CHAPTER 3

MATERIAL CHARACTERISTICS WORK AND
TESTING PROCEDURES

3.1 Introduction

Concrete having compressive strength at 28 days started with 70N/mm^2 and above has been widely used in construction industry throughout the world. Concrete with a strength stated above has been known as high strength concrete (HSC). It is due to a better engineering and performance properties of a concrete.

In mix proportioning of concrete, Ordinary Portland Cement (OPC) remains a basic hydraulic binder. In obtaining HPC, high performance cement with filler effect and pozzolanic action known as mineral admixture is needed. These properties of minerals admixtures improve cement matrix at microstructure level during hydration of cement.

Phase 1 involved a preliminary test on the design of mix proportion of MIRHA concrete. The mixes proportion of concretes containing prepared binders was select from table 2, BS4550: Part 3: section 3.4: 1978. The objective of the mix proportioning is to determine the most appropriate proportions of the constituent materials for grade 70 concrete. Different replacement levels of MIRHA at 5%, 7.5% and 10% by weight of cement, with the addition of superplasticizer (Sp) were carried out.

Phases 2, 16 series of mixes were batched. The 1st series were the reference batches, i.e. 100% OPC with Sp. The 2nd series consisted of mixes in which OPC was replaced

by different percentages of MIRHA (5%, 7.5%, 10%). The 3rd series consisted of mixes in which OPC was replaced by 8% for consistency of SF. The 4th series consisted of mixes in which OPC was replaced by 10% for consistency of PFA. The 5th series consisted of mixes in which OPC was replaced by different percentages of MIRHA (5%, 7.5%, 10%), 8% SF and 10% PFA under Multiple Blended Binders. Table 3.1 present the design mix ratio for Multiple Blended Binders Concrete

Table 3.1: Design mix ratio

Item	OPC (%)	MIRHA (%)	SF (%)	PFA (%)
1	100			
2	95	5		
3	92.5	7.5		
4	90	10		
5	92		8	
6	87	5	8	
7	84.5	7.5	8	
8	82	10	8	
9	90			10
10	85	5		10
11	82.5	7.5		10
12	80	10		10
13	82		8	10
14	77	5	8	10
15	74.4	7.5	8	10
16	72	10	8	10

In Phase 3, mechanical tests were conducted based on mixes derived from the 16 mix series sample. The mechanical tests performed were the compressive strength, flexural strength, tensile splitting strength, ultrasonic pulse velocity, rebound hammer and gas permeability.

3.2 Materials Used

The constituent materials used in the laboratory used Portland cement (Ordinary Portland Cement BSEN 197-1-2000), crushed aggregate with maximum size of 20mm according

to BS 812-103.2 1989, natural sand, with 100 % passing 425 mm sieved (BS EN 12620:2002), microwave incinerator rice husk ash (MIRHA) with high reactive silica content, free water (BS 3148: 1980), superplasticizer (BS 5075-3:1985 and ASTM C494/C 494M-2004), silica fume (SF) and pulverized fuel ash (PFA).

3.2.1 Ordinary Portland Cement (OPC)

The type of cement used was the Ordinary Portland Cement (OPC) branded 'Cap Rumah' supplied by the Lafarge Malayan Cement (Ordinary Portland Cement BSEN 197-1-2000) was used in the research. It was stored in a dry area to prevent from moisture. The chemical properties of OPC used are shown in Table 3.2.

Table 3.2 OPC Binder Properties

Oxide composition	Weight (%) OPC
Na_2O	0.02
MgO	1.43
Al_2O_3	2.84
SiO_2	20.44
P_2O_5	0.10
K_2O	0.26
CaO	67.73
TiO_2	0.17
Fe_2O_3	4.64
SO_3	2.20
MnO	0.16

Noted : The sample were examined by X-ray diffraction (XRD) model Bruker AXS D8 ADVANCE. Tested done at SIRIM

3.2.2 Microwave Incinerator

The rice husks are residue produced during the defusing operation of paddy rice, and microwave incinerator rice husk ash is the ash produced from the burning of rice husk.

The rice husk used in the present investigation was obtained from a rice mill in Changkat Lada, Perak, Malaysia.

Microwave incinerator of materials offers a number of advantages over conventional incinerator methods. Microwave energy can penetrate the material, achieving rapid internal incinerator which may also improve the structural properties of the product. Along with the possibility of a more controlled incinerator, this results in an efficient process that has the potential to reduce the requirements on time and energy. Microwave incinerator heated produce sintering, drying and joining.

3.2.2.1 Benefits of Microwave Incinerator

There is a fundamental difference in the nature of microwave incinerator when compared to conventional methods of incinerator materials. Conventional incinerator relies on one or more of the heat transfer mechanisms of convection, conduction, or radiation to transfer thermal energy into the materials. 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. In microwave incinerator, 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 incinerator does not rely on conduction from the surface to bring heat into thecore region. Since the incinerator rate is not limited by conduction through the surface layer, the material can be heated more quickly. Another important aspect of microwave incinerator is that it results in a temperature gradient in the reverse direction compared to conventional incinerator, that is to say, the highest temperatures occur at the centre of the object and heat is conducted to the outer layers of the material.

For operations such as material drying, this effect is highly beneficial. In addition to the reversal of the temperature gradient, the gradient is smaller compared to conventional incinerator because the heat is generated from all parts of the materials that are receiving the radiation. This effect reduces the internal stresses in the material and can help eliminate problems such as cracking that may occur when the internal stresses become too large. In some cases, the difference in product quality between the two incinerator methods is sufficient to justify the use of microwave incinerator. In other cases, the smaller equipment used in microwave incinerator devices may be essential to fitting a new device within the limited existing space in a factory. In most instances where microwave incinerator is economically justifiable, the shorter process time afforded by the volumetric incinerator aspect tips the scales in favor of microwave incinerator. The bottom line is that microwave incinerator has more potential than is economically affordable in some instances.

3.2.2.2 Microwave Incinerator Application

Drying of materials involves the mechanisms of heat and mass transport. Heat must be delivered into the material as a means to drive moisture from the material. Incinerating the material causes an increase in the saturation vapur pressure within the material, so that it is higher at the surface than the partial pressure of the surrounding air. The resulting pressure gradient drives moisture from the material by means of evaporation. The drying

rate of a material is limited by the rate at which capillary suction draws moisture to the surface from within the material. When using conventional incinerator methods, the temperature gradient and moisture gradient in the material occur in opposite directions because the material is heated externally. This can result in excessive drying of the surface layers, or "crusting". This in turn inhibits the transfer of heat into the material and the transport of moisture to the surface. Both of these effects are detrimental to the drying rate. Using microwave incinerator, both the temperature and moisture gradients occur in the same direction. This effect minimizes the likelihood of crusting and optimizes the rate

f moisture removal from the material. Increasing the drying rate with the use of microwaves allows for the use of smaller drying units in industrial processes.

Companies employing the use of microwaves in the printing industry report a 30% cost savings compared to conventional incinerator for the task of drying the ink in printed materials. An added benefit of this technology in the drying process for certain products, such as paper, is that the risk of fire is eliminated since the use of open-flame heaters has been discontinued.

