Behavior of High Strength Concrete Containing Rice Husk Ash (RHA) and Superplasticizer

By

Mohd Zulhairi Bin Sobri

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

JANUARY 2008

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Behavior of High Strength Concrete Containing Rice Husk Ash (RHA) and Superplasticizer

by

Mohd Zulhairi Sobri

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons)
(Civil Engineering)

Approved:

____
Assoc. Prof. Dr. Nasir Syafiq,
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 acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD ZULHAIRI BIN SOBRI

ABSTRACT

Rice-husk is a waste product that cause pollution and disposal problem. Rice-husk ash however has been acknowledged as a natural pozzolan that can contribute in concrete industry with its high silica contain and easily obtained with very low cost. This paper presents the results of an experimental investigation regarding the effect of microwave incinerated rice-husk ash (MIRHA) into the mix of high strength concrete, in which the source of rice-husk is from BERNAS rice paddy milling industry in Malaysia. Five trial mix proportion containing MIRHA were design and cast into cubes, cylinders and slabs in the laboratory and the strength development of the hardened concrete investigated. From the observation, MIRHA accelerate the hydration process and provide the cube with high compressive strength capability at early age (i.e 3 day). This is due to high silica contain in the MIRHA which is proved by the XRD test at SIRIM facilities. The investigation showed that it is possible to cast concrete with strength above 70MPa by using locally available rice-husk. It can be concluded that MIRHA provides high compressive strength at early age and the contribution of MIRHA is similar to silica fume.

ACKNOWLEDGEMENTS

First and foremost, thanks to Allah SWT for this opportunity and guidance through every moment of this Final Year Project (FYP). His blessing made all complicated things possible.

The author would like to grab this chance to show much appreciation to Assoc. Prof. Dr. Nasir Syafiq, for his endless support and guidance in assisting the author throughout this study. All his knowledge, advice and encouragement have given the author so much energy and desire to complete this study. It has been such honor for author to learn and work under his supervision as his wide experiences in this field.

A special credit is owed to Ms. Salmia Beddu for being such a dedicated and supportive and very helping co-supervisor who works with the author as a team. Since the beginning she shows her kindness and great attitude by her willingness to sacrifice her precious time assisting and guiding through the project until the author finally ended it successfully.

The author also would like to express so much gratitude to all laboratory assistances, Mr. Johan, Mr. Meow and Mrs. Norhayama for their help in monitoring and assisting the author for completion of this project study.

Last but not least, the author wishes to extend his thanks to family and friends especially to Mr. Sobri Taib and Mrs. Norma Ariffin for their help, encouragement and never-ending moral support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ave	average
Cagg	Course aggregates
Fagg	Fine aggregates
HSC	High Strength Concrete
MIRHA	Microwave Incinerated Rice-husk Ash
NSC	Normal Strength Concrete
OPC	Ordinary Portland Cement
RHA	Rice-husk Ash
SCC	Self-Compacting Concrete
SF	Silica Fume
SP	Superplasticizer
UHSC	Ultra High Strength Concrete

CHAPTER 1

INTRODUCTION

1.1 Background Study

Concrete with compressive strength higher than 50MPa are usually defined as high-strength concrete (HSC), according to ACI Committee. The potential advantages of HSC extend beyond strength to include improvement in durability and service life of concrete structures.

Recently, the diversification of structures emphasized the interest of the workability and durability of concrete resulting from the growing necessity to provide high performance concrete exhibiting high strength and high durability.

Representative admixture that has been developed to date is fly ash, silica fume, blast furnace slag and rice husk ash. In most cases, concrete containing these materials with pozzolanic or latent hydraulic characteristics have mechanical properties and durability superior to that OPC concrete. Fly RHA were identified for the 73-SBC RILEM Committee as the principal by-products that possess pozzolanic and/or cementitious properties. It has been recognized that pozzolanic additions lead to important changes in fresh and hardened concrete

1.2 Problem Statement

Civil structures today such as building are design higher and stronger compare to previous years. Simultaneously the construction cost becomes higher. There is a need for a study to develop a high-strength concrete proportion/mixture yet is cost effective. Lower water to cement ration (w/c) and higher content of binder are needed to produce HSC. Consequently, high range water-reducing admixtures are used to achieve the required workability.

Over a year, there were thousands of tonnes of agricultural by product produces such as rice-husk ash. The study of their characteristic and possible application becomes a priority as their use brings benefit in technical, economic power and environmental terms.

1.3 Objectives

The objectives to be achieved in the study are:

i. To determine the optimum mix proportions for the HSC contain RHA and superplasticizer as the admixture.
ii. To investigate the effect of high strength concrete containing rice husk ash (RHA) and superplasticizer in fresh and hardened condition.
iii. To determine the compressive strength, porosity, split cylinder and slump of the design mix in the range at 3, 7, 28, and 90 days

1.4 Scope of Study

The scope of work includes preparing the materials for the mixture, casting the concrete, curing and testing procedure. Finally the result will be analyzed.

Materials for mixing:

Materials especially aggregates strongly influence concrete's freshly mix and hardened properties, mixture proportions and economy. Consequently, selection and preparation of materials is an important process in casting concrete.

The materials are:

i. Ordinary Portland cement, OPC
ii. Rice husk ash, RHA
iii. Coarse aggregates
iv. Fine aggregates
v. Superlasticizer
vi. Water

Mixing and Casting

Mixing is process which mixes all the materials that has been prepared according to proper procedure. The procedure of mixing is discussed in Chapter 3. Casting will involve process in placing the fresh concrete into it's' mould. There are three kinds of mould that would be used in this study that is cube mould, cylinder mould and slab mould.

Curing

Curing is the process of keeping concrete under a specific environmental condition until hydration is relatively complete. After removal of concrete from its mould on the next day, the concrete cube, cylinder and slab must places inside a curing tank until the desired period of curing is achieved before the testing procedure take place. The purpose of curing is to avoid shrinkage cracking due to temperature fluctuation and also to gain the maximum strength of the concrete.

Testing for the concrete:

Upon completing the curing process, the concrete cube, cylinder and slab will be test for their properties. With regard of this study, the tests involve are:

i. Slump test*
ii. Compression strength
iii. Split cylinder test

*Slump test does not need curing. It should be done on fresh concrete.

Analyzing

Analyzing would take place

This is the next step after finishing the entire tests for the hardened concrete. The parameters that will be included during the analysis are the concrete behavior with the admixtures, its rheology and the cost. Eventually, the result from the analysis should conclude to the objective of the study that has been described previously.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concretes with compressive strength higher than 50 MPa are usually defined as high-strength concrete (HSC), according ACI Committee 363 . The potential advantages
of HSC extend beyond strength to include improvements in durability and service life of concrete structures. High-strength concretes (HSC) are characterized by a low porosity and show an internal structure more uniform at the matrix–aggregate interface than normal strength concretes (NSC). Strong interfaces enhance the strength and stiffness, although such concrete usually shows more brittle behavior.

In this study, it is required to use rice-husk ash and superplasticizer as natural and chemical admixtures in order to gain the high strength concrete. Investigating the behavior of the concrete also included in the study.

2.2 Rice Husk Ash (RHA)

Over the past years, there has been an increase in the use of industrial, agricultural and thermoelectric plant residues in the production of concrete. Different materials with pozzolanic properties such as fly ash, condensed silica fume, blast-furnace slag and rice-husk ash have played an important part in the production of high-performance concrete. Thousands of tonnes of these residues and industrial byproducts are produced every year; therefore, the study of their characteristics and possible applications becomes a priority as their use brings benefits in technical, economic, power and environmental terms (Malhotra *et. al.* 1996).

