The Mechanical Properties of MIRHA Foamed Concrete

by

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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 by,

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(AP Ir Dr Muhd Fadhil bin Nuruddin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 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.

ROBEATUL ADAWIAH BINTI OSMAN

ABSTRACT

The study deliberates on the incorporation of Microwave Incinerated Rice Husk Ash (MIRHA) as a cement replacement material to produce foamed concrete. The mixes incorporating 0%, 5%, 10% and 15% MIRHA were prepared. The optimal mix design of MIRHA based on the mechanical properties is established. During this study, the research on RHA as cement replacement material is conducted. Besides, analysis of concretes characteristics are done for hardened concrete while the workability test is done for fresh concrete. This research adopts Taguchi approach with an L16 (45) to reduce the numbers of experiment. The optimal mix design properties are determined by using analysis of variance (ANOVA) method. The results obtained from this research shows that by adding MIRHA into foamed concrete, early strength can be developed within 3 to 7 days because it has fasten the reaction in the concrete. Beside that, as the optimal MIRHA that was found in this research is 5%, the data shows that the target strength of foam concrete according to load bearing which is 17 Mpa has been achieved.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Foamed concretes, produced by introducing preformed foam, are lightweight concretes consisting of a system of macroscopic air voids of approximately 0.1 to 1 mm size [1], uniformly distributed in either a matrix of aggregate and cement paste or cement paste alone. It can be produced anywhere in any shape or building unit size using conventional equipment and machines which is cost-effective and simple to produce.

The basic contribution of foamed concrete to the field of concrete technology is the ability to control its density over a wide range. The fresh density of foamed concrete typically ranges from approximately 320 to 1920 kg/m^3 (20 to 120 lb/ft^3). The density control is achieved by adding a calculated amount of foam to slurry of water and cement, with or without the addition of sand or aggregate.

However, the skin of the air voids must be tough and persistent to withstand the rigors of mixing and placing, during which the air voids are separated, coated with cement paste, and the concrete can be pumped or transported to the casting location. The preformed foam process of making foamed concrete is the most economical and controllable pore-forming process consisting of stable, unconnected air voids. Under some circumstances, however, the air voids may also coalesce during mixing and transporting and form larger air voids; this is undesirable. In recent years, high strength foamed concrete has been developed with a low water-to-binder ratio ($\leq$0.3) and using silica fume and ultrafine silica powder [2] and fly ash [3] & [4] without using sand. A compressive strength of up to 60 MPa for the foamed concrete under special curing conditions has been reported together with the relationships between compressive strength and porosity and density.

Rice Husk Ash (RHA) is a by product of paddy that can be obtained with the combustion process of rice husk. The high content of amorphous silica and very large surface area make RHA a highly reactive pozzolanic material that can be used to improve the strength and durability of concrete. Generally, reactivity of pozzolanic material can be achieved by increasing the fineness of the material [5]. However, Mehta has argued that grinding of RHA to a high degree of fineness should be avoided, since it derives its pozzolanic activity mainly from the internal surface area of the particles. At a certain stage of grinding the RHA, the porous structure of the particle will collapse, thereby reducing the surface area of the RHA [5].

By proper control of the incineration process (Kusbiantoro Andre, 2007), the quality of RHA can be assured. Microwave Incinerated Rice Husk Ash (MIRHA) has been used as a highly reactive pozzolanic material to improve the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in high-performance concrete.

In this paper, the results of an investigation carried out to better understand the effect of MIRHA on strength development of the foamed concrete. By using Taguchi method, the experimental work was designed to give the optimum working conditions of the parameters that affect some mechanical properties of foamed concrete. One of the advantages of the Taguchi method over the conventional experimental design methods, in addition to keeping the experimental cost at the minimum level, is that it minimizes the variability around the investigated parameters when bringing the performance value to the target value. Its other advantage is that the optimum working conditions determined from the laboratory work can also be reproduced in the real production environment.

1.2 PROBLEM STATEMENT

Since long time ago, normal concrete has been used as the material for construction either in building, bridges or other structures. The main problem faced by construction industries while using the normal concrete is that the self weight carried by the concrete will increase the design load of the structure. Nowadays, lightweight concrete has been introduced broadly all over the world as a new approach in replacing the normal concrete. However, in producing the lightweight concrete, the strength of the concrete must be taken into consideration. It is because the higher the strength, the smaller the size of the concrete. Thus, cost for producing the concrete will be reduced. Studies have been done from time to time to find out the best approach in producing the high strength lightweight concrete that can replace the usage of normal concrete.

Current practice shows that Ordinary Portland Cement (OPC) is widely used as one of concrete ingredients. However, a problem that the construction industries have to overcome when using the OPC is the increase of carbon dioxide (CO_2) in air. The largest emissions from cement (actually clinker) manufacture is of CO_2, amounting to nearly 1 metric ton of gas per metric ton of clinker. About one-half of which is derived from the calcinations of calcium carbonate raw materials, and the rest, from the combustion of fuels. Currently, there are a lot of cement replacement materials from waste that have been found to be good alternatives for OPC such as rise husk ash, fly ash, silica fume and many more. It is a good practice if these wastes can be used in producing concrete as environment can be saved and emission of CO_2 can be reduced. The purpose of this project is to produce high strength lightweight concrete that incorporates Microwave Incinerator Rice Husk Ash (MIRHA).

1.3 OBJECTIVES

The main objectives of this research are:

1. To determine the optimum mix proportion of foamed concrete containing MIRHA by using Taguchi method.
2. To establish the effect of MIRHA focusing on the strength development of foamed concrete.

1.4 SCOPE OF STUDY

The scope of study conducted during this project includes the analysis of mechanical properties for every mixes. The analysis will be based on some tests conducted such as Compressive Strength, Porosity, Dry Density, Ultrasonic Pulse Velocity (UPV) and Water Absorption Test. For Compressive Strength Test, the data will be collected at 3, 7 and 28 days of age of the concrete with 6 samples per test. For Porosity, Dry Density, UPV and Water Absorption Test, the 28-day samples from each mix are tested with one sample per test.

The final analysis will be done by comparing all the data to get the optimal mix proportion as to fulfill the objectives of this study. Besides, the effect of MIRHA on strength development of foamed concrete will be observed by using the result of Compressive Strength.

CHAPTER 2

LITERATURE REVIEW

2.1 LIGHTWEIGHT CONCRETE

Concrete is a composite material that composed of water, cement, and aggregate, Common aggregates include sand, gravel, or crashed stone. Concrete is a well known structural component with typical compressive strength of approximately 2500 psi [7]. Structural lightweight concrete has been introduced to solve the problems of weight and durability in buildings and exposed structures. The strength of structural lightweight concrete is typically 25% to 35% lighter than normal weight concrete. Structural lightweight concrete offers design flexibility and substantial cost savings by providing less dead load, improved seismic structural response, longer spans, better fire ratings, thinner sections, decreased story height, smaller size structural members, less reinforcing steel, and lower foundation cost.

Structural lightweight aggregate's provides internal curing through water entrainment which is especially beneficial for high-performance concrete (HPC). Internal curing improves the contact zone which mitigates micro cracking. Structural lightweight concrete has its obvious advantages of higher strength/ weight ratio, better tensile strain capacity, lower coefficient of thermal expansion due to air voids in the lightweight aggregate [22]. The uses of structural lightweight concrete include;

- floors in steel frame buildings,
- concrete frame buildings & parking structures,
- bridge decks, piers & AASHTO girders,
- specified density concrete,
- lightweight concrete precast & prestressed elements (beams, double-tees, tilt-up walls, hog slats, etc),
- marine structures, floating docks, ships, & offshore oil platforms, and

There are many types of lightweight concrete such as lightweight aggregate, foamed concrete and many more. These types of concrete have been broadly commercialized as the alternatives for normal concrete in construction industries.

2.2 FOAMED CONCRETE

Foamed concretes has been produced by introducing preformed foam, are lightweight concretes consisting of a system of macroscopic air voids of approximately 0.1 to 1 mm size. It was uniformly distributed in either a matrix of aggregate and paste or cement paste alone. It can be produced anywhere in any shape or building unit size using conventional equipment and machines and be cost-effective and simple to produce. The basic contribution of foamed concrete to the field of concrete technology is the ability to control its density over a wide range. The fresh density of foamed concrete typically ranges from approximately 320 to 1920 kg/m^3. The density control is achieved by adding a calculated amount of foam to slurry of water and cement, with or without the addition of sand and aggregate. However, the skin of air voids must be tough during which the air voids are separated, coated with cement paste, and the concrete can be pumped or transported to the casting location [1].

The preformed foam process of making foam concrete is the most economical and controllable pore-forming process, consisting of stable, unconnected air voids. However, under some circumstances, the air voids may also coalesce during mixing and transporting and form larger air voids. A comprehensive review of literature dealing with both autoclaved and non-autoclaved aerated concrete properties suitable mostly for nonstructural has been report recently. Generally, air voids that govern the porosity of foamed concrete are considered to have a significant effect on compressive strength of the concrete [1].

The definition of a foamed concrete is one that has an air content of over 30% so typically the densities of foamed concrete range from $200kg/m^3$ to $1700kg/m^3$

(densities below 400kg/m³ need to be attempted and undertaken with care, using specialized curing systems). The strength of foamed concrete is generally accepted as being between 1 & 10 N/mm². Strengths up to 25 N/mm² at 1400kg/m³ have been produced in laboratory tests but are not common place in practice. The effects of foamed concrete density, cement type and content, water/cement ratio, foam type and curing regime will influence the compressive strength [9].

The thermal insulation value is its stability to resist the flow of heat across it. The measure of heat flow rate is known as a materials K value and the lower this value the higher the products thermal efficiency [9].