Drying rates are increased while the product temperature only reaches 80° F instead of 200°-300° F as with conventional incinerator. Glued products can be dried much more quickly, and leather products can be dried in 30%-50% less time after tanning and with less shrinkage using microwaves. Due to the penetrating effects of microwaves, large poured molds used in the foundry industry can be dried faster and with improved product quality. In the case of large foundry molds, the low thermal conductivity of the material and high thermal gradients present in drying creates significant complications such as cracking, when conventional incinerator methods are employed. In the plastics industry, where solvents must be removed from the product, microwave incinerator is highly effective because the solvents are heated more readily than the material. The selective incinerator of the solvents results in less distortion and damage to the final product.

One of the most interesting industrial applications involves the use of microwaves to generate extreme internal stresses in rock and concrete to "crush" the material for removal or disposal. One industrial application that results in superior material quality with microwave incinerator is the sintering of ferrite and ceramic materials. Sintering involves applying pressure and heat to a mold filled with granular or powdered material to cause the grains to fuse together into a solid entity.

3.2.2.3 Basics of Microwave

Microwaves are part of the electromagnetic spectrum are located between 300 MHz and 300 GHz. Microwave incinerator is defined as the incinerator of a substance by electromagnetic energy operating in that frequency range. The term radio frequency is used for high frequency mainly in the United Kingdom. The infrared region is located between microwaves and visible light. Only restricted microwave or high frequencies are freely allowed for incinerator in industrial, scientific, and medical applications, the so-called ISM frequencies. Of these, only 2450 MHz is commonly used in food processing in Europe, while 915 MHz dominates in America and 896 MHz in the UK. Higher frequencies are not in active use.

3.2.2.4 Principle of Paddy Husk Microwave Incinerator *(microwave kiln (INC-21))* **operation**

Bench scale result shows that paddy husk is a good dielectric material and can absorb the microwave energy more efficiently when it carbonised. This microwave kiln (INC-21) uses the microwave energy as the only incinerator source to burn the paddy. The kiln consists of a metallic cavity, a refractory and insulation, waveguide, microwave generator, mode stirrer and microwave leakage proof feeding and discharging door.

The metallic cavity is used to house both the material and the microwave energy, where both are interacted to generate the heat. After starting the microwave firing, microwave tends to carbonize the material first volumetrically and then once it is burning temperature the material start burning and thus the heat of combustion of the paddy husk is just enough to sustain the temperature inside the cavity. Once the material burned, the microwave energy will generate heat inside the carbonised material and keep it at the specified temperature. Only the material is heated by microwave and becomes the source of incinerator, while the empty part of the chamber together with the lining will be kept at relatively lower temperature. Plate 3.1 shows the detailing for Microwave Incinerator used to burn the paddy.
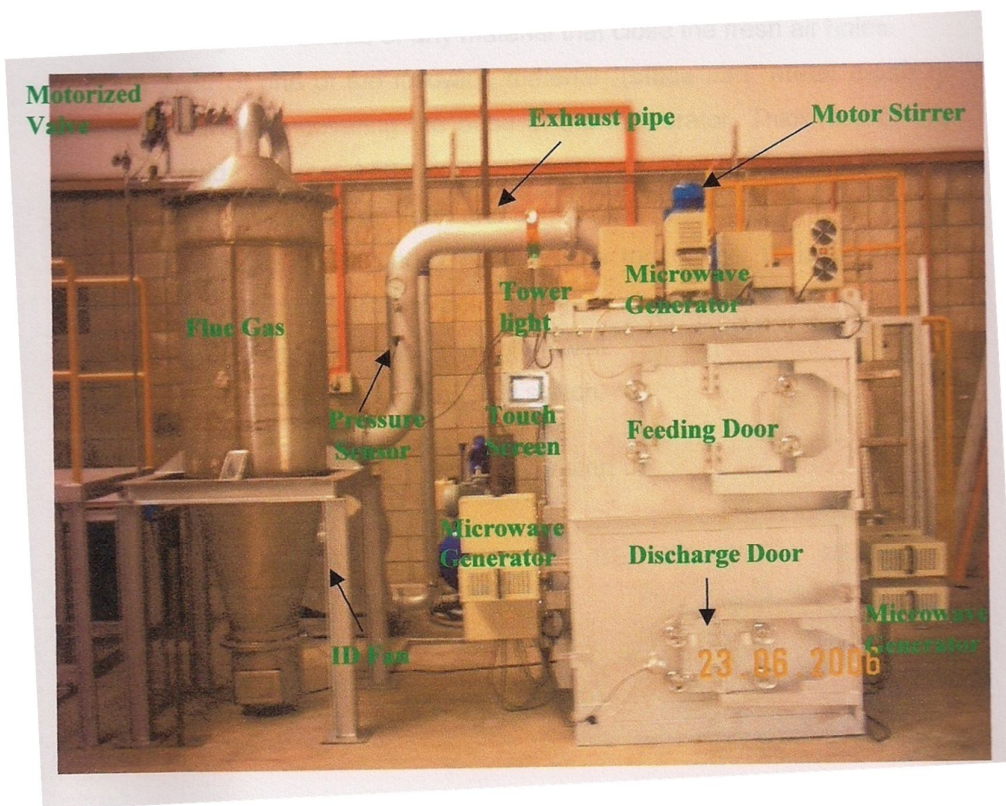
Adapted from manufacturer Pollution Engineering Sdn. Bhd.

Plate 3.1: Detailing for Microwave Incinerator

3.2.2.5 Combustion of MIRHA

MIRHA was produced from the Rice Husk Carbon (RHC) that was obtained from a rice mill in Changkat Lada, Perak. The burning of rice husk in a microwave incinerator was carried out at the concrete laboratory, Department of Civil Engineering, Universiti Teknologi Petronas, Malaysia. For each incineration, eight gunny sacks (80kg) of rice husk were used. There is one big door (discharge door) provided underneath the furnace for ventilation purposes and to start fire. The design of the microwave incinerator was based on UTPMI (Automatic UTP Microwave Incinerator) as shown in plate 3.2. After maintaining the flame for about 20 minutes, the eight gunny sacks (80 kg) of husk were allowed to burn slowly for about 2 hours at 800^0C. The ash was left to cool down inside the microwave incinerator for 24 hours before taken out for grinding.

Plate 3.2: Automatic UTP Microwave Incinerator

3.2.2.6 Grinding of MIRHA

After burning and cooling, the rice husk ash (remained in the cage) was removed from the microwave incinerator. The grey colour amorphous was taken and placed inside the Los

Angeles (LA) grinding machine. The LA machine consists of a rotating drum with an opening at the centre top of the drum. Fourteen numbers of mild steel balls of 50 mm diameter were placed inside the drum together with 5 kg of burnt ashes. For each grinding, the drum was set to rotate for 2997 revolutions using an electric motor at a speed of 33.3 rpm (revolution per minute). The time taken for grinding was about 2 hours and 30 minutes. Plate 3.3(a, b) shows the Los Angeles machine used for grinding the ashes into a finer form.

The ash was then grounded in a ball mill machine (Plate 3.3) for 2 hours to obtain a fineness that is almost equivalent to that OPC fineness requirement which is 18% retained on 45µm sieve as prescribed by BS 3892: Part 1: 1982.