Among the different existing residues and by-products, the possibility of using rice-husk ash (RHA) has attracted more attention of cement researchers than other crop residues. First, due to the overabundance of this residue, 100 million tonnes of husk are obtained from an annual world production of 500 million tonnes of rice, a huge quantity of residue that can only be consumed by the cement and concrete industries that use a wide range of by-products. Mehta *et. al.* (1992) in his study said that, rice-husk is not appropriate as feed for animals due to its few nutritional properties and its irregular abrasive surface is resistant to natural degradation, which poses serious accumulation problems. When it is incinerated, it produces a great quantity of ash. On average, each tonne of rice-husks, on complete combustion, produce 200 kg of RHA. No other crop residue generates a greater quantity of ash when it is burnt according to Bharatkumar (2005). Thirdly, the use of RHA as a supplementary cementing material is of great interest to many developing countries where portland cement is in short supply but rice production is in abundance.

Fly ash, iron blast-furnace slag, condensed silica fume and RHA were identified for the 73-SBC RILEM Committee as the principal by-products that possess pozzolanic and/or cementitious properties. It has been recognized that pozzolanic additions lead to important changes in fresh and hardened concrete, which depend on the mineral admixture type and content as well as on other mix components.

Pozzolanic additions reduce the porosity of concrete especially at the interfaces between cement paste and aggregates, which are the weakest zones of the material. The improvements produced by the mineral additions can modify the failure mechanism in concrete.
Recently, a study on the fracture characteristics of high performance concrete was performed concluding that there is a reduction in the fracture energy due to the addition of fly ash and slag, attributed to the presence of unhydrated

particles of size larger than that of normal flaws in concrete as reported by Bharatkumar (2005). However, in this case mineral additions were included replacing 25% or 50% of the cement, and then a reduction in strength was also measured. That is not necessarily the situation when highly effective mineral additions such as silica fume replace part of the cement (usually no more than 10%).

The development and use of rice-husk ash (RHA) is not new. There is a lot of researcher working on it as Mehta (1992) studied on supplementary cementing material and Aminul *et. al.* (2007) reported on concrete with mineral admixture and RHA. Rice-husk ash is a mineral admixture for concrete, and much data has been published concerning its influence on the behavior of concrete. Results for concretes with a 10% substitution of portland cement by RHA indicate excellent performance when compared to control concretes. However, none of these studies investigated the effects of RHA on the failure mechanism of normal and high-strength concrete, including its influence on strength, stiffness, and fracture energy. As RHA is not commonly used in the production of HSC, this study is a contribution toward that goal. Specimens produced from several RHA concretes of differing water/binder ratios are tested in flexure and uniaxial compression. Analyses are made of the specimens' response to these load conditions, with particular interest in the fracture properties of the material.

2.3 Super Plasticizer

Superplasticizer is chemical admixtures that can be added to concrete mixtures to improve workability. Strength of concrete is inversely proportional to the amount of water added or water-cement (w/c) ratio. In order to produce stronger concrete, less water added, which makes the concrete mixture very much unworkable and difficult to mix, necessitating the use of plasticizers and superplastcizers.

Superplastcizers are also often used when pozzolanic ash is added to concrete improve strength. This method of mix proportioning is especially popular when producing high strength concrete and fiber reinforced concrete.

Ding (2003) in his journal said that adding 2% superplasticizer per unit weight of cement is usually sufficient. However, note that most commercially available superplastcizers come dissolved in water, so the extra water added has to be accounted for in mix proportioning. Adding an excessive amount of superplastcizers will result in excessive segregation of concrete and is not advisable. Some studies also show that too much superplasticizer will result in a retarding effect

Superplasticizer is commonly manufactured from lignosulfonates, a by-product from the paper industry. Superplasticizer have generally been manufactured from sulfonated naphthalene formaldehyde or sulfonated melamine formaldehyde, although new generation products based on polycarboxylic ethers are now available. Traditional superplastcizers disperse the flocculated cement particles through a mechanism of electrostatic repulsion. In normal plasticizers, the active substances are adsorbed on to the cement particles, giving them a negative charge, which leads to repulsion between particles. Napthalene and melamine superplastcizers are organic polymers. The long molecules wrap themselves around the cement particles, giving them a highly negative charge so that the repel each other.

According to Kirby *et. al.* (2002), Polycarboxylate Ethers (PCE), the new generation of superplastcizers is not only chemically different to the older sulphonated melamine and naphthalene based products but their action mechanism is also different, giving cement dispersion is more powerful in its effect and gives improved workability retention to the cementationous mix. Furthermore, the chemical structure of PCE allows for a greater degree of chemical modification than the older generation products, offering range of performance that can be tailored to meet specific needs.

Table 2.1: History of Superplasticizer development

Year	Chemical Base	Generation	Water Reduction
1930	Ligno-sulphonates, Gluconates	1st	10%
1970	Sulphonated Malamine/Napthalin polymers	2nd	20%
1990	Vinyl-copolymers	3rd	30%
2000	Modified Polycarboxylates	4th	40%

2.4 Aggregate

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories; fine and coarse.

Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch (9.5-mm) sieve. Coarse aggregates are any particles greater than 0.19 inch (4.75 mm), but generally range between 3/8 and 1.5 inches (9.5 mm to 37.5 mm) in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder. Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed. Crushed aggregate is produced by crushing quarry rock, boulders, cobbles, or large-size gravel.

Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered when selecting aggregate include; grading, durability, particle shape and surface texture, abrasion and skid resistance, unit weights and voids, absorption and surface moisture.

Particle shape and surface texture of aggregates influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio. Generally, flat and elongated particles are avoided or are limited to about 15 percent by weight of the total aggregate. Unit-weight measures the volume that graded aggregate and the voids between them will occupy in concrete. The void content between particles affects the amount of cement paste required for the mix. Angular aggregate increases the void content. Larger sizes of well-graded aggregate and improved grading decrease the void content. Absorption and surface moisture of aggregate are measured when selecting aggregate because the internal structure of aggregate is made up of solid material and voids that may or may not contain water. The amount of water in the concrete mixture must be adjusted to include the moisture conditions of the aggregate. Abrasion and skid resistance of an aggregate are essential when the aggregate is to be used in concrete constantly subject to abrasion as in heavy-duty floors or pavements. Different minerals in the aggregate wear and polish at different rates. Harder aggregate can be selected in highly abrasive conditions to minimize wear.

Flakey is the term applied to aggregate or chippings that are flat and thin with respect to their length or width. Aggregate particles are said to be flakey when their thickness is less than 0.6 of their mean size. This is done by grading the size fractions, obtained from a normal grading aggregate, in special sieves for testing flakiness. These sieves have elongated rather than square apertures and will allow aggregate particles to pass that have a dimension less than the normal specified size, i.e. 0.6 of the normal size. Well graded means that within a material that is well graded there is a good distribution of all the aggregate sizes from largest to smallest, coarse aggregate to ''dust''. With a well graded material all the different size aggregate particles will position themselves within the total matrix in such a way to produce a tightly knit layer of maximum possible density, when compacted correctly. Segregation is separation of particular aggregate sizes, usually the larger sizes, is much more likely to occur in a poorly graded material. Segregation leaves laid areas with too many fines, or areas that are "open" due to patches of coarse material.

2.5 Water

The key to achieving a strong, durable concrete rests in the careful proportioning and mixing of the 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 an excess of cement paste will be easy to place and will produce 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.

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. 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.

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.