Table 1: Relationship between density and Thermal Conductivity of foamed concrete [9]

Density	400	600	800	1000	1200	1400	1600
W/mk	0.08	0.1	0.14	0.22	0.35	0.5	0.62

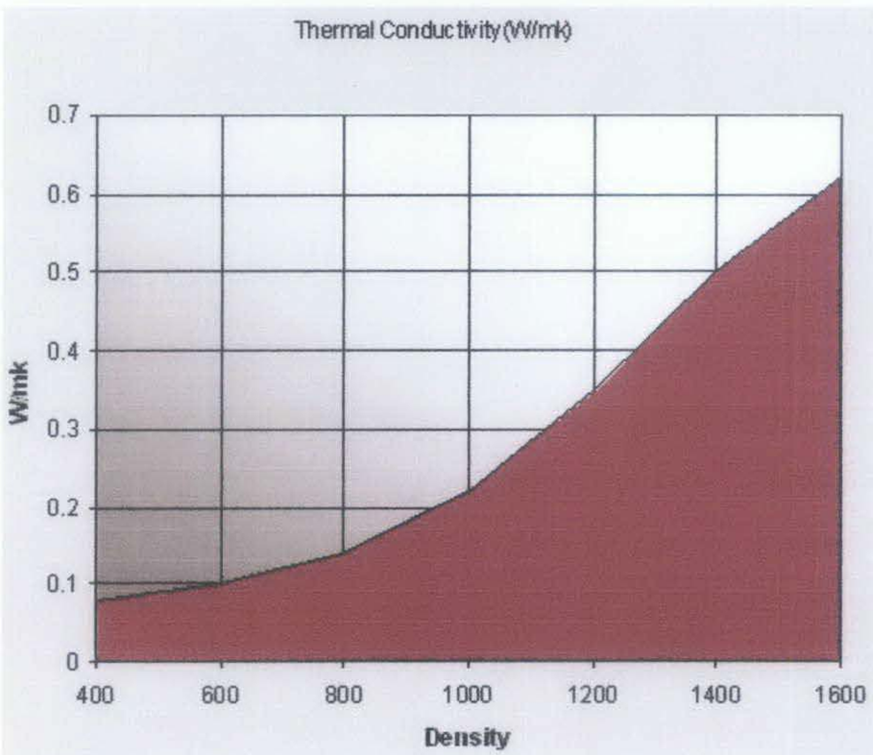

Figure 1: Graph of Density vs Thermal Conductivity of foamed concrete [9]

2.3 TAGUCHI METHOD

Taguchi method was developed as a process optimization technique by Genichi Taguchi during the 1950s [23]. It is used to obtain products (or processes) more robust under varying environmental conditions and to consider the variability in the products' components (sub-products). The Taguchi method after bringing the mean performance of products to some targeted values has shown that experimental designs could be used to make the variability around the targeted value minimum. According to Taguchi, the performance of a product (i.e. optimum working conditions) may be affected by environmental conditions in which it is going to be used and components used in its production [24].

The Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments [23]. Using orthogonal arrays significantly reduces the number of experimental configurations to be studied. Furthermore, the conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings. In this study, the following parameters are considered in the mix proportions:

1. Water to cementitious materials ratio (W/C);
2. Water content (W);
3. Fine aggregate to total aggregate percent (s/a);
4. Microwave Incinerated rice husk ash content (MIRHA);
5. Air entraining agent content (AE);
6. Superplasticizer content (SP).

Optimum working conditions determined by using the experimental data should always be able to provide the same or very close performance values (i.e. physical properties) at different times and different working environments. The optimization criteria to be used to meet this task should be able to control both whether the target value has been reached, and also whether the variability around the target is kept at the minimum. According to Taguchi, performance statistics can meet the above requirement. Without a systematic approach, some difficulties in solving problems or developing projects in any area may occur. For that reason, a systematic approach covering the necessary steps of the method applied is very beneficial [23]. In order to apply Taguchi methods to the solution of the problems in various areas, a systematic approach is needed. A systematic and efficient approach for this purpose is given in Fig 2. The operations of the flowchart can be grouped into thirteen operational steps for achieving design optimization. The steps are:

1. determination of the problem and organizing the team,
2. determination of the performance characteristic(s) and the measuring system,
3. determination of the variables (parameters) affecting the performance characteristic(s),
4. conducting the screening design,
5. determination of the number of the levels and values of
6. the controllable variables (parameters) and uncontrollable ones (parameters),
7. determination of the interactions to be examined,
8. selection of appropriate OAs and assigning the variables to the suitable columns,
9. determination of the loss function (s) and performance statistics,
10. conducting experiments and recording of results,
11. analyzing data and selection of the optimum value of the controllable variables,
12. testing the results,
13. establishing tolerance design, and
14. evaluation, implementation, and observation.

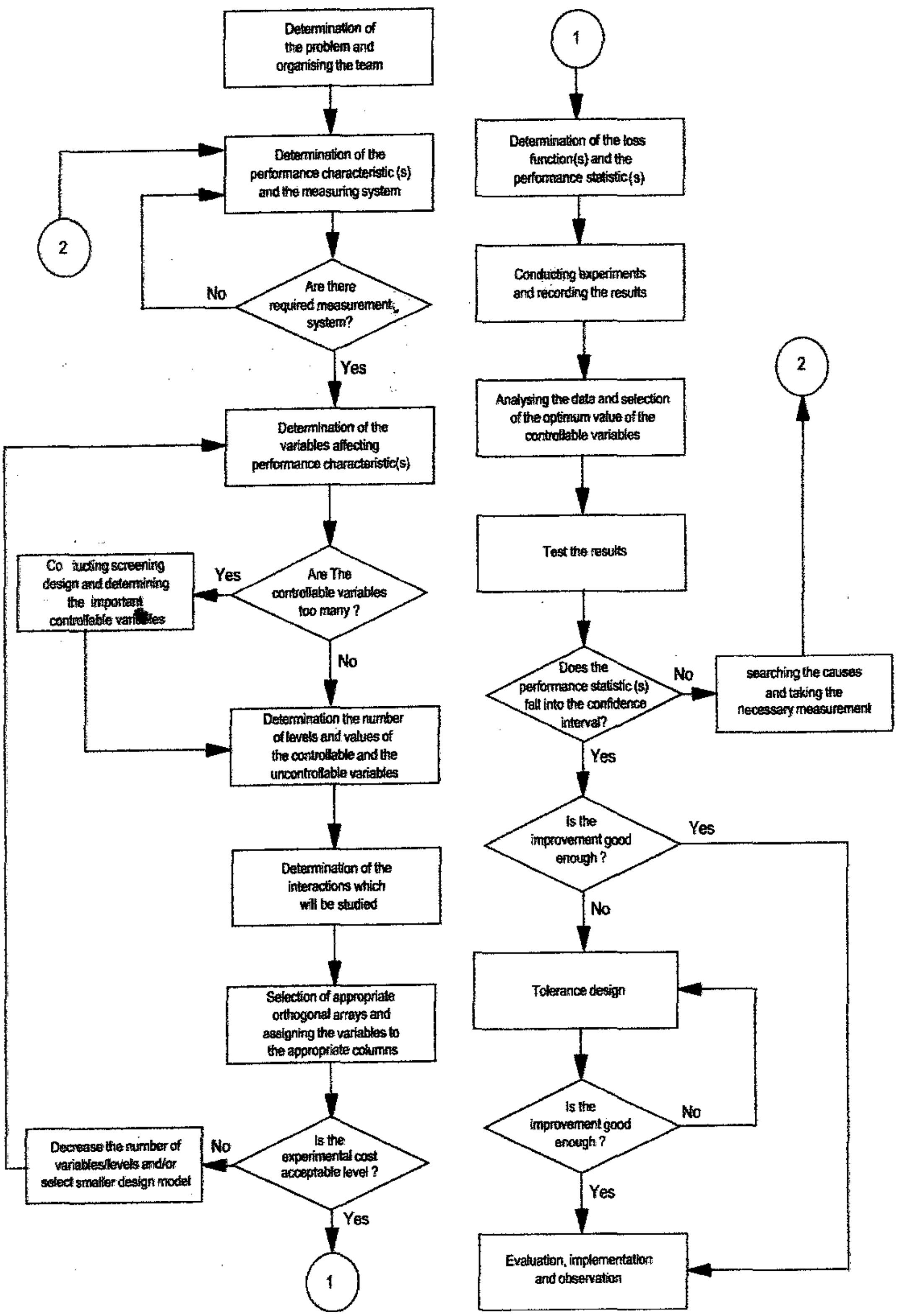

Figure 2 : Flowchart of the systematic approach to the application of Taguchi methods [23]

2.4 MICROWAVE INCINERATED RICE HUSK ASH (MIRHA)

2.4.1 Agricultural Waste

Every year tons of agriculture wastes are being produced in the whole world. Rice husk as a by-product of paddy, tobacco waste from the cigarette factory, sugar cane in sugar industries, and groundnut shell are some examples of by products that are produced largely from agricultural sector [10, 11].

Disposal of this waste has become a challenging problem, since it possesses rough and abrasive surfaces that are highly resistant to natural degradation [10]. It leads the researchers to find the proper methods in utilizing this waste. Cement, biotechnology, and energy generation industries are recognized as the large sectors that are able to consume such huge quantities of these wastes [10, 12]. With the biotechnology, some agriculture wastes like wheat straw can be converted into nutrient rich bio-fertilizer (vermicompost) for sustainable land restoration practices [12], de-oiled soya can be used as the potential adsorbents for the removal of hazardous part from wastewater [13], coconut coir and durian peels as the desiccant for air conditioning system [14], and also selected herbaceous crops residue including *Brassica carinatai* are currently under study as the potential energy resources [15].

Meanwhile cement industries provide the opportunities for rice husk, sugar cane waste, tobacco waste, and groundnut shell as the cement replacement material (CRM). It gives opportunity to the construction industries to reduce their cost while also preserving the environmental quality [16]. The use of cement in concrete can be partially replaced by this pozzolanic material that is obtained from the combustion of agriculture waste.