(a) Grinding machine

(b) 16 nos. steel ball

Plate 3.3 : Grinding machine with steel ball

3.2.2.7 Composition of MIRHA

Table 3.3 also presents the chemical compositions of MIRHA used in the investigation. It is found that SiO_2 is a major compound found in MIRHA compared to other compositions. MIRHA used in this study was found to contain about 90.7% of SiO_2. The amount of SiO_2 in RHA may vary depending on properties of rice husk used, temperature and period of firing during production of RHA (Cook, 1986). Malhotra et a1 (2004) stated that the SiO_2 content of the commercially RHA produced generally ranges between 80% to 95% depending on the unburnt carbon present in RHA. MIRHA also found to contain about 0.87% of CaO, 0.75% of Al_2O_3, 0.28% of Fe_2O_3 and 0.63 % of MgO. The amount of CaO contains in MIRHA is the highest compared to other pozzolans study in this investigation. The presence of CaO in the MIRHA will increase the amount of CaO contains in OPC when it was used as cement replacement materials to OPC. The increments of CaO may lead the cement paste to having soundness problems and deleterious expansion (Neville, 1997).

Table 3.3 MIRHA Binder Properties

Oxide composition	Weight (%) MIRHA
Na_2O	0.02
MgO	0.63
Al_2O_3	0.75
SiO_2	90.75
P_2O_5	2.5
K_2O	3.77
CaO	0.87
TiO_2	0.02
Fe_2O_3	0.28
SO_3	0.33
MnO	0.08

Noted : The sample were examined by X-ray diffraction (XRD) model Bruker AXS D8 ADVANCE. Tested done at SIRIM

MIRHA used in the investigation was also classified according to ASTM C6l8, where the total amount of principal oxides named as $SiO_2 + Al_2O_3 + Fe_2O_3$ is 91.78%, that is, about 18.45% more than the minimum requirement stated by ASTM C618. The chemical properties of MIRHA used are shown in Table 3.3.

Percentage of MIRHA used in this research was selected after done the testing for cubes by vary percentage of MIRHA (4%, 5%, 7.5%, 10% and 12% as shown in Figure 3.1. Base on that result, 5%, 7.5% and 10% MIRHA as a cement replacement was selected.
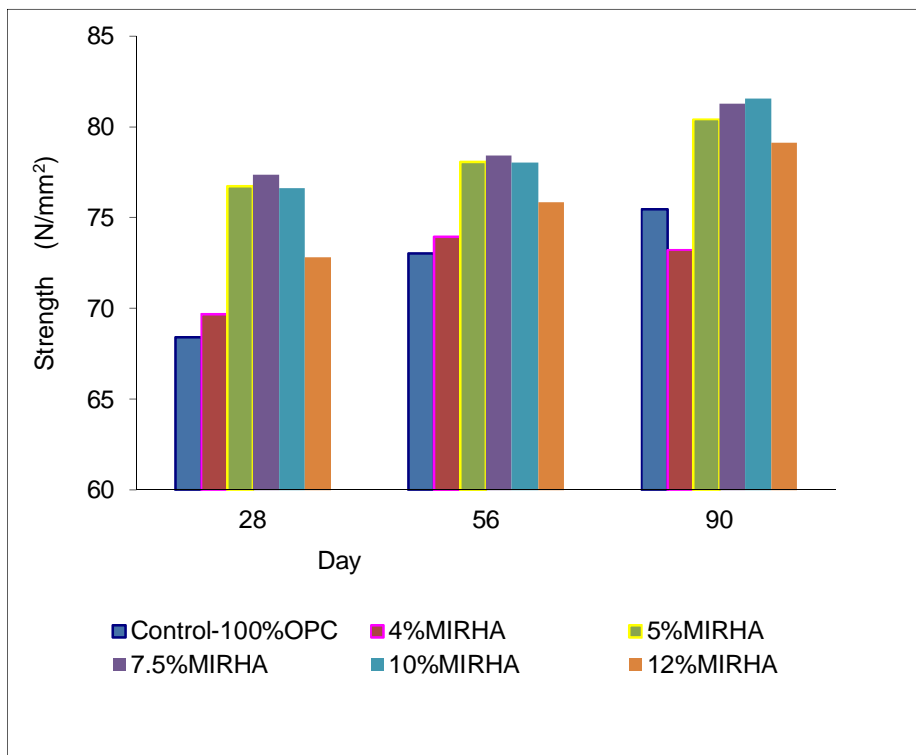

Figure 3.1: Strength development for cement replacement using MIRHA.

3.2.3 Silica Fume (SF)

Silica Fume (SF) used in this study is that which is commercially available in market and supplied by MBT (Malaysia) Sdn. Bhd. It was supplied in a 25kg/pack and was stored in an air tight container The SF was analysed in accordance with ASTM specification C 1240-04. The chemical properties of SF used are shown in Table 3.4.

Table 3.4 Silica Fume (SF) Binder Properties

Oxide composition	Weight (%) SF
SiO_2	91.7
Al_2O_3	1
Fe_2O_3	0.9
CaO	0.68
MgO	0.8
SO_3	0.87
Na_2O	0.1
K_2O	1.3
LOI	2.64

Noted : The sample were examined by X-ray diffraction (XRD)
 model Bruker AXS D8 ADVANCE. Tested done at SIRIM

Percentage of SF used in this research was selected after done the testing for cubes by vary percentage of SF (4%, 6%, 8% and 10% as shown in Figure 3.2. Base on that result, 8% SF as a cement replacement was selected.
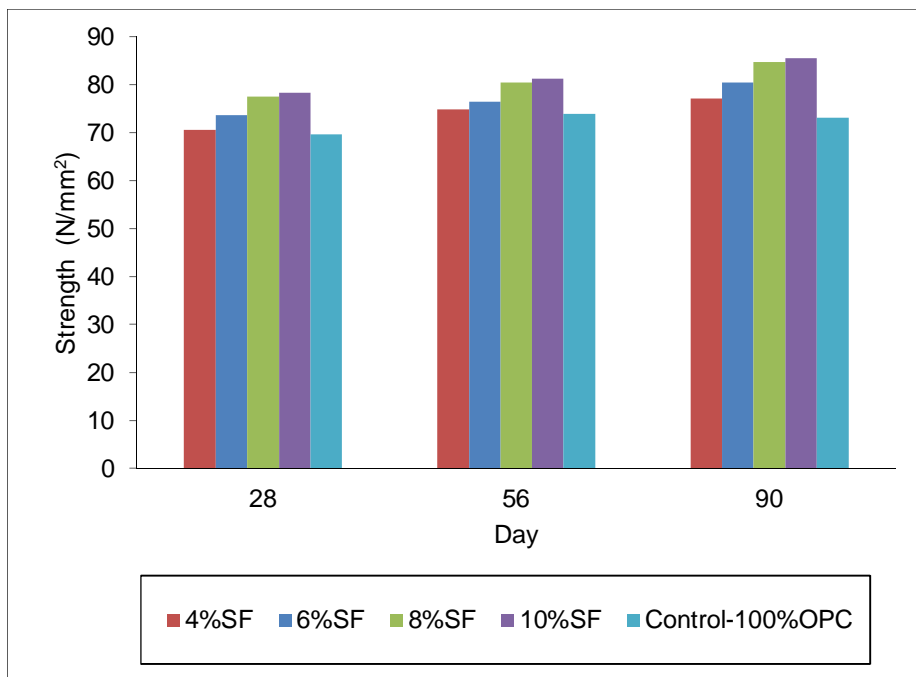

Figure 3.2: Strength development for cement replacement using SF.