CHAPTER 3

METHODOLOY

3.1 Project Process Flow

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

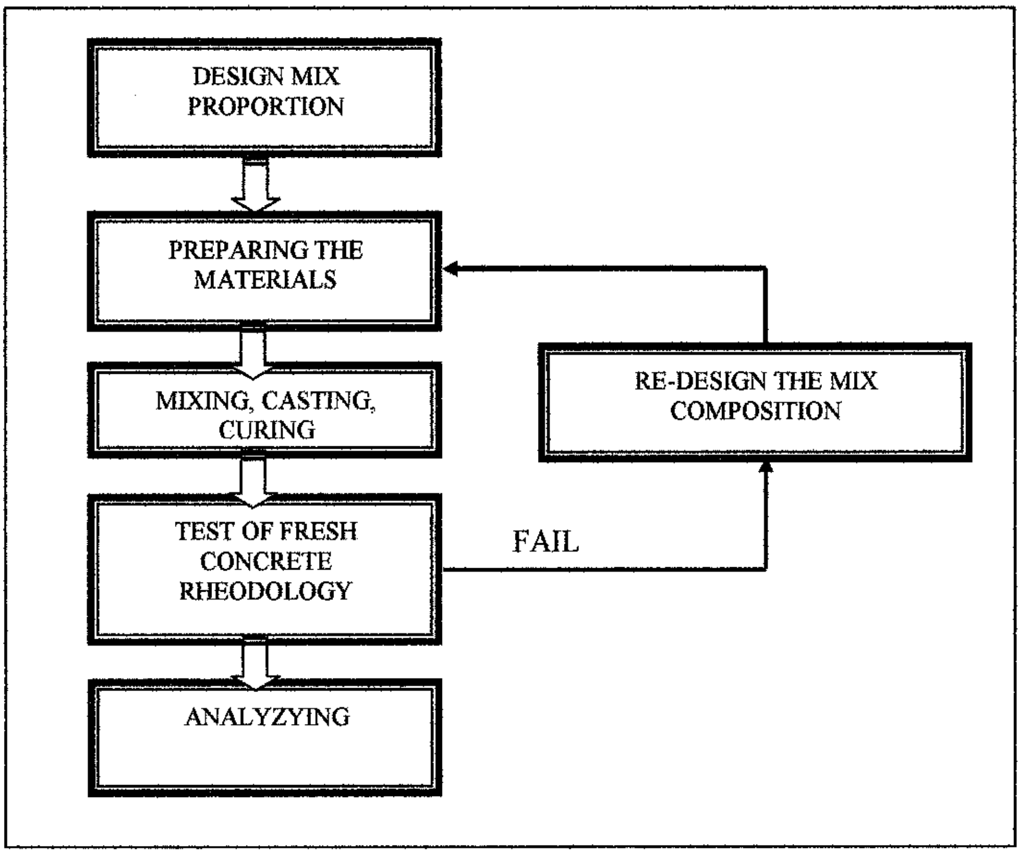


Figure 3.1 Flow chart of activities

3.2 Mix Design Proportion

In order to complete this project, lab work must be conducted to experiment the best proportion of the mix to obtain the optimum mix proportion and water to cement ratio. The mix must be ensured that it contains the admixtures, super plasticizer and RHA that is the parameters to be monitored. The mix proportion is very important because it determines the strength of the concrete. The optimum proportion will be concluded from the result obtained from lab work/test.

This project includes six types of mixes in order to achieve the compressive strength of more than 50MPa. Material used are Ordinary Portland cement (OPC), sand as fine aggregates, Crushed Basalt or Gravel of 20 mm maximum size for crushed aggregates, Superplasticizer and RHA. 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 3.1: Mix design proportion for overall laboratory work

Mix Type	OPC	CA	FA	w/c	RHA (%)	SP (%)
M500a	500	1150	690	0.3	10	3
M500b	500	1150	690	0.3	10	4
M550a	550	1120	670	0.3	10	3
M550b	550	1120	670	0.3	10	4
M600a	600	1090	650	0.3	10	3
M600b	600	1090	650	0.3	10	4

All units are in kg/m^3

3.3 Material Preparation

Before proceed with the mixing process, all materials should be prepared according to the proper procedure. It is to make sure that the raw materials are ready is important and it must be done days before the mix to avoid error during the mi

3.3.1 Ordinary Portland cement

Cement is a powder, which by hydraulic reaction (i.e. with water) forms a solid, cohesive mass. Ordinary Portland Cement (OPC), which is the standard, grey cement used for most purposes. Ordinary Portland cement sets by hydraulic (i.e. water) reaction. It is a complex mixture of components, probably the most important of which are dicalcium and tricalcium silicates (C_2S and C_3S to cement chemists). Besides that it also contains tricalcium silicate and tetracalcium aluminoferrite. The water/cement ratio is of paramount importance to the final set strength of the concrete, and the cement/aggregate ratio and aggregate size distribution are also important.

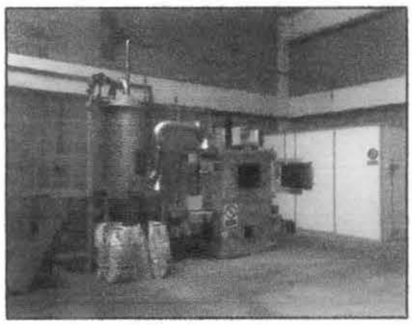
3.3.2 Aggregate preparation

Preparation of the aggregates take 2 days as we need to sieve the aggregates, soak it in the water and let it dry for one day at the room temperature. Sieve analysis need to be conducted to ensure that all sizes of the aggregates are being graded well. This is because we need to do the mix based on the different weight of the aggregates according to the sizes. The aggregates sizes that we sieve vary from less than 3.35mm to more than 20mm. The sieve sizes that we use are 20mm, 14mm, 10mm, 5mm and 3.35mm. The grading will be from 3.35mm-5mm, 5mm-10mm, 10mm-14mm and 14mm-20mm. The retained aggregate at each sieve will be separated according to the grade and aggregate that retained on the last pan will be considered as fine aggregates because the size is less than 3.35mm. After conducting sieve analysis, the aggregates need to be soaked in the water for 24 hours. The purpose is to remove dirt at the surface of the aggregates that might disturb the strength or proportion of the concrete and as well ensured that the aggregates are fully saturated. Then the aggregates must be dried for one day at room temperature. The purpose is to obtain the saturated surface dry aggregates. This is to ensure that the aggregates will not absorb water during the mix. If the aggregates are too dry, they can absorb the water content during the mix and this will lead to lack of water in the mix and will disturb the flowability of the concrete. Water content is the most important aspect to be taken into consideration during the mix. Lack or too much of water content will fail the self compacting concrete.

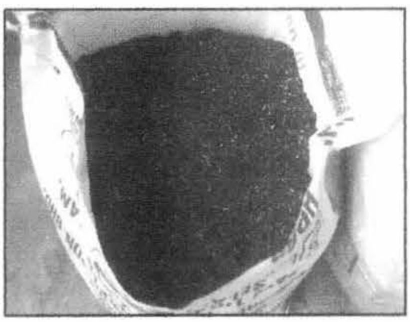
3.3.3 Preparation of RHA

RHA will be burn and grind before used as additive in the mixing (see Figure 3.2). RHA burned so that we can get the ash of it which is free from activated carbon. It will be grind so that we can get the finer RHA. The final process before use the RHA in the mixing is sieving the grinded RHA until it pass through 180μm pan size.

Rice-husk



Incinerator



Rice-husk ash

Grinding machine

Figure 3.2: Process to gain Rice Husk Ash

3.4 Concrete Mixing

All concrete should be mix thoroughly until it is uniform. The sequence of concrete mix is very important and it must be followed accordingly. The procedure of concrete mix incorporating with MIRHA is shown below:

1. Pour all coarse and fine aggregates into the mixer and mix for 25 seconds to ensure uniform distribution between both materials.
2. Pour half of the water and mix for 1 minute.
3. Leave the mixes for 8 minutes to let both coarse and fine aggregates to absorb water.
4. Pour all Portland cement into the mixer and mix for 1 minute.
5. Pour another half of the water and add MIRHA and mix for 3 minutes.
6. Finally perform hand mixing until the mix is in uniform stage.

3.5 Concrete Casting

Fresh concrete will then poured into cube, cylinder and slab. The purpose is to cure the concrete and perform several tests on the concrete.