2.4.2 Cement Replacement Material

Environmental issues that resulted from Portland cement production have made researchers to create advance methods to obtain materials that are sufficiently reactive to replace cement portion in concrete. These materials are generally a waste by-product and contain highly reactive silica to react with calcium hydroxide resulted from hydration process between cement and water. RHA that is resulted from burning process of paddy husk is one of the cement replacement materials (CRM) produced from agriculture waste.

Nowadays, there are a lot of wastes that have been found out to be the cement replacement material for OPC. The existing wastes that have been commercialized widely in construction industry are fly ash, silica fume, ground granulated blast furnace slag (GGBFS) and many more. These types of wasted was found out to have slightly the same characteristic with OPC which can be use as alternatives in replacing the OPC. Recently, rice husk ash has been studied as another material that can replace the OPC in producing concrete.

It is a very good approach in using these types of cement replacement material as to save the environment in order to reduce the wastage of these materials and also to lower the production of CO2 in the air as the usage of OPC is reduced.

2.4.3 RHA as Cement Replacement Material

Rice is cultivated as a major agricultural food crop in 75 countries of the world. About 400 million tons of paddy rice is produced annually in these countries. Based on various studies and research work, it is established that 1 ton of rice husk is generated from every 5 tons of paddy; thus, there should be about 80 million tons of rice husk available annually worldwide of which 64 million tons are produced in the Far East countries.

The increasing demand for rice by the growing populations in the rice-eating regions of the world creates an upward trend in the annual production of paddy rice. Due to the improvement in the milling process, there is also an expected increase in the amount of rice husk to be generated. The disposal of this low value by-product-rice husk-will continue to pose as a problem to the 75 countries where rice is grown. Apart from the construction potentials of rice husk its conversion into ash cement is, therefore, a better alternative to the present-day dumping and burning methods of disposing it.

Apart from its potential use as low grade fuel, insulation material and filler, rice husks can be used (after having incinerated to produce reactive ash) as a pozzolana to replace, partially, cement and also to be used in block-making.

In view of its abundant availability, many research institutions have undertaken considerable research over the last two decades, and the results and findings have been well documented. Table 2 gives an example of results of the average compressive strengths of mortar cubes made of Portland rice-husk ash cements.

Table 2: Average compressive strength of the RHA/OPC mortar cubes [8]

Sample No.	Composition of the cementitious material (percentage)	Number of specimens tested	Age (days)	Compressive strength	Remarks
C_1	100 OPC	30	7	12.4	Control samples 100 per cent OPC
P/C/10	10 RHA 90 OPC	60	7	14.3	115.3 per cent of controlled samples strength
P/C/20	20 RHA 80 OPC	60	7	12.9	104.0 per cent of controlled samples strength
P/C/30	30 RHA 70 OPC	60	7	11.7	94.0 per cent of controlled sample strength
P/C/40	40 RHA 60 OPC	60	7	10.5	84.7 per cent of controlled strength
P/C/50	50 RHA 50 OPC	60	7	10.2	82.3 per cent of controlled strength
A/L/30	30 RHA 70 Lime	90	7	8.2	Samples were at 50°C for 4 days
A/L/40	40 RHS 60 Lime	90	7	10.2	Strength for such accelerated curing is equivalent to the strength of 28 days normal curing
C_1	100 OPC	30	28	17.85	Control samples 100 per cent OPC
P/C/10	10 RHA 90 OPC	60	28	19.41	108.7 per cent of controlled samples strength
P/C/20	20 RHA 80 OPC	60	28	16.88	94.6 per cent controlled samples strength
P/C/30	30 RHA 70 OPC	60	28	15.33	81.1 per cent of controlled samples strength
P/C/40	40 RHA 60 OPC	60	28	14.29	80.1 per cent of controlled samples strength
P/C/50	50 RHA 50 OPC	60	28	12.24	68.6 per cent of controlled samples strength

Besides the use of rice-husk ash for producing blended cements and for block-making, a recent research work has proved that rice-husk ash can be used in manufacturing sodium silicate (waterglass) solution. Waterglass can be used as water proofing agent if applied, as paint to the external walls, foundation plinths, etc. It has also been used in the manufacture of adobe blocks to increase the durability of walls [8].

2.4.4 Burning Procedure

The quality of RHA actually depends on the method of ash incineration and the degree of grinding. It also depends upon the preservation of cellular structure and the extent of amorphous material within structure [10]. Burning temperature, time, and environment, have different effects to the RHA produced. Table 3 shows the chemical composition of RHA under different burning temperature.

Table 3: Chemical Composition of RHA under Different Burning Temperatures [17]

		Temperature (°C)				
		<300	400	600	700	1000
Element (%)	Si	81.90	80.43	81.25	86.71	92.73
	K	9.58	11.86	11.80	7.56	2.57
	Ca	4.08	3.19	2.75	2.62	1.97
	Na	0.96	0.92	1.33	1.21	0.91
	Mg	1.25	1.20	0.88	0.57	0.66
	S	1.81	1.32	1.30	1.34	0.16
	Ti	0.00	0.00	0.00	0.00	0.45
	Fe	0.43	1.81	0.68	0.00	0.68
Oxide (%)	SiO_2	88.01	88.05	88.67	92.15	95.48
	MgO	1.17	1.13	0.84	0.51	0.59
	SO_3	1.12	0.83	0.81	0.79	0.09
	CaO	2.56	2.02	1.73	1.60	1.16
	K_2O	5.26	6.48	6.41	3.94	1.28
	Na_2O	0.79	0.76	1.09	0.99	0.73
	Fe_2O_3	0.29	0.74	0.46	0.00	0.43

Burning the RHA with higher temperature will increase the SiO_2 content. But it is not suggested to burn rice husk above 800°C longer than one hour, because it tends to cause a sintering effect (coalescing of fine particles) and is indicated by a dramatic reduction in the specific surface [10].

Combustion environment also plays an important role. It should be noted that a change in the rate of oxidation from moderately oxidizing conditions (CO_2 environment) to highly oxidizing conditions (oxygen environment) is responsible for the steep drop in the micro porosity and surface area [10]. The effect of the combination of various conditions to RHA is shown in Table 4.

Table 4: Effect of Burning Conditions on the Crystal Structure and Surface Area of Rice Husk Ash [18].

Burning Temperature (° C)	Hold Time	Environment	Properties of ash	
			Crystalline	Surface Area (m^2/g)
500-600	1 min	Moderately oxidizing	Non crystalline	122
	30 min			97
	2 hours			76
700-800	15 min – 1 hr	Moderately oxidizing	Non crystalline	100
	> 1 hour	Highly oxidizing	Partially crystalline	6-10
> 800	> 1 hour	Highly oxidizing	Crystalline	< 5

Longer burning time will cause collapse of the cellular form and also coalescence of the fine pores [17], which consequently causes a reduction in surface area [17]. At higher temperatures with longer burning times, a crystalline structure is formed with a sharp reduction in surface area. This lowers the pozzolanic activity. Figure 2 indicates the ideal time/temperature path to obtain optimum quality rice husk ash with a microporous and cellular structure which is highly reactive [12].

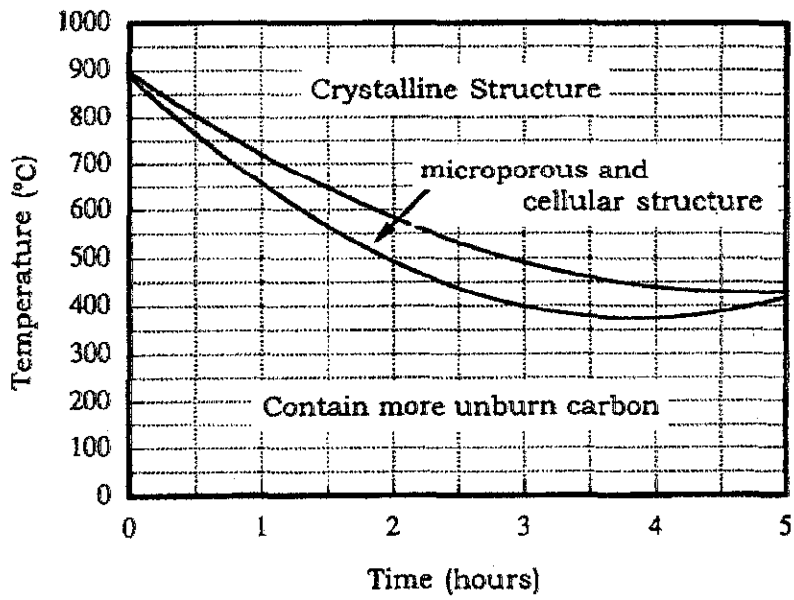

Figure 3: The Optimum Incineration Condition Curve for obtaining Reactive Cellular RHA [12].

Nair, Jagadish, and Fraaij have investigated that burning procedure is significantly affect the properties of RHA in terms of the amount of silica oxide obtained. Silica oxide content obtained from open burning method will be lower than those obtained from controlled burning (muffle furnace) [19]. Properties of different RHA sample that is obtained in this previous research is shown in Table 5.

Table 5: Properties of RHA under Different Burning Procedure [19]

Burning Method	Colour	LOI (%)	SiO_2 Total (%)
Annular Oven (Open Burning)	Light Grey	10.8	81.95
Brick Oven (Open Burning)	Light Grey	12.1	85
Pit Burning (Open Burning)	Grey	15.3	82
Muffle Furnace (Controlled Burning)	Dull White	0.84	88.50
Rice Factory (Uncontrolled Burning)	Black	20.5	76.7

2.4.5 Procedure for Microwave Incineration

Proper burning method is important to obtain RHA with high reactive silica content. Modern incinerator is designed to avoid environmental problem as caused by open burning. Microwave incinerator as one of the modern incinerators is proposed to produce amorphous RHA with high pozzolanic reactivity as a result this can significantly enhance the concrete properties.