3.2.4 Pulverized Fly Ash

PFA used in this study was PFA that produced from coal-burning power plants at Lumut, Perak.   It is a siliceous or aluminous material which possesses no binding ability by itself. When it is in finely divided form, they can react with calcium hydroxide in the presence of moisture to form compounds with cementing properties. During cement hydration with water, calcium hydroxide is formed which is non-cementitious in nature.

However, when pulverized fly ash is added to calcium hydroxide, they react to produce calcium silicate hydrates which is highly cementitious. This results in improved concrete strength. This explains how pulverized fly ash can act as cement replacement. The studied properties were check and compared with the ASTM specification C 618. The chemical properties of PFA used are shown in Table 3.5.

Table 3.5: Chemical Composition and Physical Properties of PFA

Oxide composition	Weight (%) PFA
SiO_2	45.2
Al_2O_3	20.52
Fe_2O_3	11.99
CaO	2.51
MgO	2.30
SO_3	0.55
K_2O	0.72
Na_2O	0.14
LOI	16.05

Noted : The sample were examined by X-ray diffraction (XRD)
 model Bruker AXS D8 ADVANCE. Tested done at SIRIM

Percentage of PFA used in this research was selected after done the testing for cubes by vary percentage of SF (4%, 6%, 8%, 10% and 12% as shown in Figure 3.3. Base on that result, 8% SF as a cement replacement was selected.
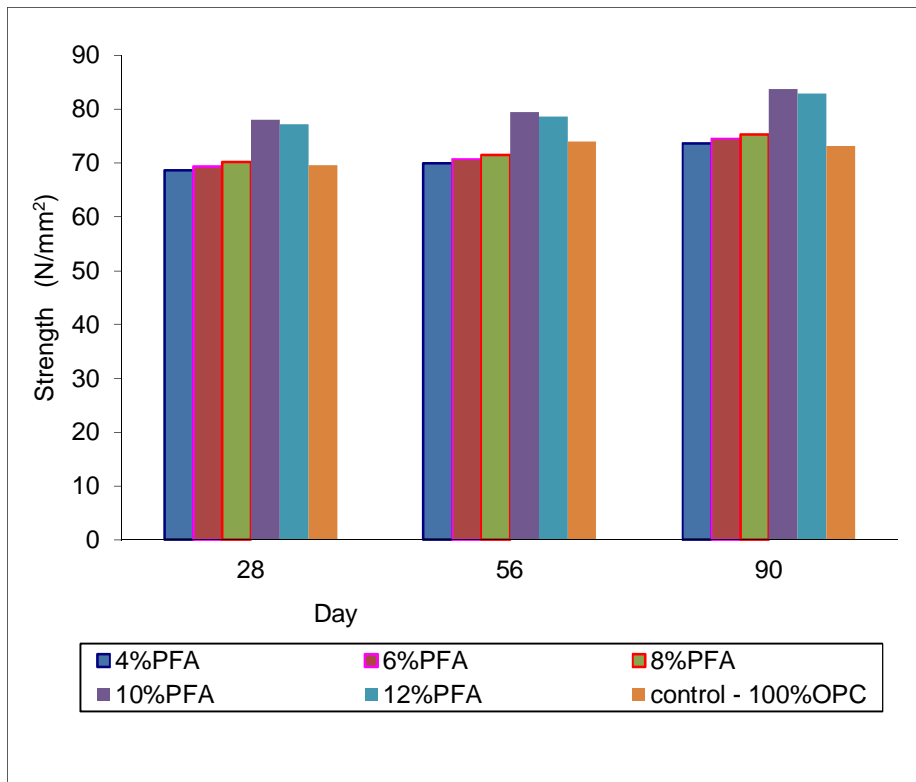
3.3: Strength development for cement replacement using PFA.

3.2.5   Aggregates

3.2.5.1 Size Classification

The sizes of aggregate used in concrete ranged from tens of millimeters down to the order of a tenth of a millimeter in cross-section. The maximum size actually used varied but in any mix particles of different sizes are incorporated, the size distribution being referred to as grading. Basically, it is possible to distinguish the sizes of aggregate into two types: (Neville, 1997).

3.2.5.2 Coarse Aggregates

The coarse aggregates used was crushed granite of angular shape and of rough surface texture. The maximum size of the coarse aggregates was 20mm according to BS 882. 1992. The grading is shown in Table 3.6.

Table 3.6: BS 882: 1992. Grading limits for coarse aggregates

Sieve Size (mm)	Percentage by mass passing sieve	BS882 grading limits for coarse aggregate
20.0	100	100
14.0	95.36	90-100
10.0	63.93	50-85
5.0	5.22	0-10
2.36	0	-

Fine and coarse aggregates such as river sands and gravels, crushed sands and stones, silica sands and artificial lightweight aggregates recommended for ordinary mortar and concrete are used for cement mortar / latex mixes. The aggregates should be clean, sound and have a proper grading as shown in Figure 3.4.
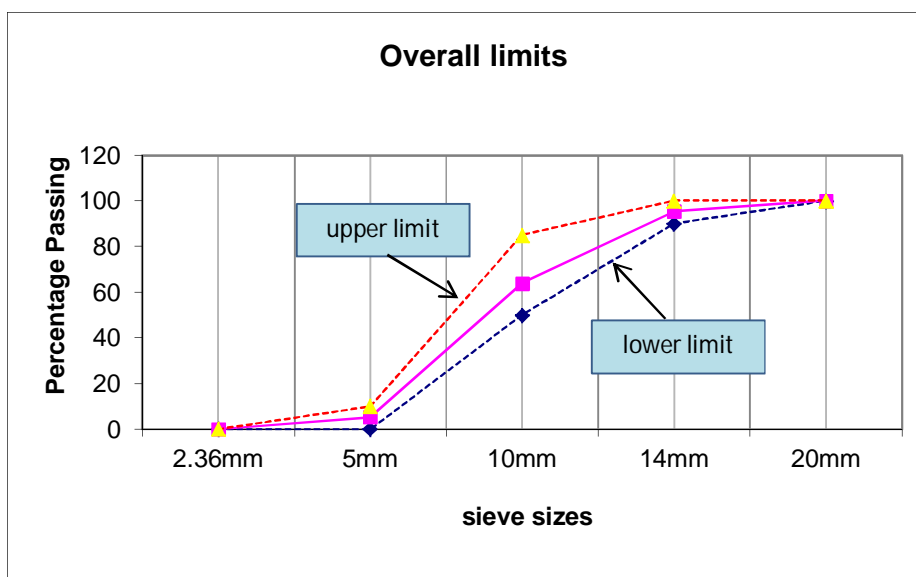
Overall limits

Figure 3.4: Grading curve coarse aggregate

3.2.5.3 Fine Aggregates

The fine aggregates used were obtained from Tronoh, Perak. A sieve analysis was carried out on representative sample in accordance with B.S. 812: 1991. Result indicated that the sand complied with the requirement of BS 882. 1992 where it has fallen into zone overall limits. The grading is as shown in Table 3.7.

