BIOMASS CLINKER AS PARTIAL CEMENT REPLACEMENT IN CONCRETE

KWAN CHUN SIONG

UNIVERSITI TUNKU ABDUL RAHMAN

BIOMASS CLINKER AS PARTIAL CEMENT REPLACEMENT IN CONCRETE

KWAN CHUN SIONG

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

May 2019

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ______________________

Name : Kwan Chun Siong

ID No. : 1402480

Date : 6 May 2019

APPROVAL FOR SUBMISSION

I certify that this project report entitled **BIOMASS CLINKER AS A PARTIAL CEMENT REPLACEMENT IN CONCRETE** was prepared by **KWAN CHUN SIONG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _________________________

Supervisor : Dr Lee Foo Wei

Date : 6 May 2019

Signature : _________________________

Co-Supervisor : _________________________

Date : _________________________

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Dr LEE FOO WEI for his invaluable advice, guidance and his enormous patience throughout the development of the research.

ABSTRACT

The industrial byproduct will be affected by increasing of the industrialization. The byproduct being collected to a huge extent, leading to economic and environmental concerns related to their disposal (landfill). Wood ash is the residue produced from the incineration of wood and its products (chips, sawdust, bark) for power generation or other uses. The wood ash is disposed through land filling; however, the potential risk of airborne particles and ground water contamination requires a well designed and prepared landfill site, leading to high cost. Moreover, the concern of land filling is growing due to less availability of space and stricter environmental regulations. As a result, new and more economical solutions are essential for disposing the wood ash over the long run. One of the beneficial applications is to incorporate the wood ash as a partial cement replacement. This study presents an overview of the work and studies done on the incorporation of wood ash as partial replacement of cement in concrete. The aim of this experiment is to study the mechanical properties of the concrete by using the wood ash as a partial replacement of cement in terms of thermal conductivity, compressive strength, water absorption, microstructure and the density of the concrete. There had four different design ratio of cement replacement from 0 % to 30 % by wood ash. All the specimens were cured in the tank for 7^{th} and 28^{th} day before being tested. It is found that increasing the percentage of wood ash as a partial cement replacement caused declines in thermal conductivity, compression strength and oven dry density. Only the water absorption increases as percentage replacement increases due to the unburn carbon contain in wood ash.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

Al_2O_3	Alumina
CaO	Calcium oxide
LOI	Loss of Ignition
CO_2	Carbon Dioxide
kg/m^3	Density
kg	Mass
SiO_2	Silica
ASTM	American Society for Testing and Materials
A	Cross Sectional area
BS	British Standard
F	Compressive Strength of the concrete
MPa	Mega Pascal, Pressure
P	Maximum compressive load
W_{dry}	Weight of the specimens before curing process
W_{sat}	Weight of the specimens after curing process
W_1	Empty weight of pycnometer
W_2	Weight of pycnometer + oven dry of wood ash
W_3	Weight of pycnometer + water + oven dry of wood ash
W_4	Weight of pycnometer + water

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Common material that widely uses for construction in the structural work is concrete. Cement is unsustainable recourse and will bring negative environmental impact in the long term. The infrastructural development in Malaysia will increased demand for construction material. Based on research on the population growth in Malaysia, in the 1960s, the Malaysian population was 8.16 million as compared to 2018. The Malaysian population was 32 million which has increased 392 % in this 58 year (Malaysia Population, 2018).

Concrete is an artificial conglomerate stone that produces by sand, aggregates, admixture, cement and water. However, the consumption of concrete is high due to the population increased and made current construction was unstable because it needs uncountable quantities of aggregates, water, cement, and sand. Manufacture of the cement need consumption a huge quantity of raw material, energy and heat. It not only uses energy, but also releases the greenhouse gas emission and the solid waste material in the world. From the calculation process, which is 62 % of carbon emission and 38 % is related to fuel combustion. It creates global warming due to the limestone is a natural resource and deplete slowly by the human being. The used of cement is not environmental friendly, thus the industry needs to find the alternative replacement to replace the cement which is the wood ash.

Renewable energy plays a fundamental role in the transition towards the sustainable energy system. Traditionally, the harvested crop regrowth will absorb the released carbon that considers as carbon neutral. Wood ashes are the residues which are produced by the combustion of the wood product. By recycling the wood ash, can save the environment and money to build the disposal for it. Non-hazardous waste is the incineration of untreated wood. This study focuses on the effect of using wood ash as a partial replacement for cement in concrete. The used of cement replacement offers environmental gains from lowering CO_2 emissions, as CO_2 emission from cement production currently represents about 5 % of anthropogenic global emissions.