Microwaves are part of the electromagnetic spectrum and are located between 300 MHz and 300 GHz. Microwave heating is defined as the heating of a substance by electromagnetic energy operating in that frequency range. There is a fundamental difference in the nature of microwave heating when compared to conventional methods of heating material. Conventional heating relies on one or more of the heat transfer mechanisms of convection, conduction, or radiation to transfer thermal energy into the material. In all three cases, the energy is deposited at the surface of the material and the resulting temperature gradient established in the material causes the transfer of heat into the core of the object. Thus, the temperature gradient is always into the material with the highest temperatures being at the surface [20].

In microwave heating, the microwave energy not only interacts with the surface material but also penetrates the surface and interacts with the core of the material as well. Energy is transferred from the electromagnetic field into thermal energy throughout the entire volume of the material that is penetrated by the radiation. Microwave heating does not rely on conduction from the surface to bring heat into the core region. Since the heating rate is not limited by conduction through the surface layer, the material can be heated quicker. Another important aspect of microwave heating is that it results in a temperature gradient in the reverse direction compared to conventional heating. That is to say, the highest temperature occurs at the centre of the object and heat is conducted to the outer layer of the material [20].

2.5 MECHANICAL PROPERTIES OF MIRHA FOAMED CONCRETE

2.5.1 Compressive Strength

Compressive strength is the capacity of a material to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. Concrete can be made to have high compressive strength, e.g. many concrete structures have compressive strengths in excess of 50 MPa, whereas a material such as soft sandstone may have a compressive strength as low as 5 or 10 MPa.

By definition, the compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied. As can be imagined, the specimen (Usually cylindrical) is shortened as well as spread laterally. A Stress–strain curve is plotted by the instrument and would look similar to the figure 4:

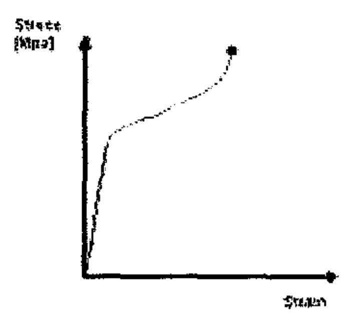

Figure 4: Engineering Stress-Strain curve for a typical speciment

The compressive strength of the material would correspond to the stress at the red point shown on the curve. Even in a compression test, there is a linear region where the material follows Hooke's Law. Hence for this region $\sigma = E\varepsilon$ where this time E refers to the Young's Modulus for compression.

This linear region terminates at what is known as the yield point. Above this point the material behaves plastically and will not return to its original length once the load is removed.

2.5.2 Porosity

Porosity is a measure of the void spaces in a material, and is measured as a fraction, between 0–1, or as a percentage between 0–100%. The term is used in multiple fields including ceramics, metallurgy, materials, manufacturing, earth sciences and construction. Used in geology, hydrogeology, soil science, and building science, the porosity of a porous medium (such as rock or sediment) describes the fraction of void space in the material, where the void may contain, for example, air or water. It is defined by the ratio:

$$\varphi = \frac{V_V}{V_T}$$

where V_V is the volume of void-space (such as fluids) and V_T is the total or bulk volume of material, including the solid and void components. Both the mathematical symbols φ and n are used to denote porosity.

Porosity is a fraction between 0 and 1, typically ranging from less than 0.01 for solid granite to more than 0.5 for peat and clay, although it may also be represented in percent terms by multiplying the fraction by 100.

A value for porosity can alternatively be calculated from the bulk density ρ_{bulk} and particle density $\rho_{particle}$:

$$\varphi = 1 - \frac{\rho_{bulk}}{\rho_{particle}}$$

Normal particle density is assumed to be approximately 2.65 g/cm³, although a better estimation can be obtained by examining the lithology of the particles.

2.5.3 Ultrasonic Pulse Velocity (UPV)

The velocity of an ultrasonic pulse through a material is a function of the elastic modulus and density of the material. The pulse velocity can therefore be used to assess the quality and uniformity of the material. The method is also useful for estimating crack depth and direction, and determining the thickness of surface layers damaged by chemical attack, fire, etc.

The ultrasonic pulse velocity (UPV) of a material can be determined by placing a pulse transmitter on one face of a sample of the material, and a receiver on the opposite face. A timing device measures the transit time of the ultrasonic pulse through the material. If the path length is known, then the UPV can be calculated from the path length divided by the transit time.

The accuracy of the method will depend on the geometry of the test, and the width of the contact faces of the transducers. A degree of uncertainty is introduced by flat faced transducers because the precise point of contact for maximum pulse transmission and reception is not known - it could be anywhere within the width of the contact face.

The method is most accurate in direct transmission mode, where the transmitter and receiver are placed directly opposite each other on parallel faces of the test piece, and the path length can be measured or calculated with a high degree of accuracy. A lesser degree of accuracy is achieved when the test is applied on mutually perpendicular faces of the test piece, such as at a corner, due to the uncertainty of the true contact point. This is known as semi-direct transmission. The method is least accurate when both transducers are applied to the same face of the test piece, or indirect transmission. Also, the inaccuracy will be proportionally greater for shorter transmission path than for longer ones.

2.5.4 Water Absorption

Water absorption is a phenomenon in the transmission of electromagnetic radiation through a medium containing water molecules. Water molecules are excited by radiation at certain wavelengths and tend to selectively absorb portions of the spectrum while allowing the balance of the spectrum to be transmitted with minimal effect. It is also can be defined as the amount of water absorbed by a composite material when immersed in water for a stipulated period of time. Water absorption is measured by the ratio of the weight of water absorbed by a material, to the weight of the dry materials. All organic polymeric materials will absorb moisture to some extent resulting in swelling, dissolving, leaching, plasticizing and/or hydrolyzing, events which can result in discoloration, embrittlement, loss of mechanical and electrical properties, lower resistance to heat and weathering and stress cracking.

CHAPTER 3

METHODOLOGY

3.1 EQUIPMENT

Portafoam Model TM-2 that the equipment that will be produced stable aqueous foam for the production of foamed concrete. Foam output volume – 100 to 150 lit / min. The Portafoam generators work by the uptake of premixed (diluted) chemicals from a pressurized tank which is delivered to a main unit (tank delivery). ***Tank delivery*** means that the premix solution (chemical concentrate + water) is placed in pressure tanks which deliver the premix to the main generating unit. Pressure tanks have limited capacity and therefore foam volume and delivery is limited to their size. The main unit consists of several gauges and valves (all pneumatic) and is responsible for the generation of stable foam. The stable foam is then delivered to a lance unit which further stabilizes the foam before it exits into the concrete mixer.

3.2 CONSTITUENT MATERIALS

The constituent materials used to produce foamed concrete are given in Table 6.

Table 6: Constituent materials used to produce foamed concrete

Materials	Remarks
Cement	Ordinary Portland Cement BSEN 197-1
Sand	A maximum grain size of 2 mm, with 60-95 % passing 600 μm sieve (David Bennett, 2002 & BS EN 12620)
RHA	In order to produce MIRHA with high reactive silica content, controlled combustion of rice husk (Kusbiantoro A, 2007 & BS EN 450)
Foam	Preformed foam by aerating protein based"Noraite SA-1," a ratio of 1:33 (by volume), aerated to a density of 70-80 kg/m3, ASTM C 869-91 (reapproved 1999), ASTM C 796-97

Table 7: Binder properties

Oxide composition	Weight %	
	MIRHA	OPC "Tasek"
Na_2O	0.02	0.02
MgO	0.63	1.43
Al_2O_3	0.75	2.84
SiO_2	90.75	20.44
P_2O_5	2.50	0.10
K_2O	3.77	0.26
CaO	0.87	67.73
TiO_2	0.02	0.17
Fe_2O_3	0.28	4.64
SO_3	0.33	2.20
MnO	0.08	0.16

3.3 PROJECT FLOW CHART

During the research, a systematic approach has been followed as to ensure the project run smoothly and able to finish within the estimated time of study which is 1 year. The research started with preliminary study which consists of finding the problem statement and doing the literature review based on the problem statement found. Then, the mixing process has been started by preparing all the ingredients first. After mixing the foamed concrete, some tests based on mechanical properties of the concrete has been conducted. Finally, the results has been analyzed to find the optimal mix design properties for the mechanical properties of foamed concrete and to determine the effect of MIRHA on strength development of foamed concrete. Fig. 5 shows the flow chart of this project.