Table 3.2: Sample of test

Test	Item per mix	Age (day)				Total Sample
		1	3	7	28	
Compression Stress	3			√	√	18
Porosity	3	√	√	√	√	12

Size of cube and slab are as stated below:

Cube = 100mm x 100mm x 100mm

Slab = 250mm x 360mm x 60mm

Cylinder = 100mm x 200mm

3.6 Concrete Curing

Curing the concrete aids the chemical reaction called hydration. Most freshly mixed concrete contains considerably more water than is required for complete hydration of the cement; however, any appreciable loss of water by evaporation or otherwise will delay or prevent hydration. If temperatures are favorable, hydration is relatively rapid the first few days after concrete is placed; retaining water during this period is important. Good curing means evaporation should be prevented or reduced.

3.7 Concrete Testing

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, such as drying shrinkage, thermal coefficient, modulus of elasticity.

3.7.1 Fresh Concrete Test

Slump test is a measurement of the workability or fluidity of the concrete. The slump of the fresh concrete was tested once the mixing was completed. It was carried out conforming to BS 1881: Part 102:1983.

3.7.2 Hardened Concrete Test

Compressive Strength Test

Comparative performance of hardened concrete is investigated by measuring the development of compressive strength with curing age of 1, 3, 7, and 28. The compressive strength was taken as the maximum compressive load it could carry per unit area. Concrete cubes of 150x150x150 mm were cast, cured and tested for each mixes at ages 3,7, and 28 days. Compressive strength test were carried out according to BS 1881: Part 116, 1983 whereby the concrete cubes was then compressed between two parallel faces. The compressive strength of each mixture was obtained by calculating the average of three specimen's strengths. The stress at failure is taken to be the compressive strength of the concrete. The specimens were tested by using Universal Hydraulic Testing machine with a maximum capacity 2000 kN. During the test, concrete cube was loaded with 6.8 KN/s constant loads without any sudden shock loads.

Figure 3.3 : Compression machine (ADR 1500)

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 cast into (0.048 x 0.315 x 0.205) m slabs. The cored slices were put inside vacuumed desiccators for 30 minutes, and then the desiccator 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:

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

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

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.

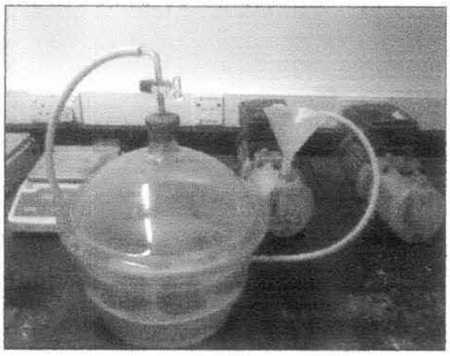


Figure 3.4: Vacuum desiccators

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.

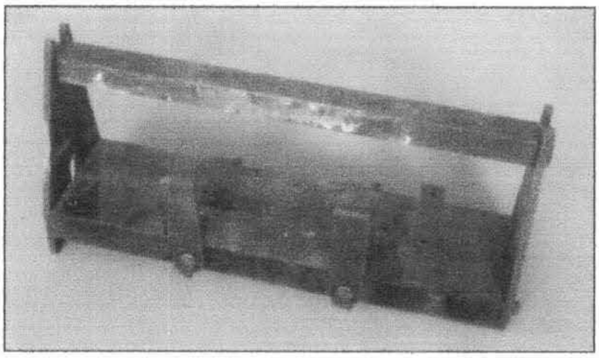


Figure 3.5: Cylinder holder

3.8 Analyzing

The result and data from all tests that has been made should be recorded for the investigation. The information regarding the materials including the cost also included. Data from tests should be plotted in graph or other method that can ease the analyzing process. The concrete behavior need to be investigated thoroughly to find the maximum strength with optimum mix proportion. The result from this stage will be summarized as the final outcome from this project.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

From the experimental program that has been carried out, fresh and hardened concrete was investigated. In this study, slump test was conducted to measure the workability of concrete in fresh state. Hardened concrete measured by conducting compressive strength test, split cylinder test and porosity test. It was very important to investigate all these properties in order to determine the performance of high strength concrete containing used microwave incinerated rice husk ash. Water to binder (w/b) ratio for all mixes is 0.3.

4.2. MIRHA Characteristic

Grounded MIRHA has been brought to SIRIM to undergo X-Ray Florescence test, XRF to determine the composition. The results obtained are shown in the Table 4.1. From the XRF test, it was identified that the MIRHA consist of high composition of silicon oxide (SiO_2) content which are 90.75 percent.

This amount of silica in MIRHA is almost at the same figure with silica fume which reported by Laskar *et. al.* (2007), González *et.al.* (2007) and Zhang *et. al.* (1996) which range from 80 percent to 94 percent of weight. It means that the MIRHA has the capabilities to become an alternative for silica fume in concrete industry.

According to A. Behnood (2007), the very high content of amorphous silicon dioxide (SiO_2) and very fine spherical particles are the main reasons for its high pozzolanic activity.

Table 4.1: Oxide composition of MIRHA

Oxide	Weight %
SiO_2	90.7479
K_2O	3.7675
P_2O_5	2.5049
CaO	0.8676
Al_2O_3	0.7539
MgO	0.6287
SO_3	0.3328
Fe_2O_3	0.2788
MnO	0.0760
Na_2O	0.0218
TiO_2	0.0201

SiO_2 = Silicon Dioxide, P_2O_5 = Phosphorus Pentoxide, K_2O = Potassium Oxide,
CaO = Calcium Oxide, Fe_2O_3 = Ferric Oxide, MgO = Magnesium oxide, Al_2O_3 = Aluminum Oxide, SO_3 = Sulfur trioxide, MnO = manganous oxide.

4.3. Fresh Properties

4.3.1. Slump test

Properties of fresh concrete in this study were measured based on its workability characteristics. A high dosage of High water reducing admixture or Super Plasticizer (SP) was added to the MIRHA high strength concrete mix proportion in order to improve the workability of fresh concrete. Slump test was conducted to measure a workability of concrete. Mix proportion and slump are illustrated in table 4.1.

Table 4.2: Mix design proportion with slump

Mix Type	OPC	CA	FA	w/c	RHA (%)	SP (%)	Slump (mm)
M500a	500	1150	690	0.3	10	3	10
M500b	500	1150	690	0.3	10	4	15
M550a	550	1120	670	0.3	10	3	85
M550b	550	1120	670	0.3	10	4	150
M600a	600	1090	650	0.3	10	3	80
M600b	600	1090	650	0.3	10	4	100

From the result obtained, slump value is higher with 4% superplasticizer. This was due to the contain of superplasticizer which improved the workability of 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. The comparison of slump value can be illustrated more clearly in figure 4.1. Singh *et. al.* (2002) by his research found that MIRHA has the ability to reduce bleeding segregation, and thus cause significant improvement in workability.