Table 3.7: Grading for fine aggregate

Sieve Size (mm)	Percentage by mass passing sieve	BS882 grading overall limits for fine aggregate
10	100	100
5	95.21	89-100
2.36	75.49	60-100
1.18	64.13	30-100
600 μm	44.84	15-100
300 μm	22.34	5-70
150 μm	6.05	0-15

Sand is generally considered to have a lower size limit of about 0.07mm or a little less. Material between 0.06mm and 0.002mm is classified as silt, and particles which are smaller are termed clay. The overall is as shown in Figure 3.5.
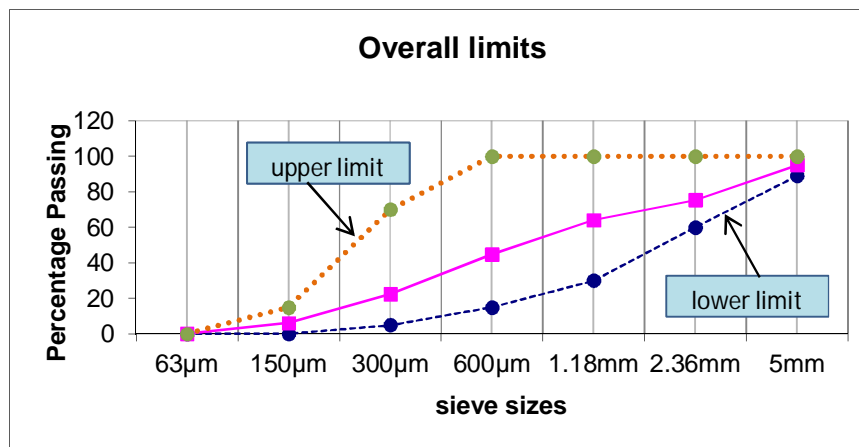

Figure 3.5: Grading curve fine aggregate

3.2.5.4 Physical Properties

The aggregate shape and surface texture influence the aggregate-cement paste bond area and bond strength. Irregular shape and rough surface texture increase the strength of concrete, particularly the tensile and impact strength. Crushed aggregate improves the cracking stress and the strength of the concrete. The effect of the surface texture is significant when the water cement ratio is below 0.40 and is negligible when the water-cement ratio is 0.65.

Shape can favorably influence strength by increasing the amount of surface area available for bonding with the pastes for a given aggregate content. However, extremes in aggregate shape may lead to high internal stress concentration and hence, easier bond failure (Mindess,Young et al., 2008)

3.2.6 Water

The quality of water used plays a significant role to the properties of binders or concrete mix. Impurities in water may interfere the setting time of cement or binders. It may also adversely affect the strength of concrete or cause staining the concrete surface and may also lead to corrosion of the reinforcement in reinforced concrete system. Mixing water should not contain undesirable organic or inorganic proportions but there is no standard prescription on the quality of mixing water. Lembaga Air Perak (LAP) specifications stated the quality of mixing water is the water that is fit for drinking. In this investigation, drinking tap water from the UTP concrete lab used free water (BS 3148: 1980),

3.2.7 Superplasticizer

Superplasticizer is an admixture used in concrete mixing to increase the workability of concrete especially in a concrete mix with low water/cement ratio. Superplasticizer also has the ability to restrain bleeding and segregation without abnormal retardation and air-entrainment to the concrete mix.

The purpose of using a superplasticizer (Sp) in this research was to improve the workability of the concrete produced at normal w/c ratio. The type of Sp used in this research was RHEOBUILD 1100 supplied by BASF Construction Chemical Malaysia Sdn. Bhd. as shown in Table 3.8. It is a water-soluble and sulfonated naphthalene-formaldehyde condensed based Sp. The pH and density of the Sp are between 6 to 10 and 1.19 to 1.21 kg/litre respectively. It satisfies Type A and Type F requirement of the BS 5075-3:1985 and ASTM C494/C 494M-2004. The recommended dosage is 800 ± 200 milliliters per 100 kg of cementitious materials.

Table 3.8: Technical data BASF Construction Chemical Malaysia Sdn. Bhd. of superplasticizer (RHEOBUILD 1100)

Form	Liquid
Colour	Dark brown
Density	1.19-1.21 kg/litre
pH	6.0 -10.0
Suitability	All Portland cements

Adapted from packing label

3.3 Optimization of Concrete Mixes

3.3.1 Design Mixes

Design mixes of the concrete carried out in this investigation was done through trial mixes. A number of trial mixes carried out to find the ultimate mixes proportions of high strength concrete with a minimum strength of 70 N/mm^2. The minimum strength of concrete was determined through cube compressive strength test at 7, 28, 56 and 90 days under water curing at a temperature of 20 ± 5°C. (From a trial mixes studies, a total binder content used according to BS 812-103.2 1989).

3.3.1.1 Multiple Blended Binders

In recent years, it has been reported that multiple blended binders cement could substantially improve the performance of concrete compared with the conventional binary blended cements or regular Portland cement. Multiple blended binders cement consisting of Portland cement, granulated OPC+SF+PFA was developed in Japan for mass concrete construction due to its very low heat of hydration(Yamamoto et al.,1982) The addition of PFA can increase workability and reduce bleeding of slag cement concrete.

By incorporating SF in slag cement or PFA cement the ternary OPC+SF+PFA blended cements can be developed and commercially manufactured. Similar to the effect of SF addition in Portland cement, PFA in OPC+SF+PFA system may have water reducing effect depending on its quality that may totally or partially compensate the increased water requirement caused by SF. The addition of SF could only slightly increase the early strength of OPC+SF+PFA system cement due to pozzolanic reaction of SF at the early age of hydration process.

On the other hand, when silica fume is added to fly ash concrete, the rate of change of elastic modulus is reduced. The incorporation of a combination of finely grounded PFA and SF with OPC was reported to produce higher compressive strengths at all ages than their binary blends.

3.3.1.2 Pozzolanic Material

Pozzolanic materials are materials that contain silica or silica alumina that will react with CaO with the present of moisture to create cementitous properties. In HSC, the pozzolanic materials were used to enhance the concrete properties and its durability.

A study on the pozzolanic materials properties is important to identify its quality before it can be used as cement replacement materials. The pozzo1anic materials used in this investigation are pulverized fly ash (PFA), silica fume (SF) and microwave incinerator rice husk ash (MIRHA).

3.4 Mixes Proportion of Multiple Blended Binders

16 batches of concrete mixes containing 100% OPC as control mix and 5%, 7.5%, 10% MIRHA, 8%SF and 10%PFA replacement level of pozzolanic materials as multiple blended binders cement systems was prepared. The materials were proportioned, so that the concrete mixes will achieve 28 days strength of greater than 68 N/mm^2. A total binder content of 825 kg/m' and a constant water/binder ratio 0.35 is used. Details of the cement mixes proportions are shown in Table 3.9.