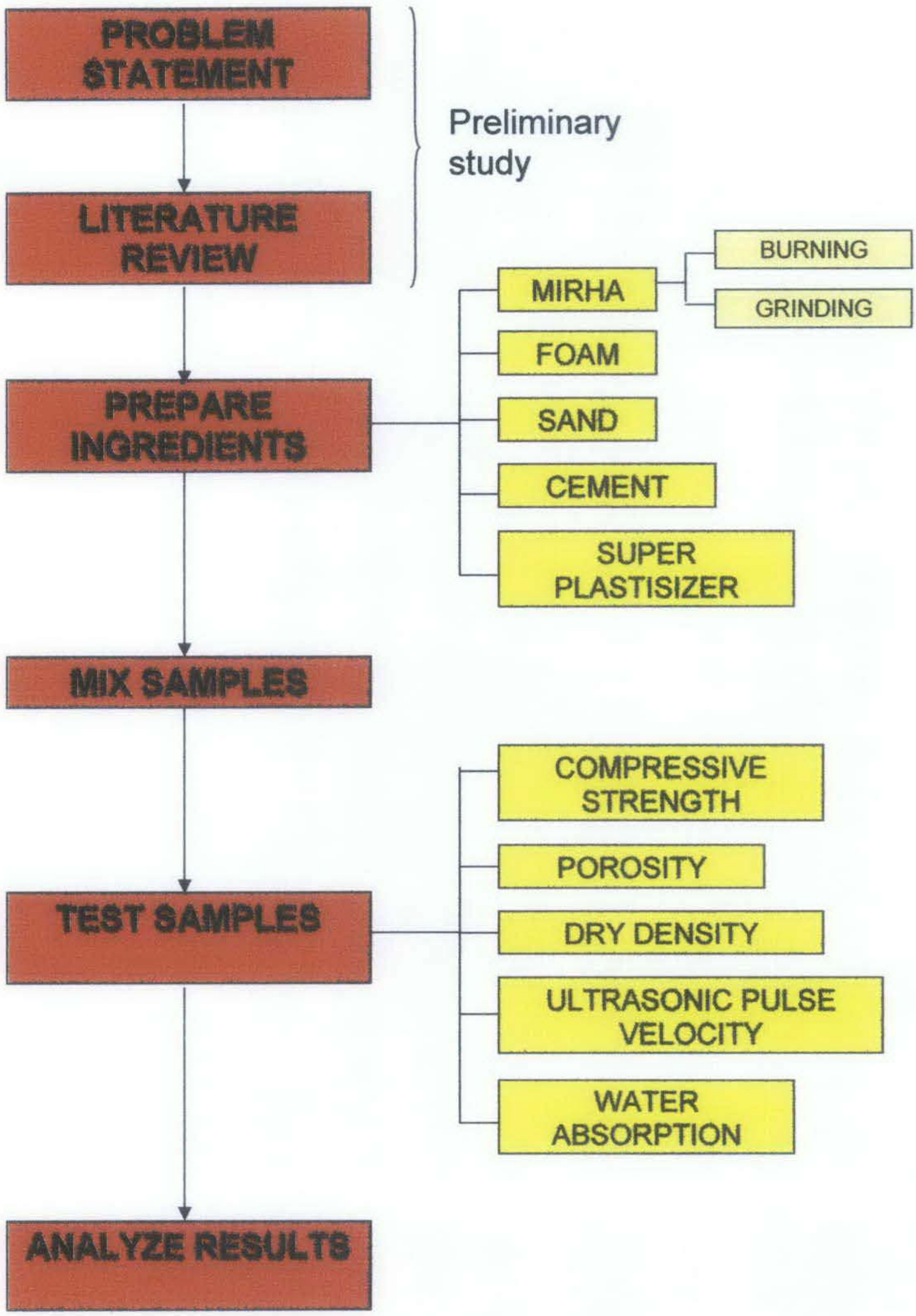

Figure 5: Flow chart of the project

3.4 MIXING PROCESS

Chemical liquid those are diluted with water and aerated forming the foaming agent. The foaming agent used was "Noraite SA-1," consisting of hydrolyzed proteins and manufactured in Malaysia. Foamed concrete is produced in the laboratory with standard inclined rotating drum mixer according to BS 1881-125.1986 by the adding of pre formed foam to mortar. The Plastic density measured in accordance with BS EN 12350-6, weighing a foamed concrete sample in pre weigh container of known volume. A tolerance on plastic density was set at 70-80 kg/m3 of the target.

The mix proportion used in this project is generated by using Taguchi method. It is done by arranging the parameters (refer Table 8) which are water to cementitious materials ratio (W/C), water content (W), fine aggregate content (sand), rice husk ash content (RHA) and Super plasticizer content (SP) using orthogonal array (refer Table 9). The mix proportion of used materials is given in Table 10. In mixtures containing rice husk ash, 0%, 5%, 10% and 15% of Portland cement by weight was replaced with rice husk ash. A super plasticizer was used to improve the workability. The cubic specimens (50 · 50 · 50 mm) were prepared to determine the effect of different temperatures on compressive strength.

Table 8: Parameters and their variation levels

Variable	unit	Level 1	Level 2	Level 3	Level 4
MIRHA	(%)	0	5	10	15
w/c	ratio	0.3	0.35	0.4	0.45
s/c	ratio	0.25	0.5	0.75	1
SP	(%)	1	1.5	2	2.5
FC	(%)	20	25	30	35

Table 9: Standard L_{16} orthogonal array

Exp. no	Independent variables					Dependent Variable (s) Performance parameter value
	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	
1	1	1	1	1	1	P1
2	1	2	2	2	2	P2
3	1	3	3	3	3	P3
4	1	4	4	4	4	P4
5	2	1	2	3	4	P5
6	2	2	1	4	3	P6
7	2	3	4	1	2	P7
8	2	4	3	2	1	P8
9	3	1	3	4	2	P9
10	3	2	4	3	1	P10
11	3	3	1	2	4	P11
12	3	4	2	1	3	P12
13	4	1	4	2	3	P13
14	4	2	3	1	4	P14
15	4	3	2	4	1	P15
16	4	4	1	3	2	P16

Table 10: Mixture proportion of concrete, w/c = 0.4

Code	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	MIRHA (kg/m^3)	Vol Foam ($liter/m^3$)	SP (kg/m^3)
LWFC-1	930	233	419	0	203	23
LWFC-2	950	475	285	0	238	19
LWFC-3	770	578	270	0	272	12
LWFC-4	620	620	248	0	324	6
LWFC-5	893	223	282	47	333	13
LWFC-6	703	352	333	37	298	7
LWFC-7	732	549	308	39	239	18
LWFC-8	703	703	259	37	240	18
LWFC-9	900	225	350	100	239	9
LWFC-10	810	405	360	90	194	12
LWFC-11	572	429	286	64	345	11
LWFC-12	648	648	216	72	305	16
LWFC-13	748	187	352	132	284	15
LWFC-14	663	332	273	117	342	17
LWFC-15	774	580	273	137	206	8
LWFC-16	565	565	299	100	267	8

3.4.1 Procedure for Mixing Samples

During the mixing process, a systematic procedure has been followed to ensure all the materials mixed well and optimal density can be achieved. Below are the procedures the author has followed during the mixing process;

1. All constituent materials are prepared first by measuring them according to mix proportion.
2. Firstly, the sand was inserted into the drum mixer and mixed for about 25 sec.
3. Half of water is added and mixed for about 1 min.
4. Cement is added with another half of water and mixed for about 1 min.
5. Finally, foam is added and the mixtures are mixed together for about 2 min.
6. The mixtures is then poured into the 50 x 50 x 50 mm moulds and let dried for about 1 day.

After the samples are dried, they have to be put in a tank containing water as to undergo curing process. Curing is essential for the concrete as to achieve best strength and hardness. Cement requires a moist, controlled environment to gain strength and harden fully. The cement paste hardens over time, initially setting and becoming rigid though very weak, and gaining in strength in the days and weeks following. In around 3 weeks, over 90% of the final strength is typically reached. Properly curing concrete leads to increased strength and lower permeability, and avoids cracking where the surface dries out prematurely. Care must also be taken to avoid freezing, or overheating due to the exothermic setting of cement. Improper curing can cause scaling, reduced strength and abrasion resistance and cracking.

3.5 LABORATORY TESTS

3.5.1 Compression Test

Compressive properties describe the behavior of a material when it is subjected to a compressive load. Loading is at a relatively low and uniform rate. Compressive strength and modulus are the two most common values produced. The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. The samples will be test at 3, 7 and 28 days with 6 samples per test.

Figure 6: Compressive Testing Machine

3.5.2 Porosity Test

Porosity is a measure of the void spaces in a material, and is measured as a fraction, between 0–1, or as a percentage between 0–100%. The procedure for porosity test is described as below;

Figure 7: Porosity equipment

1. Dry sample is vacuumed for 30 minutes
2. Water added to the vacuum tank. Sample is vacuumed with water for 6 hours and left for 24 hours.
3. After 24 hours, sample is weighted in air and the value is given as **a**. Then, it is weighted in water and the value is given as **b**.
4. Sample is dried in the oven for 24 hours. Then it is weighted and the value is given as **c**.
5. The value of porosity is calculated using the equation below;

$$\text{Porosity (\%)} = \frac{a - c}{c} \times 100\%$$

3.5.3 Ultrasonic Pulse Velocity (UPV)

The velocity of an ultrasonic pulse through a material is a function of the elastic modulus and density of the material. The pulse velocity can therefore be used to assess the quality and uniformity of the material. The ultrasonic pulse velocity (UPV) of a material can be determined by placing a pulse transmitter on one face of a sample of the material, and a receiver on the opposite face. A timing device measures the transit time of the ultrasonic pulse through the material. If the path length is known, then the UPV can be calculated from the path length divided by the transit time.

3.5.4 Dry Density

In this project, the dry density of the mixtures is also measured. Below is the procedure for dry density analysis;

1. Measure the apparent mass of the cylinders (1 inci) while suspended and completely submerged in water and record as "G", the mass of the suspended-immersed cylinders
2. Remove from the water and allow to drain for 1 min by placing the cubes on a 9.5 mm or coarser sieve cloth. Remove visible water with a damp cloth, determine the mass and record as "F", the mass of saturated surfaced dry cubes.
3. Place the cylinders in the drying oven for 72 h or until constant mass is reached. Maintain oven temperature at 110 +/- 5°C. Allow cylinders to cool to room temperature and determine the mass and record as "D"., the mass of the oven-dried cylinder

Dry density = (D x 997)/(F-G) kg/m³

3.6 HAZARD ANALYSIS

As the project running, Health, Safety & Environment (HSE) has to be taken into consideration. During the lab session there are several hazardous such as air pollution, noise and physical injuries might be occur. Thus, safety precaution has to be implemented in order to prevent any accident or injuries to happen. Before enter the lab, some safety equipments should be applied such as ear plug, hand glove, shoes, mask and etc. Each equipments and machineries in the lab should be run by referring to the manual first. Environmental policy of UTP also needs to be taken into considerations before starting the lab works. Hazard analyses have been done to determine some hazard effect of this project. Table 11 shows the hazard analysis that has been done.