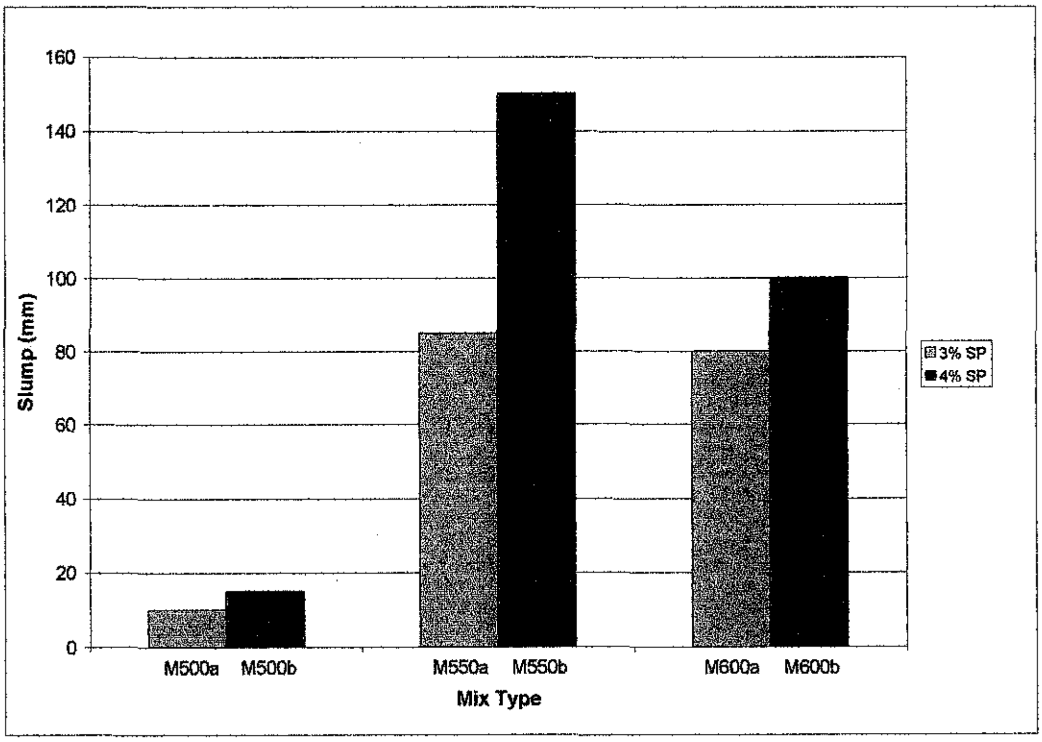


Figure 4.1: Slump value of MIRHA high strength concrete

4.3 Hardened Properties

4.3.1 Compressive strength

Compressive strength of each mix was measured at the age 3, 7, 28 and 90 days and the result is shown in Table 4.2. From the result obtained that has been summarized in table 4.2, all mixes achieved the target strength which is 70 MPa and above. Referring to table 4.2 below, the highest compressive strength is achieved by mix M550b which is 104.83 MPa that contain 10% MIRHA with 4% water reducing agent, superplasticizer.

Table 4.2: Compressive strength of MIRHA high strength concrete

Mix	Compression Test			
	Stress (MPa)			
	3 Days	7 Days	28 Days	90 Days
Mix 1: M500a	64.64	73.91	77.53	98.47
Mix 2: M500b	67.77	82.12	90.54	104.83
Mix 3: M550a	57.94	70.78	80.35	101.8
Mix 4: M550b	50.38	62.55	68.24	95.92
Mix 5: M600a	64.43	65.52	67.11	80.81
Mix 6: M600b	72.12	74.89	80.89	100.08

It can be seen from figure 4.2 that there was a sharp increment in strength of young HSC until 7 days of age. The rapid increment indicates the fast formation of hydration products in concrete. This observation is in agreement with Jin *et. al.* (2005) that stated, HSC obviously had a more rapid strength than normal strength concrete in the early stages. Massaza *et. al.* (1983) in his research also mentions that except RHA, no other pozzolanic additions including silica fume has the ability to contribute to the strength of portland cement concrete at early ages of 1 and 3 days.

The finer particles size enables MIRHA to act as filler that seeped into the tiny spaces between cement particles and as well as spaces between cement particles and aggregate. A greater surface area providing space for nucleation of C-S-H and calcium hydroxide $Ca(OH)_2$. This will accelerate the reactions and form smaller calcium hydroxide crystals.

Furthermore MIRHA also act as super pozzolan. Pozzolan contain some form of vitreous reactive silica which, in the presence of water, can combine with calcium, at room temperature, to form calcium silicate hydrate of the same type as formed during the hydration of Portland cement. 10% of MIRHA compared to cement content is the optimum content of pozzolan, Singh (2002).