Table 3.9: Preparation for concrete cubes

Item	Mix	No. of cubes	Testing involve
1	100OPC	15	3,7,28,56,90 days
2	95OPC+5MIRHA	15	3,7,28,56,90 days
3	92.5OPC+7.5MIRHA	15	3,7,28,56,90 days
4	90OPC+10MIRHA	15	3,7,28,56,90 days
5	92OPC+8SF	15	3,7,28,56,90 days
6	87OPC+5MIRHA+8SF	15	3,7,28,56,90 days
7	84.5OPC+7.5MIRHA+8SF	15	3,7,28,56,90 days
8	82OPC+10MIRHA+8SF	15	3,7,28,56,90 days
9	90OPC+10PFA	15	3,7,28,56,90 days
10	85OPC+5MIRHA+10PFA	15	3,7,28,56,90 days
11	82.5OPC+7.5MIRHA+10PFA	15	3,7,28,56,90 days
12	80OPC+10MIRHA+10PFA	15	3,7,28,56,90 days
13	82OPC+8SF+10PFA	15	3,7,28,56,90 days
14	77OPC+5MIRHA+8SF+10PFA	15	3,7,28,56,90 days
15	74.4OPC+7.5MIRHA+8SF+10PFA	15	3,7,28,56,90 days
16	72OPC+10MIRHA+8SF+10PFA	15	3,7,28,56,90 days
	Total	**240**	RH, UPV, Compressive

A concrete mix without any cement replacement materials was prepared as a control mix. All the concrete materials were mixed in the concrete mixer for 4 minutes. The concrete

mixes were than cast into steel cube moulds (150 x 150 x 150 mm) in three layers and each layer was compacted using a vibrating table. A total of 240 nos. concrete cubes were prepared as shown in Table 3.9 and all the cubes have been cured in water bath at $20 \pm 5°C$ for 3, 7, 28, 56 and 90 days. At all testing ages, three cubes tested for compressive strength in accordance with British Standard specifications for concrete.

Based on the compressive strength result of prepared samples using blended binders cement systems, the optimum replacement level of pozzolanic materials to OPC was decided as binders mixes proportions and used in preparing a multiple blended binders cement systems.

The multiple blended binders cement systems containing OPC, PFA, MIRHA and one of the three other pozzolanic materials are then used as binder materials in preparing HSC mixes. The same concrete designed mixes proportion and procedure as stated above, followed by using multiple blended binders cement systems as binder can be derived from Figure 3.6.
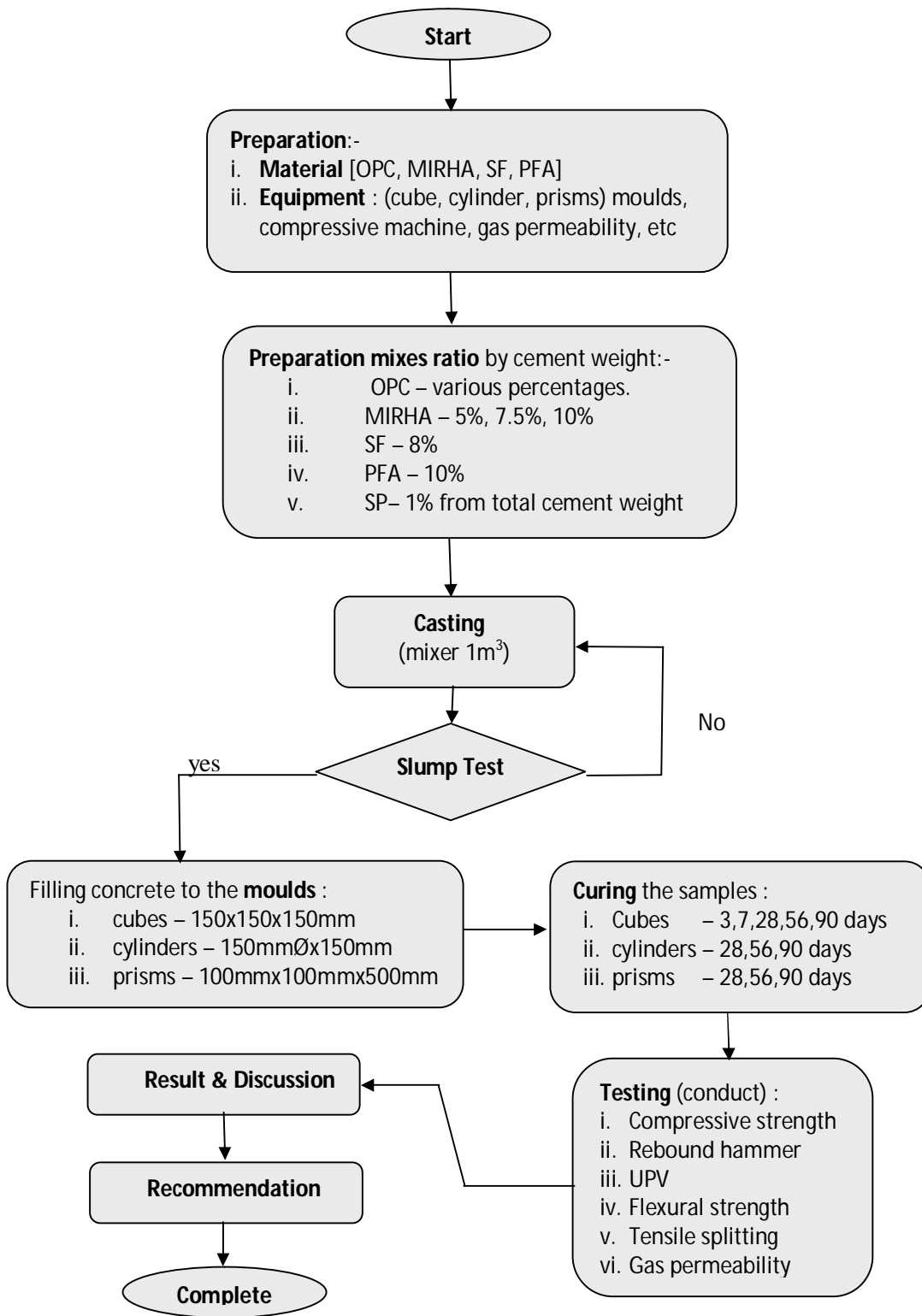
Figure 3.6 : Flow Chart for Experimental Programmed

Table 3.10: Mixes proportion of Multiple Blended Binders

Material	Percentages used in this mixing		
MIRHA	5	7.5	10
SF	8	-	-
PFA	10	-	-

Mix Designation	Cement kg/m^3	MIRHA kg/m^3	SF kg/m^3	PFA kg/m^3	Sand kg/m^3	Agg. kg/m^3	Slump mm
100OPC	825	0	0	0	610	1170	50-100
95OPC+5MIRHA	784	41	0	0	610	1170	50-100
92.5OPC+7.5MIRHA	763	62	0	0	610	1170	50-100
90OPC+10MIRHA	742	83	0	0	610	1170	50-100
92OPC+8SF	759	0	66	0	610	1170	50-100
87OPC+5MIRHA+8SF	718	41	66	0	610	1170	50-100
84.5OPC+7.5MIRHA+8SF	697	62	66	0	610	1170	50-100
82OPC+10MIRHA+8SF	676	83	66	0	610	1170	50-100
90OPC+10PFA	742	0	0	83	610	1170	50-100
85OPC+5MIRHA+10PFA	701	41	0	83	610	1170	50-100
82.5OPC+7.5MIRHA+10PFA	680	62	0	83	610	1170	50-100
80OPC+10MIRHA+10PFA	660	83	0	83	610	1170	50-100
82OPC+8SF+10PFA	676	0	66	83	610	1170	50-100
77OPC+5MIRHA+8SF+10PFA	635	41	66	83	610	1170	50-100
74.4OPC+7.5MIRHA+8SF+10PFA	614	62	66	83	610	1170	50-100
72OPC+10MIRHA+8SF+10PFA	594	83	66	83	610	1170	50-100

Notes: Super Plasticizer used 1% per cement weight

From the compressive strength studies of blended binders concrete containing SF, PFA and MIRHA, the optimum replacement level of each pozzolanic material was determined, as shown in Table 3.10

3.5 Test Procedures

3.5.1 Workability Test on Fresh Concrete

In this particular research work, only the slump test method was used to measure the workability of fresh concrete mixes. The slump test as prescribed in BS EN 12350-2:2000 consists of a tamping rod and a truncated cone of 300 mm height and 100 mm diameter at the top and 200 mm diameter at the bottom, as shown in Table 3.11. The cone was placed on a smooth surface and was filled up with three layers of concrete. Each layer was tamped 25 times with a standard 16 mm diameter steel rod rounded at the end. The top surface of the concrete will strike off by means of a swing and rolling motion of the tamping rod. Immediately after filling, the cone was slowly lifted and the unsupported concrete cone slumps down by its own weight. The decrease in the height of the slumped cone is called the slump of concrete.