Table 11: Hazard analysis of the project

HAZARD	SOURCE	ACTION
Dust	• Grinding MIRHA • Mixing concrete	Wear mask to protect dust from entering the nose and wear goggle to protect the eyes.
Noise	• Grinding MIRHA	Wear ear plug
Hand injury	• Preparing mould • Lifting heavy thing	Wear hand glove
Leg injury	• Scattered nails and other sharp tools • Lifting heavy thing	Wear shoes

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

Five tests were conducted on the samples which are Compressive Test, Porosity Test, Ultrasonic Pulse Velocity Test, Dry Density and Water Absorption. The results are shown as below:

Table 12: Test result on hardened concrete

MIX ID	Dry Density (kg/m3)	SSD Density (kg/m3)	3-day compressive strength (Mpa)	7-day compressive strength (Mpa)	28-day compressive strength (Mpa)	28 day UPV (m/s)	28 day Porosity (%)	28 day Water absorption (%)
M1	1,856	2,119	31.2	28.6	61.3	2,633	30	14
M2	1,899	2,145	54.9	43.0	76.5	2,183	22	11
M3	1,541	1,834	19.6	21.6	25.2	2,644	31	11
M4	1,340	1,621	12.4	11.0	13.8	2,821	40	13
M5	1,400	1,647	25.5	26.1	29.7	2,764	38	11
M6	1,504	1,860	22.8	24.5	26.6	2,368	34	20
M7	1,918	2,365	36.6	39.2	54.8	4,471	24	10
M8	1,886	2,196	45.0	56.3	63.9	4,743	22	11
M9	1,409	1,769	21.0	24.4	30.0	2,588	37	15
M10	1,517	1,888	24.6	30.3	37.5	2,776	29	16
M11	1,208	1,588	8.6	13.6	18.2	2,643	43	17
M12	1,668	1,958	23.3	30.2	40.1	3,123	26	11
M13	1,249	1,671	16.1	20.9	27.8	2,713	36	20
M14	1,412	1,777	26.6	25.2	30.8	2,940	30	14
M15	1,703	2,059	6.9	7.5	10.2	2,742	26	13
M16	1,374	1,671	15.7	20.1	25.5	3,002	30	16

