.27	
W_{oven}	28	258.6	259.4	251	256.33	1.983
W_{water}		110.9	111.9	106.3	109.7	
W_{sat}		261.9	262.3	253.7	259.3	
W_{oven}	90	256.6	258.6	268.6	261.27	1.719
W_{water}		117.6	118.4	118.9	118.3	
W_{sat}		260	261	270.3	263.7667	

Table B-3 Porosity of mix design m550a

Weight in water, of saturated and in oven	days	weight (g)			ave	porosity (%)
		1	2	3		
W_{oven}	3	281.2	277	273.8	277.33	1.972
W_{water}		118	119.5	112.4	116.63	
W_{sat}		283.5	281.3	276.9	280.57	
W_{oven}	7	291.4	287.5	277.9	285.6	1.555
W_{water}		129.6	129	123.3	127.3	
W_{sat}		293.8	290.5	280	288.10	
W_{oven}	28	304.9	301.9	301.6	302.80	1.363
W_{water}		133.9	130.7	129.9	131.50	
W_{sat}		307	304.6	303.9	305.17	
W_{oven}	90	283	293.7	287.2	287.97	1.328
W_{water}		125.8	125	122.7	124.5	
W_{sat}		285.1	296	289.4	290.17	

Table B-4 Porosity of mix design m550b

Weight in water, of saturated and in oven	days	weight (g)			ave	porosity (%)
		1	2	3		
W_{oven}	3	233.4	231.1	236.7	233.73	1.723
W_{water}		123.1	119.4	122.2	121.57	
W_{sat}		235.1	233.9	238.1	235.70	
W_{oven}	7	224.8	238.6	233.2	232.20	1.450
W_{water}		100.5	94.9	93.5	96.30	
W_{sat}		226.8	240.7	235.1	234.20	
W_{oven}	28	254.5	245.6	231.5	243.87	1.278
W_{water}		149.8	147	133.5	143.43	
W_{sat}		257.9	249.9	227.7	245.17	
W_{oven}	90	226.2	232.8	229.4	229.47	1.228
W_{water}		91.8	94.3	92.2	92.77	
W_{sat}		228	234.1	231.4	231.17	

Table B-5 Porosity of mix design m600a

Weight in water, of saturated and in oven	days	weight (g)			ave	porosity (%)
		1	2	3		
W_{oven}	3	259.6	256.6	263.2	259.8	1.630
W_{water}		112	106.2	108.6	108.9	
W_{sat}		261.2	258.9	266.8	262.3	
W_{oven}	7	262.4	266.6	264.8	264.6	1.334
W_{water}		147	151.3	148	148.8	
W_{sat}		263.9	269.4	265.2	266.2	
W_{oven}	28	276.9	263.7	270	270.2	1.219
W_{water}		162.5	155	112.3	143.3	
W_{sat}		278.2	264.5	272.6	271.8	
W_{oven}	90	279.2	277	287.8	281.33	1.198
W_{water}		121.2	118.5	117.9	119.2	
W_{sat}		281.1	279.2	289.6	283.30	

Table B-6 Porosity of mix design m600b

Weight in water, of saturated and in oven	days	weight (g)			ave	porosity (%)
		1	2	3		
W_{oven}	3	222.6	224	224.1	223.6	1.424
W_{water}		91.8	91.1	93.2	92.0	
W_{sat}		224.1	226	226.3	225.5	
W_{oven}	7	248.8	259.7	251	253.2	1.303
W_{water}		105.1	113	102.1	106.7	
W_{sat}		250.9	261.4	253	255.1	
W_{oven}	28	277.6	272.6	278.8	276.3	1.209
W_{water}		160.3	162.3	163.2	161.9	
W_{sat}		279	273.9	280.3	277.7	
W_{oven}	90	266.4	263.5	271.6	267.17	1.189
W_{water}		115.9	114.4	114.1	114.8	
W_{sat}		268.2	265.6	273.2	269.00	

APPENDIX C

Table C-1 Strain and modulus of elasticity of m500a

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	3.89	3.82	3.88	3.86
28	192.4kN	162kN	174.5kN	
	6.1227	5.1553	5.5531	5.61
E=modulus of elasticity (GPa)	11.704	10.74	11.146	11.20
weight (kg)	3.91	3.84	3.84	3.86
90	181kN	219.5kN	201.9kN	
	5.763	6.9852	6.4251	6.39
E=modulus of elasticity (GPa)	11.35	12.501	11.99	11.95

Table C-2 Strain and modulus of elasticity of m500b

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	3.81	3.81	3.84	3.82
28	120.3kN	118kN	119.2kN	
	3.828	3.7551	3.7869	3.79
E=modulus of elasticity (GPa)	9.254	9.166	9.205	9.21
weight (kg)	3.88	3.87	3.82	3.86
90	113kN	132.4	133.2	
	3.596	4.2134	4.2388	4.02
E=modulus of elasticity (GPa)	8.97	9.71	9.74	9.47

Table C-3 Strain and modulus of elasticity of m550a

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	3.85	3.9	3.84	3.86
28	135.4kN	166.4kN	157.3kN	
	4.3088	5.2953	5.0058	4.87
E=modulus of elasticity (GPa)	9.818	10.884	10.583	10.43
weight (kg)	3.82	3.85	3.84	3.84
90	189.9kN	189.6kN	172.3kN	
	6.0432	6.0336	5.5117	5.86
E=modulus of elasticity (GPa)	11.63	11.618	11.105	11.45

Table C-4 Strain and modulus of elasticity of m550b

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	3.81	3.81	3.94	3.85
28	69.2kN	77.3kN	90.3kN	
	2.202	2.46	2.874	2.51
E=modulus of elasticity (GPa)	7.019	7.419	8.019	7.49
weight (kg)	3.81	3.83	3.83	3.82
90	117.2kN	165.1kN	166.6kN	
	3.729	5.255	5.3027	4.76
E=modulus of elasticity (GPa)	9.134	10.843	10.89	10.29

Table C-5 Strain and modulus of elasticity of m600a

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	3.85	3.85	3.85	3.85
28	151.1kN	136.8kN	114.5kN	
	4.809	4.355	3.644	4.27
E=modulus of elasticity (GPa)	10.372	9.871	9.03	9.76
weight (kg)	3.88	3.86	3.87	3.87
90	135.8kN	186.4kN	178.6kN	
	4.323	5.934	5.685	5.31
E=modulus of elasticity (GPa)	9.835	11.522	11.28	10.88

Table C-6 Strain and modulus of elasticity of m600b

	Maximum Load (kN)/Stress (MPa)			
days	1	2	3	ave
weight (kg)	3.86	3.86	3.84	3.85
28	137.2kN	91.8kN	104.6kN	
	4.367	2.922	3.328	3.54
E=modulus of elasticity (GPa)	9.884	8.085	8.63	8.87
weight (kg)	3.92	3.83	3.87	3.87
90	165kN	186.3kN	184kN	
	5.251	5.86	5.858	5.66
E=modulus of elasticity (GPa)	10.839	11.45	11.45	11.25