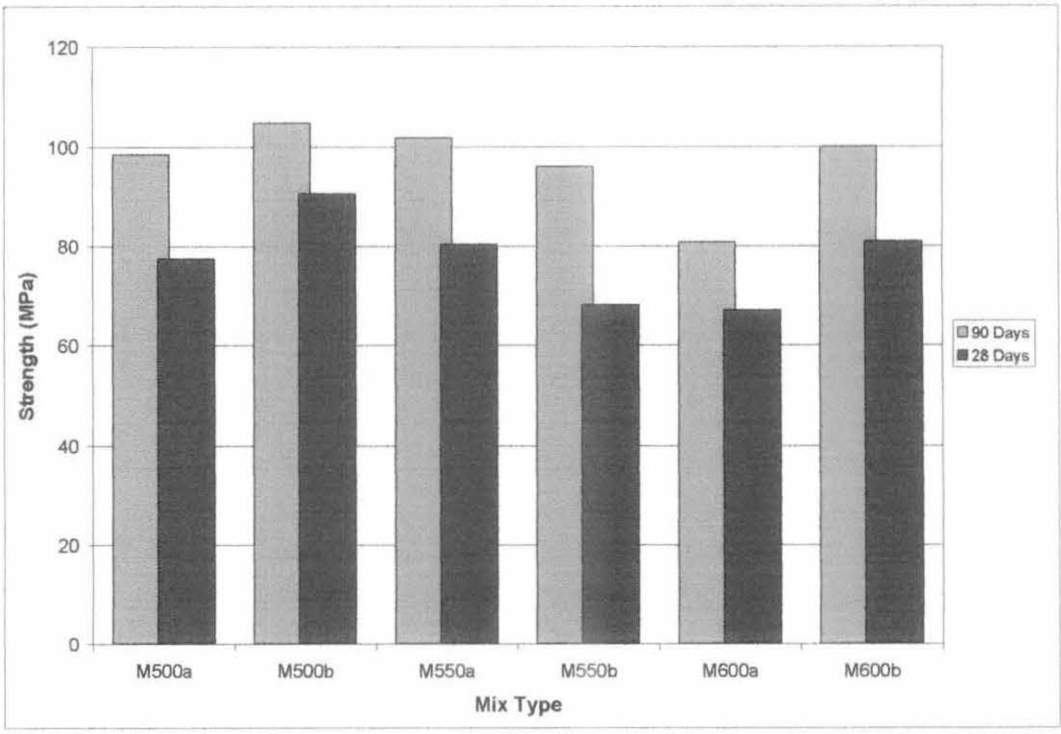


Figure 4.2: HSC strength at 28 days and 90 days age

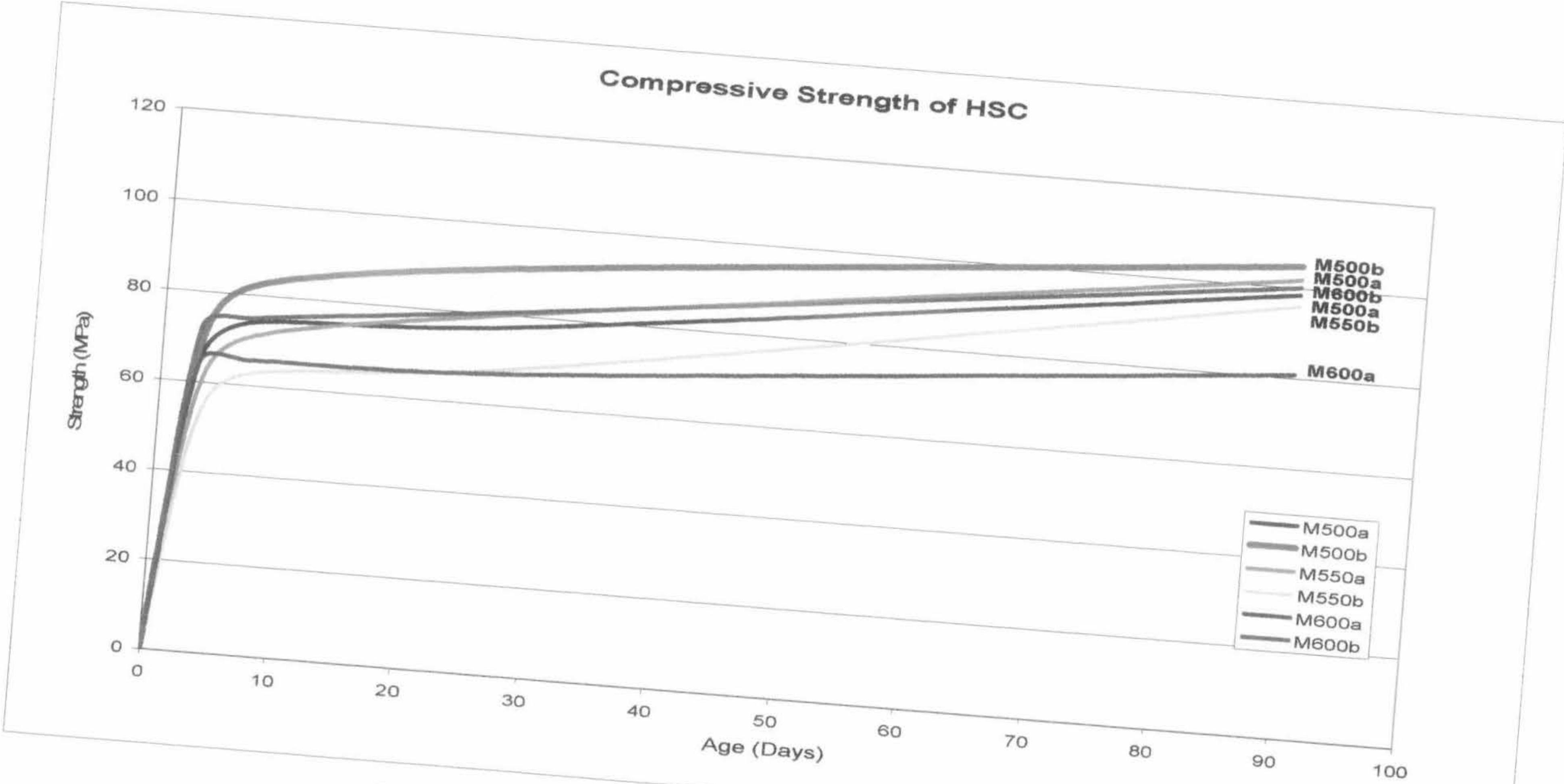


Figure 4.2: Strength development of MIRHA high strength concrete

4.3.2 Tensile

Split cylinder test was carried out at 28 and 90 days age to measure the tensile strength of the concrete. Table 4.3 and figure 4.3 illustrated the result of tensile strength of MIRHA high strength concrete. The results obtained from tensile analysis are consistent with the compressive strength development from compression test. It can be seen by comparing figure 4.2 with figure 4.3.

Table 4.3: Tensile strength of MIRHA high strength concrete

Mix	Split Cylinder Test	
	Stress (MPa)	
	28 Days	90 Days
Mix 1: M500a	6.00	4.17
Mix 2: M500b	6.72	4.36
Mix 3: M550a	4.88	4.25
Mix 4: M550b	4.31	3.88
Mix 5: M600a	3.29	3.24
Mix 6: M600b	6.49	3.62

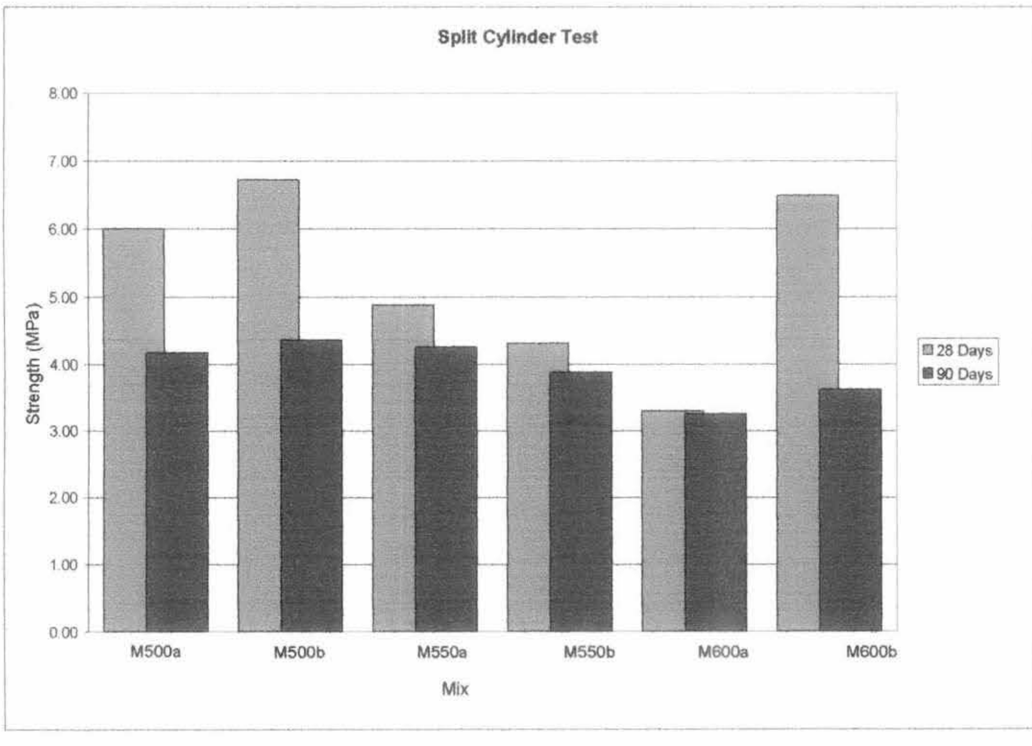


Figure 4.3: Tensile strength of MIRHA high strength concrete

4.3.3 Porosity

Porosity of each mix was measured at the age 90 days and the result is shown in Table 4.4. Porosity define as the total volume of the overall volume of pores larger than gel pores, expressed as a percentage of the overall volume of the hydrated cement paste, is a primary factor influencing the strength of the cement paste.

Table 4.4: Porosity of MIRHA high strength concrete at 90 days

Mix	Porosity (%)
M500a	6.62
M500b	6.04
M550a	7.27
M550b	9.02
M600a	9.36
M600b	7.92