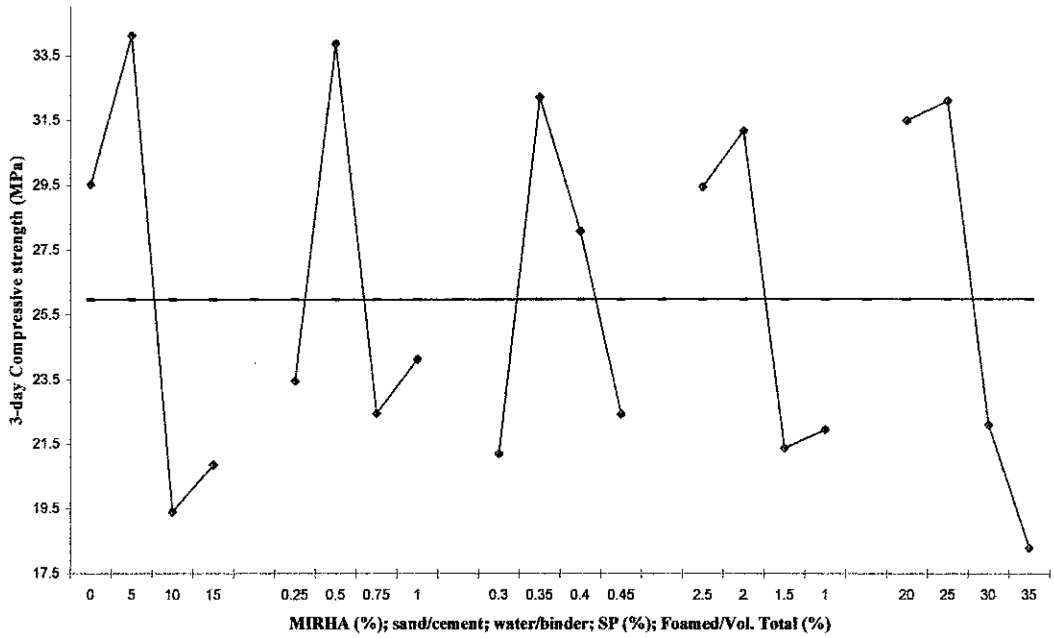

Figure 8: Main plot for 3-day compressive strength

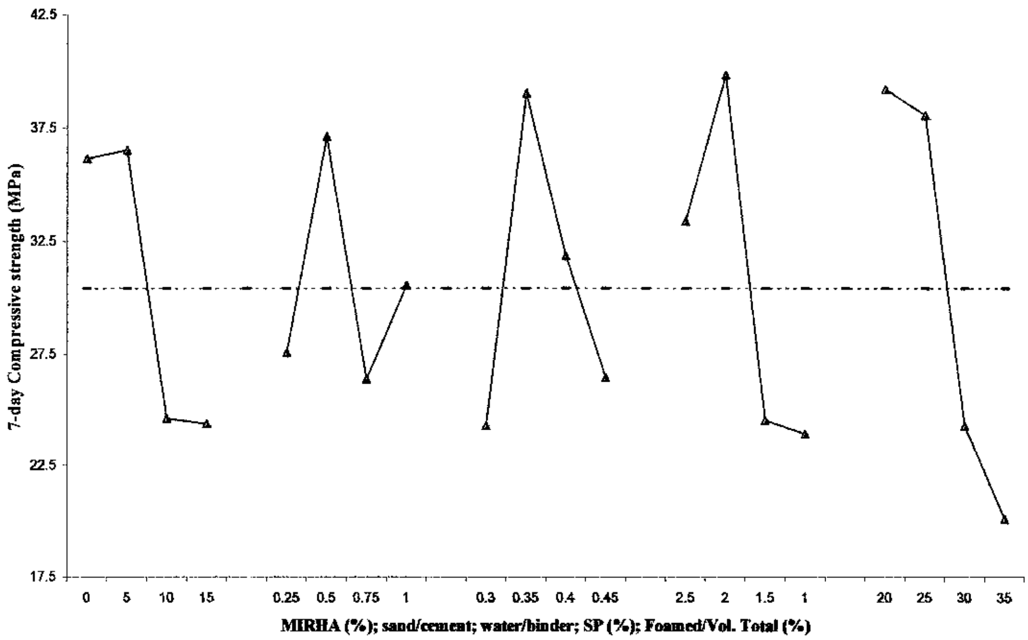

Figure 9: Main plot for 7-day compressive strength

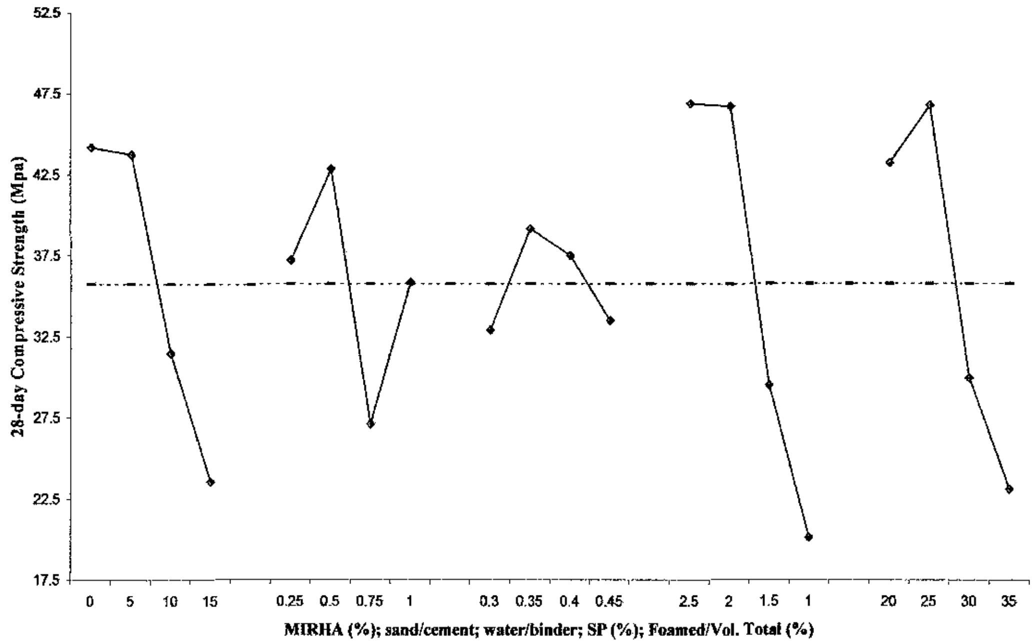

Figure 10: Main plot for 28-day compressive strength

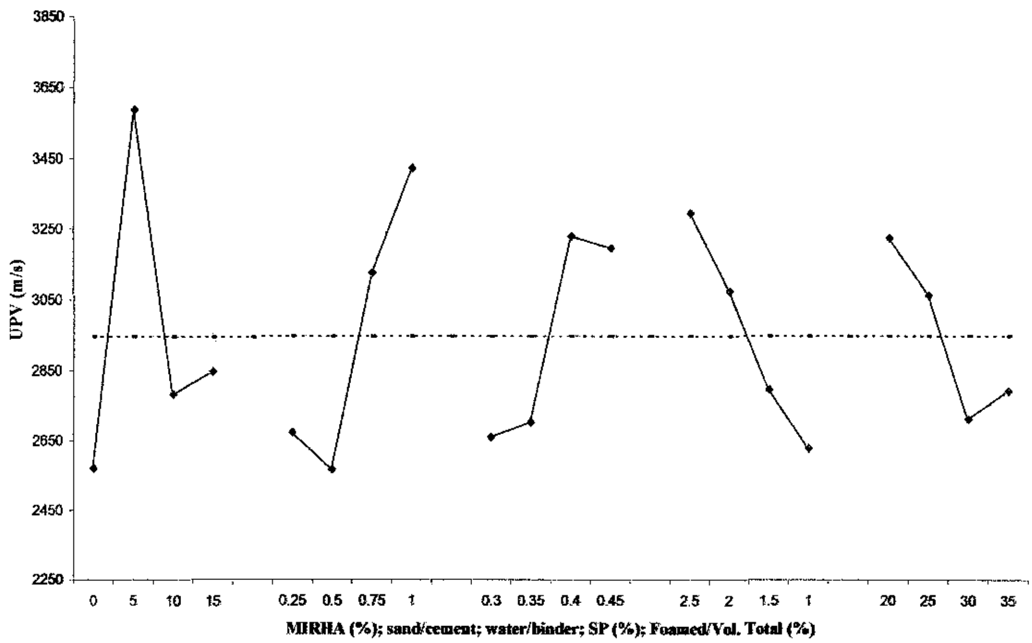

Figure 11: Main effect plot for 28-day ultrasonic pulse velocity

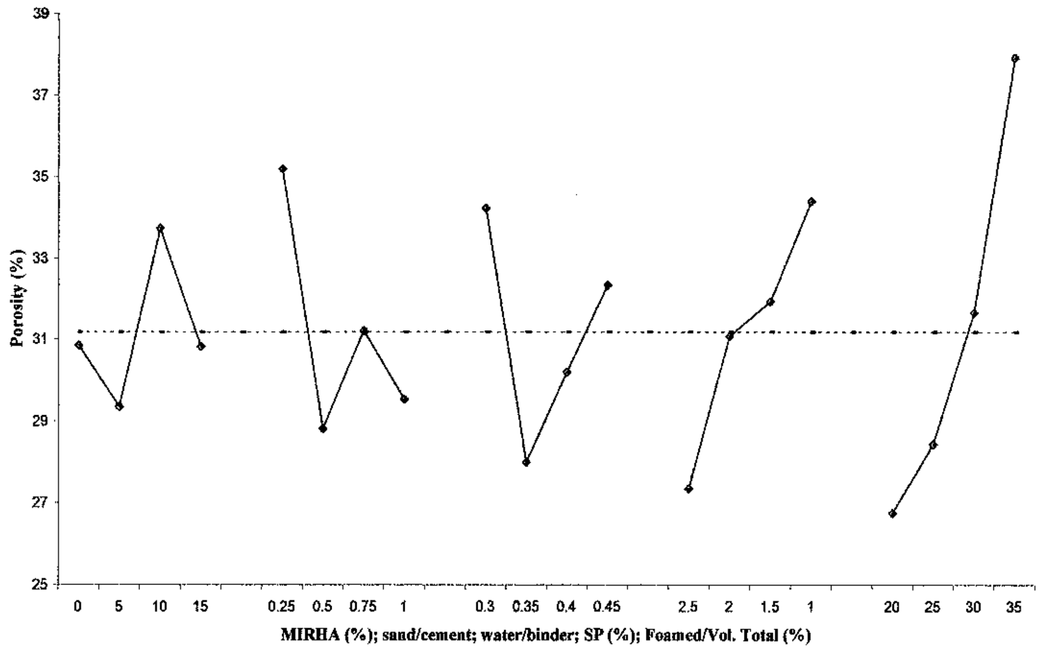

Figure 12: Main effect plot for Porosity

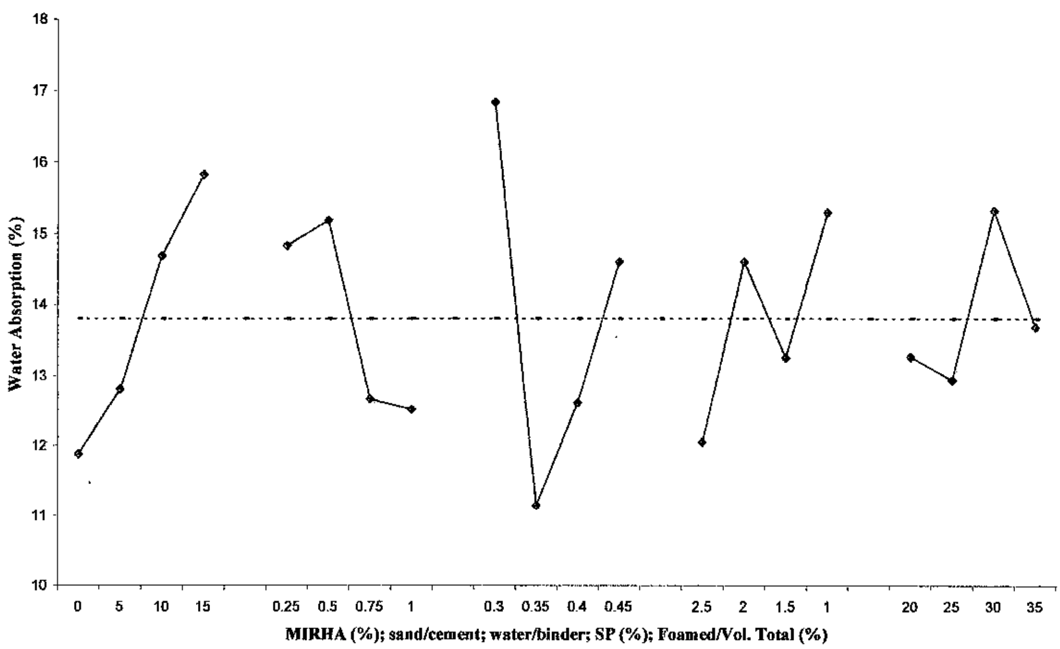

Figure 13: Main effect plot for water absorption

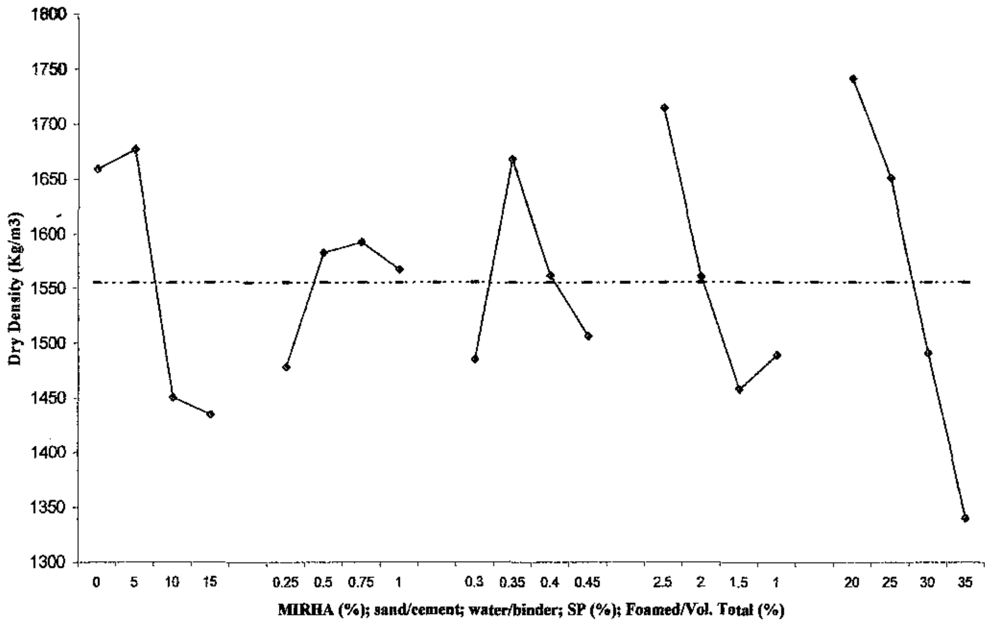

Figure 14: Main effect plot for dry density

4.2 DISCUSSION

The collected data were analyzed by using the ANOVATM computer software package for evaluation of the effect of each parameter on the optimization criterion. The results obtained are given in Table 11and the detail results for each parameter are shown in Figure 8-14.

The explanation of the graphs will be given in terms of example. For Figure 5, it shows the variation of the performance statistics as a function of compressive strength. As for example, below are some explanations in determining the experimental conditions for the first data point.

The MIRHA is level 1 for this parameter (see Table 8). Experiments corresponding to the MIRHA level 1 are found in Table 9 (Variable 3). It is seen in Table 9 that the experiments for which Variable 3 is 1 are experiments with numbers 1, 6, 11, and 16. Consequently, the performance statistics value of the first data point is the average of those obtained from the experiments with experiment numbers 1, 6, 11, and 16. The experimental conditions for the second data point, thus, are the conditions of the experiments for which Variable 3 is 2 (i.e. experiments with experiment numbers 2, 5, 12, and 15) and so on.

The optimal value for Water Absorption, Porosity and Dry Density are taken from the lowest value achieved by each parameter. It is because the lower the value, the concrete would be much better. The high value of water absorption, porosity or dry density gives bad impact to the concrete as it may reduce the hardness of the concrete and at the same time, reduce its strength. However, for Compressive Strength and UPV, the highest values are taken as optimal mix design. It is clear for compressive strength that the higher value shows that the concrete has higher strength. Meanwhile for UPV, the higher value means that the elasticity of the concrete is higher thus the concrete has better quality.

The optimal design of MIRHA for compressive strength is 5% at 3-day and 7-day age of concrete and 0% at 28-day age of concrete. However, the optimal mix design of MIRHA can be taken as 5%. It is because based on the results at 3-day and 7-day, the sample with 5% MIRHA can achieve high compressive strength which shows that the early strength concern is achievable. This can be concluded that as for future application, by adding 5% MIRHA, we don't have to wait for 28 days to achieve the high strength of the concrete.