3.5.2 Mechanical Tests on Hardened Concrete

The mechanical tests conducted on hardened concrete were the destructive tests which comprised compressive strength, flexural test, tensile splitting strength and equivalent cube compressive strength. Meanwhile, the non-destructive tests were the ultrasonic pulse velocity (UPV), rebound hammer (RH) and gas permeability. The strengths of the concrete specimen were tested the ages of cubes on 3, 7, 28, 56 and 90 days under water curing conditions, except for flexural strength test and tensile splitting strength test in which the strengths were taken at the ages of 28, 56 and 90 days. Under water curing, the temperature in water tank with a temperature 27 ± 0.5^0C. The making, curing of and testing of the specimens for the mechanical tests were conducted at the concrete laboratory of the Department of Civil Engineering, UTP and UiTM.

3.5.2.1 Compressive Strength

The most common test conducted on hardened concrete is the compressive strength test. Cube specimens l50mm x 150mmx l50mm were prepared and tested following BS EN 12390-1:2000 and BS EN 12390-3:2002. The test machine used was an ELE (Engineering Laboratory Equipment) testing machine with a load capacity of 3000 kN running at a pace rate of 3.0 KN/sec., in accordance to BS EN 12390-4:2000. In determining the strength of the mixes, the specimens were tested at the ages of 3, 7, 28, 56 and 90 days, under water curing conditions. For the compressive strength, the series involved were the OPC, 5%MIRHA, 7.5%MIRHA, 10%MIRHA, 8%SF and 10%PFA.

3.5.2.2 Flexural Strength Test

The flexural strength, as modulus of rupture, is essential to estimate the load at which concrete members may crack. For that reason, the modulus of rupture at failure was conducted on the concrete prism. Prism specimens of 100mm x l00mm x 500mm were prepared and tested according BS EN 12390-l:2000 and BS EN 12390-5:2000. The specimens were tested the ages of prism on 28, 56 and 90 days, under water curing conditions. For the modulus of rupture, the series involved were the OPC, 5%MIRHA, 7.5%MIRHA, 10%MIRHA, 8%SF and 10%PFA.

The modulus of rupture was determined by means of a constant moment in the central zone of the specimen using a two-point loading of the EL 33-6090 flexural testing machine. Load was applied steadily and continuously at the rate of 0.067 kN/sec. until failure. The flexural tensile strength expressed in terms of the modulus of rupture, f_r (N/mm^2), is the maximum stress at rupture computed from the flexural formula given by BS EN 12390-5:2000 as shown below:-

$$f_r = \frac{F \times L}{b \times d^2} \qquad \ldots\ldots\ldots\ldots\text{Eq. 3.1}$$

where,

f_r = modulus of rupture, (N/mm^2)

F = maximum d of load, (N)

L = span length between supporting rollers, (mm)

b = width of the cross section, (mm)

d = depth of the cross section, (mm)

3.5.2.3 Tensile Splitting Strength

The most common test for estimating the tensile strength of concrete is the splitting tension test as prescribed in BS EN 12390-6:2000. Cylindrical concrete specimens sized 150mm diameter and length of 150 mm of OPC, 5%MIRHA, 7.5%MIRHA, 10%MIRHA, 8%SF and 10%PFA mixes were prepared as in accordance to BS EN 12390-1:2000. The specimens were tested at the ages of 28, 56 and 90 days, under water curing conditions. The calculation for tensile splitting strength, f_{ct} in N/mm^2 was computed from the formula given by BS EN 12390-6:2000 as follows:-

$$F_{ct} = \frac{2F}{\pi \times L \times d} \qquad \ldots\ldots\ldots\ldots\text{Eq.3.2}$$

where

f_{ct} = tensile splitting strength, (N/mm^2)

F = maximum d of load, (N)

L = length of specimen, (mm)

D = diameter of specimen, (mm)

3.5.3 Non-Destructive Tests on Hardened Concrete

The range of availability for non-destructive tests are extensive, thus the selection was based on the material properties. In this research work, the tests chosen were to measure the surface hardness and the ultrasonic pulse velocity.

3.5.3.1 Ultrasonic Pulse Velocity (UPV)

This test determines velocity of longitudinal wave, as a measurement the time taken by the pulse to travel a measured distance through the concrete specimen. It is related to the density of the concrete. For a given aggregate and a given richness of the concrete is affected by changes in the hardened cement or MIRHA:SF:PFA concrete, such as a fixed in the w/c ratio, which affects the modulus of elasticity of the hardened cement or OPC:MIRHA:SF:PFA concrete as well. Moisture condition of the concrete affects the pulse velocity, which arises from the fact that pulse travels faster through a water-filled void than through an air-filled void. From the value of pulse velocity, the quality of concrete can be predicted.

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This test was conducted in accordance to BS EN 12504-4:2004. Test was subjected to 150mm cube specimens the ages of 28, 56 and 90 days under water curing conditions. The series involved were the OPC:MIRHA:SF:PFA.

The instrument used to determine the pulse velocity is 'Pundit Plus' supplied by CNS Farwell. In this research work, the determination of the pulse velocity was by direct transmission, in which the transducers were placed opposite to each other, so that the maximum energy of the pulse is transmitted and the accuracy of the velocity determination could be achieved. An electro-acoustical transducer held in contact with the surface of the produced pulse of longitudinal vibration. After traversing a known path length in the concrete specimen (150 mm), the pulses of vibrations were converted into an electrical signal by a second transducer. The digital indicating device measures the time interval for the pulse to travel between the two transducers. In ensuring the vibration of the transducer being transmitted to the concrete by close contact, grease was applied on the contact faces

of the concrete specimen. Plate 3.4 shows the UPV test equipment and the schematic diagram of the direct transmission method of propagating ultrasonic pulse respectively. The pulse velocity, *V*, can be calculated using the formula given in BS EN 12504-4:2004 as shown below:-
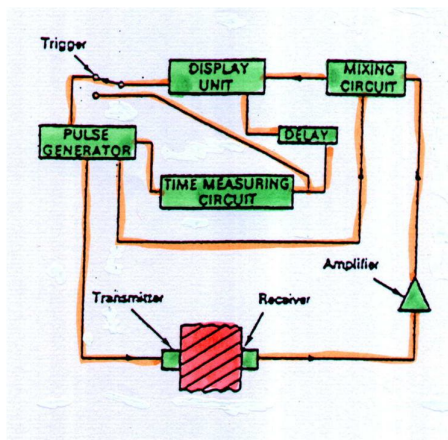
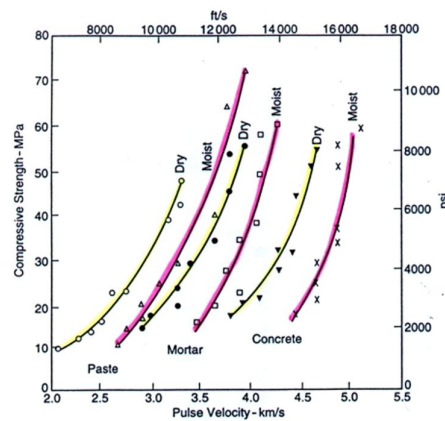$$V = L/T \qquad \dots\dots\dots\dots\dots\dots\text{Eq. 3. 3}$$

where

V = pulse velocity, (km/sec)
L = path length, (km)
T = time taken by the pulse to traverse the path length, (sec.)