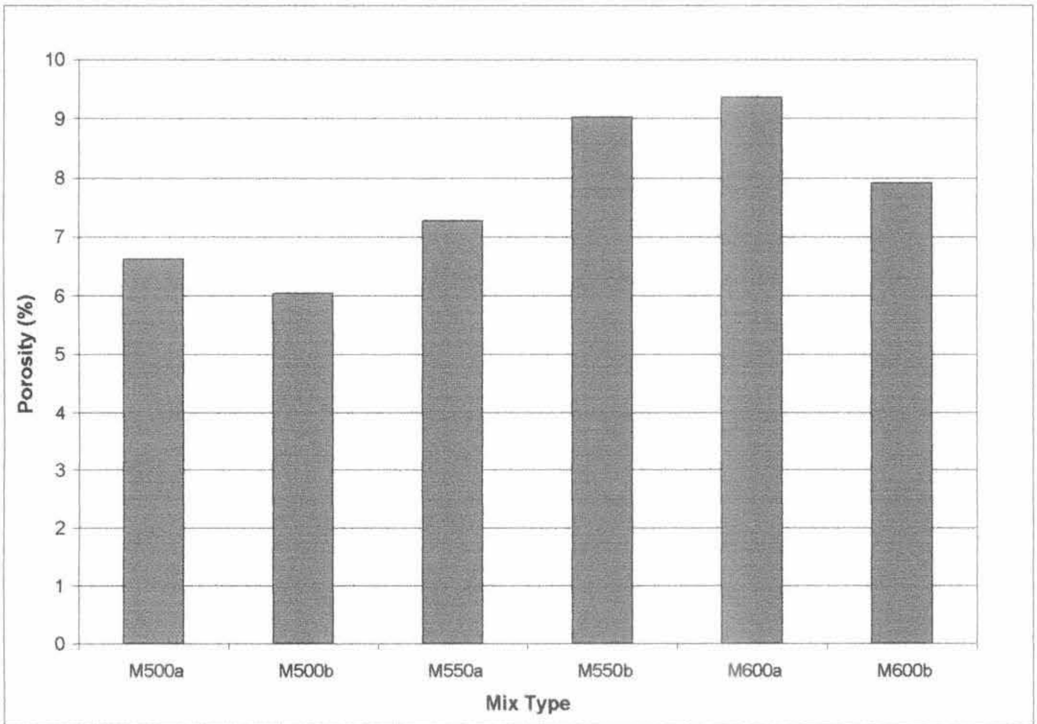


Figure 4.4: Porosity of MIRHA high strength concrete at 90 days

Comparing the chart with compressive strength chart we can observe that the porosity is inversely proportional to the strength of the concrete. When porosity is low, both compressive and tensile strength is high. Mix M550b which has the highest compressive strength have lowest porosity, this reflect a situation in which the porosity in a concrete decreases as the hydration of cement develops, as said by Jin *et. al.* (2005). This happen because of low water to binder ratio that means less free water was available and so, fewer capillary voids were formed. Hence, it was easier for hydration products to integrate on the macro level and higher compressive strength was achieved as well decreasing the porosity.

creates environmental issues and disposal problems. By taking it to the concrete batching plant, it can cut the cost for disposal of the by product and at the same time solve the environmental issues.

5.2 Recommendation

For further investigation to improve the M500b mix proportion, another mineral admixture can be added into the proportion such as calcium chloride, $CaCl_2$ and lignosulfate, LS. Both admixtures are well-known as accelerator and retarder respectively. Singh (2005) in his study regarding the effect of admixtures in hydration process through free lime determinations and differential thermal analysis found that $CaCl_2$ accelerates pozzolanic reaction of $Ca(OH)_2$ and RHA.

Observation made from casting concrete from other experiment, 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 are appropriate so that we could obtain more accurate results. Moreover, mixing the proportion of 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. Moreover, 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. Hence, getting inaccurate value for testing.

REFERENCES:

ACI Committee 363 (1998). *State-of-art report on high-strength concrete (ACI 363.R-92/97).* In: manual of concrete practice ACI; 55 pp.

Aminul Islam Laskar , Sudip Talukdar (2007). "*Rheological behavior of high performance concrete withmineral admixtures and their blending*". Construction and Building Materials.

B.Y. Pekmezci, S. Akyuz (2004). "*Optimum usage of a natural pozzolan for the maximum compressive strength of concrete*". Cement and Concrete Research 34 2175–2179.

Bharatkumar BH, Raghuprasad BK Ramachandramurthy DS, Narayanan R, Gopalakrishnan (2005). "*Effect of fly ash and slag on the fracture characteristics of high performance concret*". Mater Struct;38 (275):63-72.

Christine Isabella, Grant C. Lukey, Hua Xu Jannie, S.J. van Deventer (2005). "*The Effect of Aggregate Particle Size on Formation of Geopolymeric Gel*", ECI Conference on Advanced Materials for Construction of Bridges, Buildings, and Other Structures III.ECCOMAS 2004.

Edward G. Nawy, Alan Moreton, Bryant Mather, Mohan Malhotra, Michael Sprinkel (2003). "*Concrete Properties*". A2E03: Committee on Properties of Concrete.

Ludovic Jason, Gilles Pijaudier-Cabot, Antonio Huerta, Shahrokh Ghavamiano (2004). "*Damage and plasticity for concrete behavior*". European Congress on Computational Methods in Applied Sciences and Engineering

M. Nehdi, J. Duquette, A. El Damatty (2003). "*Performance of rice husk ash produced using a new technology as amineral admixture in concrete*". Cement and Concrete Research 33; 1203–1210.

M.H. Zhang, R. Lastra, and V.M. Malhotra (1996). "*Rice-husk ash paste and concrete: some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste*". Cement and Concrete Research, Vol. 26, No. 6, pp. 963-977.

Mehta PK. Rice Husk Ash (1992). "*A unique supplementary cementing material*". Pg 419-443 RILEM Committee 73-SBC. Final Report: Siliceous by-product for use in concrete.

Moncef Nehdi (2007). A reply to the discussion by A. Demirbas of the paper "*Performance of rice husk ash produced using a new technology as a mineral admixture in concrete*" Cement and Concrete Research 34; 1271–1272.

Muhammad Shoaib Ismail* and A. M. WaliuddintS (1996). " Effect of rice husk ash on high strength concrete". *Construction and Building Materials,* Vol. 10, No. I, pp. 521-526.

N.B. Singh, V.D. Singh, Sarita Rai, Shivani Chaturvedi (2002). "*Effect of lignosulfonate, calcium chloride and their mixture on the hydration of RHA-blended portland cement*". Cement and Concrete Research 32; 387–392.

Z.L Ding Zhu (2003). "*Property improvement of Portland cement by incorporating with metakaolin and slag*". Cem Concr Res 33, pp. 579-584.

APPENDICES

RAW DATA

Compression Test and Split Cylinder Test Result:

Mix 1: M500a

SP: 3% MIRHA: 10% w/c: 0.3 Slump: 10mm

Compressive Strength

Cube dimension: 150mm x 150mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
3	Weight (Kg)	8.54	8.71	8.57	64.64
	Max. Load (KN)	1447.00	NA	1462.00	
	Stress (MPa)	64.31	NA	64.97	
7	Weight (Kg)	8.48	8.55	8.69	73.91
	Max. Load (KN)	1704.00	1114.00	1622.00	
	Stress (MPa)	75.72	49.53	72.10	
28	Weight (Kg)	8.77	9.12	8.92	77.53
	Max. Load (KN)	1571.00	1690.00	1792.00	
	Stress (MPa)	69.83	75.42	79.63	
90	Weight (Kg)	8.58	8.84	8.57	98.47
	Max. Load (KN)	2192.00	2263.00	2192.00	
	Stress (MPa)	97.41	100.60	97.41	

Split Cylinder Test

Cylinder dimension: 100mm x 200mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
28	Weight (Kg)	3.821	3.8	3.813	6.00
	Max. Load (KN)	191.8	181.7	192.2	
	Stress (MPa)	6.104	5.785	6.116	
90	Weight (Kg)	3.84	3.85	3.84	4.36
	Max. Load (KN)	162.40	110.00	139.20	
	Stress (MPa)	5.16	3.50	4.43	

Mix 2: M500b

SP: 4% MIRHA: 10% w/c: 0.3 Slump: 15mm

Compressive Strength

Cube dimension: 150mm x 150mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
3	Weight (Kg)	8.80	8.78	8.81	67.77
	Max. Load (KN)	1088.00	1574.00	1476.00	
	Stress (MPa)	48.37	69.95	65.59	
7	Weight (Kg)	8.57	8.86	8.75	82.12
	Max. Load (KN)	1824.00	1841.00	1878.00	
	Stress (MPa)	81.06	81.83	83.47	
28	Weight (Kg)	8.70	8.69	8.75	90.54
	Max. Load (KN)	2175.00	1846.00	2090.00	
	Stress (MPa)	96.66	82.04	92.92	
90	Weight (Kg)	8.86	8.82	8.78	104.83
	Max. Load (KN)	2327.00	2373.00	2376.00	
	Stress (MPa)	103.40	105.50	105.60	

Split Cylinder Test

Cylinder dimension: 100mm x 200mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
28	Weight (Kg)	3.897	3.982	3.896	6.72
	Max. Load (KN)	199.5	245.5	180.5	
	Stress (MPa)	6.349	7.813	6.001	
90	Weight (Kg)	3.92	3.90	3.90	4.25
	Max. Load (KN)	198.40	111.10	91.10	
	Stress (MPa)	6.31	3.54	2.90	