From the data of compressive strength shows in Table 12 and Figure 8 – 10, it is informed that by adding MIRHA into foamed concrete, the early strength development is achieved. This is supported by Figure 8 and97 that show the strength of foamed concrete with 5% MIRHA achieve the highest strength in 3 and 7 days. However, most of the concretes with MIRHA have achieved the design strength which is 17 Mpa. It is proved that, this type of foamed concrete which incorporated MIRHA can be used as load bearing structure.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From this project, it was obtained that the optimal mix design properties of MIRHA foamed concrete for each proportion are shown in Table 13 as below;

Table 13: Optimal mix design properties for properties of Lightweight Foamed Concrete

Optimal mix Proportional	MIRHA/ cement (%)	sand/cement	water/binder	superplasticizer/ cement (%)	Foam/Total Vol (%)
Ultrasonic pulse Velocity	5	1	0.4	2.5	20
Water absorption	0	1	0.35	2.5	25
3-day compressive strength	5	0.5	0.35	2	25
7-day compressive strength	5	0.5	0.35	2	20
28-day compressive strength	0	0.5	0.35	2.5	25
Porosity	5	0.5	0.35	2.5	20
Dry Density	15	0.25	0.3	1.5	35

The effect of MIRHA on strength development of foamed concrete has been determined from the data of UPV, Compressive Strength and Porosity. It can be said that MIRHA can be applied to concrete in some amount as to maintain the strength to the concrete and at the same time, reduce the usage of OPC as to solve the problem that has been stated at the early phase of the project.

5.2 RECOMMENDATION

As for improvement, some factors should be taken into considerations which are;

- The effect of MIRHA to the concrete in terms of its permeability, workability and some other parameters as to get better mix design of MIRHA foamed concrete.
- The effect of other factors such as weather and environmental condition to MIRHA Foamed Concrete.

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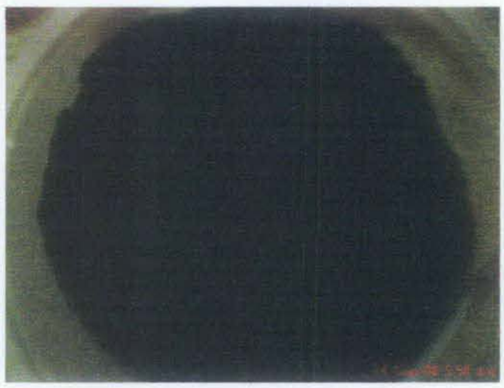
APPENDICES

Appendix A: Materials used for the project

Cement

Water with super plasticizer

Sand



MIRHA

Appendix B: Equipment used in the project

Concrete Mixer

Compression Testing Machine

Microwave Incinerator

Grinding Machine

Vacuum Tank (Porosity Apparatus)

Appendix C: Lab manual for mixing and sampling concrete

UNIVERSITI TEKNOLOGI PETRONAS	**UNIVERSITY TECHNOLOGY PETRONAS** **CIVIL ENGINEERING PROGRAMME** **BANDAR SERI ISKANDAR** **31750 TRONOH** **PERAK DARUL RIDZUAN**

MIXING AND SAMPLING FRESH CONCRETE

1. **OBJECTIVE**

   Mixing and sampling fresh concrete in the laboratory (as recommended by **BS 1881: Part 125:1986**)

2. **APPARATUS**

   A non-porous timber or metal platform, a pair of shovels, a steel hand scoop, measuring cylinder and a small concrete mixer (if machine mix)

3. **PROCEDURE**

   a. Weight the quantities of cement, sand and course aggregate to make 1:2:4 concrete mix at water ratio of 0.6

   b. Hand Mixing
      i. Mix cement and sand first until uniform on the non-porous platform
      ii. Pour course aggregate and mix thoroughly until uniform
      iii. Form a hole in the middle and add water in the hole. Mix thoroughly for 3 minutes or until the mixture appears uniform in color.

   c. Machine Mixing
      i. Wet the concrete mixer.
      ii. Pour aggregate and mix for 25 second.
      iii. Add half of water and mix for 1 minute and leave for 8 minutes.
      iv. Add cement and mix for 1 minute.
      v. Add remaining water available and mix for 1 minute.
      vi. Stop the machine and do hand mixing to ensure homogeneity.
      vii. Pour out the concrete onto the non porous surface.

4. **PRECAUTIONS**

a. The room temperature should be approximately 25-27 C

b. Make sure that fine and aggregate are dry. If they are wet find the content of the aggregates to determine the quantity of water required.

Appendix D: Lab manual for compressive strength test

UNIVERSITY TECHNOLOGY PETRONAS
CIVIL ENGINEERING PROGRAMME
BANDAR SERI ISKANDAR
31750 TRONOH
PERAK DARUL RIDZUAN

COMPRESSIVE STRENGTH TEST CUBES – TEST FOR STRENGTH

1. OBJECTIVE

To determine the compressive strength (Crushing strength) of concrete according to **BS 1881: Part 116: 1983**

2. THEORY

One of the most important properties of concrete is its strength in compression. The strength in compression has a definite relationship with all other properties of concrete. The other properties are improved with the improvement in compressive strength.

The compressive strength is taken as the maximum compressive load it can be carry per unit area. Compressive strength tests for concrete with maximum size of aggregate up to 40mm are usually conducted on 150mm cubes.

3. APPARATUS

Compression Testing Machine (it complies with the requirement of **BS 1610**)

4. PROCEDURE

a. Remove the specimen from curing tank and wipe surface water and grit off the specimen.

b. Weight each specimen to the nearest kg.

c. Clean the top and lower platens of the testing machine. Carefully center the cube on the lower platen and ensure that the load will be applied to two opposite cast faces of the cube.

d. Without shock, apply and increase the load continuously at a nominal rate within the range 0.2N/mm^{2}s to 0.4 N/mm^2 until no greater load can be sustained. Record the maximum load applied to the cube.

e. Note the type of failure and appearance of cracks.

f. Calculate the compressive strength of each cube by dividing the maximum load by the cross sectional area. Express the results to the nearest 0.5 N/mm^2

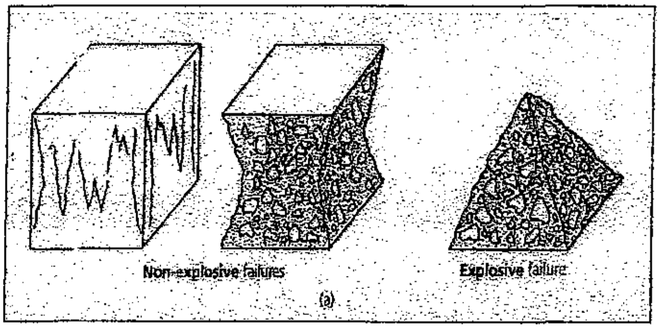


FIGURE 5: The outcome of cube test – normal case

Appendix E: Lab manual for Ultrasonic Pulse Velocity (UPV) Test

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ULTRASONIC PULSE VELOCITY TEST (UPV)

1. OBJECTIVE

The UPV test is designed to study the quality of the concrete in existing structures. It also can be used to determine the dynamic modulus of elasticity, dynamic Poisson's ratio, homogeneity, estimated compression strength, depth of crack, thickness of damaged layers and density of concrete. Fire damaged structures can also be assessed using this non destructive testing technique. Test done using the UPV test technique conforms to **BS 1881: Part 201:1986** "*Non-Destructive*" methods of test for concrete measurement of the velocity of ultrasonic pulses in concrete.

2. APPARATUS

A pulse of longitudinal vibrations is generated by an electro-acoustical transducer (transmitter) and received by a similar receiver which is placed on the opposite side of the concrete member under test. The time taken (transmit time) for the pulse of vibration to travel between the transmitter and receiver when divided by the transmit time (t) gives the pulse velocity, V = L/t

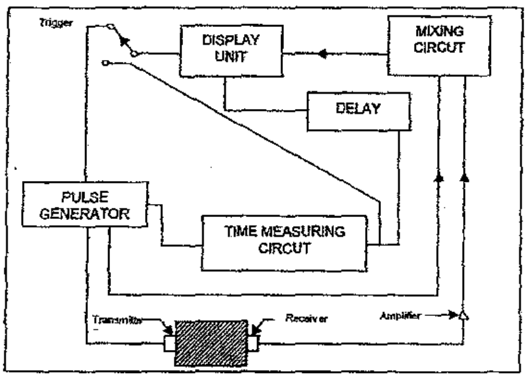

FIGURE 7: Schematic Diagram

3. PROCEDURE

a. Labeled the faces of the concrete cube with A, B, C, D, E and F
b. Make sure that A and B are place on the opposite faces.
c. The same rule applies to C,D ,E and F
d. Use of a coupling gel between the transducer and the concrete cubes or structures.
e. The transmitting and receiving transducers are placed on opposite surfaces of the concrete cube.
f. Push the transmitting and receiving transducers as strong as possible.
g. Take the lowest reading measured by UPV device

4. METHOD

The equipment (PUNDIT) used to determine the Ultrasonic Pulse Velocity in concrete consists of a transducer, receiver and the Main Control Unit. Different arrangements to determine ultrasonic pulse velocities are possible when testing concrete members for quality. Depth of cracks in test members can be determined by placing the transducers across the crack as shown in figure below.

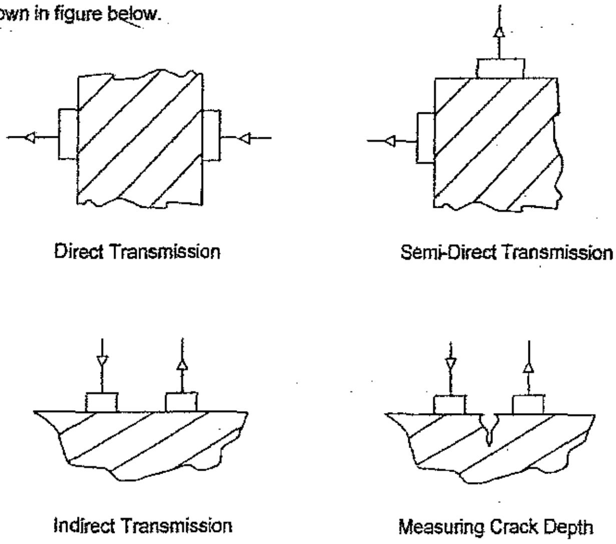

FIGURE 8: Determine Ultrasonic Pulse Velocities