(a) UPV equipment

(b) schematic diagram using UPV equipment   (c) UPV strength chart.

Plate 3.4: Principal of operation and method of propagating ultrasonic pulse (a), (b) and (c) Adapted from A.M. Neville, (2002) (1981)
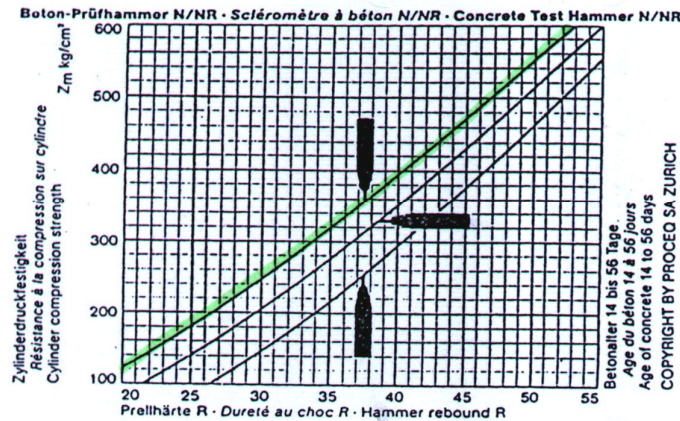
3.5.3.2 Rebound Hammer

The rebound hammer test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. Extension of the spring loaded mass to a fixed position can be achieved pressing plunger against the surface of the concrete under test. Upon release, the mass rebounds from the plunger and the distance traveled by the mass measured the graduated scale marked on the rebound hammer indicates the rebound number. By referring to the manufacturer's calibrated chart, the estimated surface strength of the concrete was the observed rebound number obtained.

The rebound hammer test was conducted in accordance to BS EN 12504-2:2001 and tested for the ages of 28, 56 and 90 days before conducting compression test. The concrete series involved were the OPC, 5%MIRHA, 7.5%MIRHA, 10%MIRHA, 8%SF and 10%PFA. The instrument used to carry the test was the Schmidt Hammer of Type N, having impact energy of 2.207 Nm intended for testing concrete with a measuring range of 10 to 70 N/mm^2 compressive strength. The test hammer plunger was placed normal to the surface of the cube under test. In assessing the hardness of the concrete within the cube, rebound hammer at five locations in close proximity were taken on each surface of the cube. It is suitable for use in ordinary building and bridge constructions. Plate 3.5 shows the rebound hammer instrument used in this research.

(a) Rebound hammer equipment

(b) RH strength chart – Adapted from A.M. Neville, 2002

Plate 3.5: Principal of operation rebound hammer (a) and (b)

3.5.4 Durability Tests on Hardened Concrete

In this present study, the durability in terms of gas permeability of the OPC, MIRHA, SF and PFA concretes were investigated. In the durability tests the series involved were the OPC, 5%MIRHA, 7.5%MIRHA, 10%MIRHA, 8%SF and 10%PFA. All the preparation, mixing, casting, curing and testing of the specimens for the durability tests were carried out at the concrete laboratory, Department of Civil Engineering, UTP.

3.5.4.1 Permeability

3.5.4.1.1 Gas Permeability

Permeability of concrete is one of the most critical parameters to be considered in identifying the properties of concrete. As the permeability of concrete is lowered, the resistance of concrete to chemical attack increases. In identifying the effected of using Multiple Blended Binders Concrete and Blended Binders

Concrete on the permeability of concrete compared to control mix, the cylindrical samples of 50mm φ x 40mm thickness are prepared and tested at 28, 56 and 90 days. Samples used for the test dried in an oven at 105°C for 24 hours before testing. The samples were then removed and silicon rubber is applied onto the curved side of the samples and kept to dry in desiccators for another 1 day.

The samples are then placed into the airtight permeability cell and a gas pressure of 2 bars is applied and left for 30 minutes to stabilize the gas pressure in the cell systems before start taking the readings.

The time of gas flow along 10 mm is recorded using bubble meter. The flow time is repeatedly measured and recorded for 5 minutes. To obtain the gas permeability the following relation is used:-

$$K = \frac{2P_2(VL \times 1.76 \times 10^{-14})}{A(P1^2 - P2^2)} \qquad \ldots\ldots\ldots\ldots Eq.3.4$$

Plate 3.6: Principal of operation air permeability

3.5.5 Summary

Chapter 3 divided into two subchapter. The production and investigations of pozzolanic materials used briefly described in the first sub chapter. Their important properties named as chemical and physical properties was determine and compared with selected standard specifications and published works as shown in Table 3.11.

Table 3.11: Experimental Program

Concrete Type	Test Type	Standard	Equipment	Testing Age	Sample Size
FRESH CONCRETE	Slump Test	BS EN 12350-2:2000	Slump Cone	Fresh Concrete	-
HARDENED CONCRETE	Compression Strength	BS EN 12390-3:2002	Compression Testing Machine	3,7,28, 56 and 90 days	150x150x 150mm cube
	Split Cylinder	BS EN 12390-6:2000	Compression Testing Machine	28,56,90 days	150mmØ x 150mm cylinder
	Flexural	BS EN 12390-5:2000	Compression Testing Machine	28,56,90 days	100x100x 500mm prisms
	UPV	BS EN 12504-4:2004	UPV	28,56,90 days	150x150x 150mm cube
	Gas Permeabilitty	German DIN 1048-1991	Gas Permeabilitty	28,56,90 days	50mmØ x 40mm cylinder
	Rebound Hammer	BS EN 12504-2:2001	Rebound Hammer	28,56,90 days	150x150x 150mm cube

In second sub chapter, the investigation on the optimum mixes proportion of blended binders concrete in designing multiple blended binders utilizing local waste product was performed. The potential of using multiple blended binders in obtaining High Strength Concrete mixes also determined.

The chemical composition were studies and outlined that all pozzolanic materials prepared and used is satisfied the standard specification and other published works.

Investigation on the optimum replacement level of pozzolanic materials used found that the optimum replacement level of SF, PFA and MIRHA is 10% while 30% replacement level to OPC is the optimum replacement level of SF. The mixes proportions of multiple blended binders were obtained through mixing the SF and PFA with MIRHA at a specific proportion determine before. The utilization of multiple blended binders concrete in achieving high strength concrete mixes found to be potential even at a replacement level of 28% to OPC.