Mix 3: M550a

SP: 3% MIRHA: 10% w/c: 0.3 Slump: 85mm

Compressive Strength

Cube dimension: 100mm x 100mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
3	Weight (Kg)	8.46	8.39	8.39	57.94
	Max. Load (KN)	1384.00	1206.00	1322.00	
	Stress (MPa)	61.50	53.59	58.74	
7	Weight (Kg)	8.14	8.32	8.29	70.78
	Max. Load (KN)	1618.00	1555.00	1604.00	
	Stress (MPa)	71.92	69.12	71.30	
28	Weight (Kg)	8.33	8.18	8.47	80.35
	Max. Load (KN)	1862.00	1668.00	1893.00	
	Stress (MPa)	82.75	74.14	84.15	
90	Weight (Kg)	8.44	8.59	8.47	101.80
	Max. Load (KN)	2318.00	2302.00	2251.00	
	Stress (MPa)	103.00	102.30	100.10	

Split Cylinder Test

Cylinder dimension: 100mm x 200mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
28	Weight (Kg)	3.856	3.83	3.844	4.88
	Max. Load (KN)	152	144.3	163.6	
	Stress (MPa)	4.838	4.593	5.206	
90	Weight (Kg)	3.81	3.81	3.84	4.17
	Max. Load (KN)	171.40	111.40	107.80	
	Stress (MPa)	5.46	3.63	3.43	

Mix 4: M550b

SP: 4% MIRHA: 10% w/c: 0.3 Slump: 150mm

Compressive Strength

Cube dimension: 100mm x 100mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
3	Weight (Kg)	2.51	2.50	2.39	50.38
	Max. Load (KN)	656.80	491.30	363.20	
	Stress (MPa)	65.68	49.13	36.32	
7	Weight (Kg)	2.47	2.48	2.49	62.55
	Max. Load (KN)	482.20	680.10	704.20	
	Stress (MPa)	48.22	69.01	70.42	
28	Weight (Kg)	2.44	2.50	2.50	68.24
	Max. Load (KN)	701.30	644.40	701.60	
	Stress (MPa)	70.13	64.44	70.16	
90	Weight (Kg)	2.502	2.479	2.539	95.92
	Max. Load (KN)	958.4	916.3	1003	
	Stress (MPa)	95.84	91.63	100.3	

Split Cylinder Test

Cylinder dimension: 100mm x 200mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
28	Weight (Kg)	3.807	3.771	3.786	4.31
	Max. Load (KN)	132.6	129.2	144.1	
	Stress (MPa)	4.221	4.112	4.587	
90	Weight (Kg)	3.831	3.849	3.818	3.88
	Max. Load (KN)	129.2	99.3	137.3	
	Stress (MPa)	4.111	3.16	4.369	

Mix 5: M600a

SP: 3% MIRHA: 10% w/c: 0.3 Slump: 80mm

Compressive Strength

Cube dimension: 100mm x 100mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
3	Weight (Kg)	2.49	2.53	2.51	64.43
	Max. Load (KN)	565.80	675.90	691.10	
	Stress (MPa)	56.58	67.59	69.11	
7	Weight (Kg)	2.49	2.49	2.46	65.52
	Max. Load (KN)	677.10	564.40	724.00	
	Stress (MPa)	67.71	56.44	72.40	
28	Weight (Kg)	2.51	2.54	N/A	67.11
	Max. Load (KN)	613.10	729.00	N/A	
	Stress (MPa)	61.31	72.90	N/A	
90	Weight (Kg)	2.48	2.52	2.52	80.81
	Max. Load (KN)	827.80	514.70	788.30	
	Stress (MPa)	82.78	51.47	78.83	

Split Cylinder Test

Cylinder dimension: 100mm x 200mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
28	Weight (Kg)	3.865	3.867	3.872	3.29
	Max. Load (KN)	115.7	110.9	83.3	
	Stress (MPa)	3.682	3.531	2.652	
90	Weight (Kg)	3.86	3.86	3.87	3.24
	Max. Load (KN)	97.10	84.70	110.40	
	Stress (MPa)	3.51	2.70	3.51	

Mix 6: M600b

SP: 4% MIRHA: 10% w/c: 0.27 Slump: 100

Compressive Strength

Cube dimension: 100mm x 100mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
3	Weight (Kg)	2.48	2.52	2.52	72.12
	Max. Load (KN)	760.20	706.50	696.90	
	Stress (MPa)	76.02	70.65	69.69	
7	Weight (Kg)	2.56	2.54	2.54	74.89
	Max. Load (KN)	625.40	805.80	815.40	
	Stress (MPa)	62.54	80.58	81.54	
28	Weight (Kg)	2.52	2.53	2.55	80.89
	Max. Load (KN)	771.10	789.10	866.40	
	Stress (MPa)	77.11	78.91	86.64	
90	Weight (Kg)	2.53	2.60	2530.00	100.08
	Max. Load (KN)	1130.00	811.30	1148.00	
	Stress (MPa)	108.32	81.13	110.80	

Split Cylinder Test

Cylinder dimension: 100mm x 200mm

Curing (Days)	Properties	Cube			Ave. Stress (MPa)
		1	2	3	
28	Weight (Kg)	3.871	3.843	3.844	6.49
	Max. Load (KN)	230.4	161.2	220.6	
	Stress (MPa)	7.333	5.131	7.02	
90	Weight (Kg)	3.86	3.86	3.85	3.62
	Max. Load (KN)	92.50	127.70	120.50	
	Stress (MPa)	2.95	4.06	3.84	

Porosity Test Result:

M500a

Cube	Properties			Porosity (%)	Average Porosity (%)
	W_{oven}	W_{water}	W_{sat}		
1	205	77.4	214.5	6.93	6.62
2	196.5	74.3	205.4	6.79	
3	212.3	82.3	220.8	6.14	

M500b

Cube	Properties			Porosity (%)	Average Porosity (%)
	W_{oven}	W_{water}	W_{sat}		
1	244.8	102	253.4	5.68	6.04
2	243.5	101	253.2	6.37	
3	243.2	99	252.5	6.06	

M550a

Cube	Properties			Porosity (%)	Average Porosity (%)
	W_{oven}	W_{water}	W_{sat}		
1	246.9	101.9	258.4	7.35	7.27
2	249.7	101.9	261.4	7.34	
3	251.2	102.9	262.6	7.14	

M550b

Cube	Properties			Porosity (%)	Average Porosity (%)
	W_{oven}	W_{water}	W_{sat}		
1	211.5	87.6	224.1	9.23	9.02
2	209.5	87.4	220.7	8.40	
3	211.2	88.4	224	9.44	

M600a

Cube	Properties			Porosity (%)	Average Porosity (%)
	W_{oven}	W_{water}	W_{sat}		
1	192.3	78.7	204.3	9.55	9.36
2	182.7	70.5	194.1	9.22	
3	184.4	69.5	196.2	9.31	

M650b

Cube	Properties			Porosity (%)	Average Porosity (%)
	W_{oven}	W_{water}	W_{sat}		
1	218.9	92	230.2	8.18	7.92
2	218.6	89.8	229.5	7.80	
3	219.7	93	230.4	7.79	

Summary of All Tests and Result:

Mix	Compression Test				Split Cylinder Test		Slump (mm)	Porosity
	Stress (MPa)				Stress (MPa)			
	3 Days	7 Days	28 Days	90 Days	28 Days	90 Days		
Mix 1: M500a	64.64	73.91	77.53	98.47	6.00	4.17	10	6.62
Mix 2: M500b	67.77	82.12	90.54	104.83	6.72	4.36	15	6.04
Mix 3: M550a	57.94	70.78	80.35	101.8	4.88	4.25	85	7.27
Mix 4: M550b	50.38	62.55	68.24	95.92	4.31	3.88	150	9.02
Mix 5: M600a	64.43	65.52	67.11	80.81	3.29	3.24	80	9.36
Mix 6: M600b	72.12	74.89	80.89	100.08	6.49	3.62	100	7.92