Also, conservation of natural resources and possible financial benefits makes use of wood ash in concrete interesting.

1.2 Problem Statement

Cement is the raw material for the concrete. The cement usage is dramatically increased a year for the year due to the development of infrastructure. The more cement is used in the concrete, the danger of the environmental impact on the world. The problem can be solved by partially replace the cement by wood ash. By using the wood ash, the carbon emission by the cement will reduce and natural resources such as limestone can be limited to use. Then the treatment of the environment will be easier to operate. Annually, a minimum of 168 million tonnes of biomass waste is generated in Malaysia. The wood residues accumulate 4 % of 168 million tons per year in Malaysia (Aziz & Mun, 2012).

Recycling of by product materials generated from various sources, the utilization in the concrete industry provides one of the innovative solutions to the above problems. The use of a variety of byproduct materials as supplementary cementing materials is growing from time to time. Wood ash has been established as mineral admixtures in the cement based on industry. It can also be used as an admixture in concrete through a proper mixture proportioning for encapsulating heavy metals and other pollutants present in the ash

Commonly, the wood ash is disposed of through land filling, however, the potential risk of airborne particles and ground water contamination requires a well designed and prepared landfill site, leading to high cost. Moreover, the concern of land filling is growing due to less availability of space and stricter environmental regulations. As a result, new and more economical solutions are essential for disposing the wood ash over the long run. One of the beneficial application is to incorporate of the wood ash as a partial cement replacement.

1.3 Aim and Objectives

The aim of this study is to investigate the characteristic of concrete fabricated by replacing cement (OPC) with wood ash at different weight ratios. The objectives are listed as below:

1. To produce a concrete achieve 30 MPA of target strength by using the wood ash to replace cement.
2. To find out the maximum replacement of wood ash from 0 % to 30 % with incremental of 10 %.
3. To study the mechanical properties in the concrete incorporate of the wood ash as a partial cement replacement in terms of thermal conductivity, compressive strength, absorption of water, microstructure and density of the concrete.

1.4 Scope of the Study

This study is to estimate maximum percentage of wood ash replacement that will not affect the quality of the concrete. Four different ratios of replacement proportions for concrete (wood ash replacement of 0 %, 10 %, 20 % and 30 %) with water cement ratio of 0.6 for a design compressive strength of 30 MPa. There are a few test needs to conduct in this study, namely compressive strength, thermal conductivity, water absorption, microstructure and density tests. After demould the concrete, it will cured inside the water tank for 7th days and 28th day before the test for the objective that listed at above.

1.5 Significance of the Study

1. The incorporation of the wood ash as a partial cement replacement will reduce using the land to dispose the waste of wood ash.
2. The incorporation of the wood ash as a partial cement replacement will lower down the cost of the concrete to develop the building and make the prices are more affordable for the consumers.

1.6 Layout of Report

This report has a total of five chapters. The first chapter explains the concrete usage in the current stage, problem statement, objective, significance and layout of this study.

Chapter 2 of this report, the properties of wood ashes were reviewed and the material that uses such as water, aggregate, cement is a study based on the article or some.

Chapter 3 of this report indicates the method to prepare the material, precaution actions and the test procedures needed for this experimental study.

The laboratory result will be discussed in chapter 4 for compressive strength, microstructure, density, water absorption and thermal conductivity tests.

The Conclusion and summary of the study are written in the last chapter, which is chapter 5 of this report. Some recommendations are purposed for the improvement of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete is manufactured by using Portland cement, a mixture of water, aggregate and admixtures proportioned to form a plastic mass capable of being placed, cast or molded into forms that will harden into a solid mass. Concrete is one of the most common construction materials used in wide variety application ranging from pilling, multi-story buildings, dam, foundations, pavements, storage tanks, bridges and many other structures. Concrete is the most economical material of building, very versatile construction material adapted to a wide variety of residential and agricultural uses.

The properties of concrete will affect mainly due to mix the proportion of cement, sand, aggregates, and water. A perfect mix can result in a good quality of concrete if correct placement, finishing and curing techniques under the proper conditions of moisture and temperature are used. With the proper materials and technique, concrete can withstand many acids, silage, milk, manure, fertilizers, water, fire abrasion. Concrete can be finished to produce surfaces ranging from glass-smooth to coarse texture and it can be coloured with pigments or painted. Concrete has substantial strength in compression, but weekly in tension.

The mechanical properties in the concrete of incorporation wood ash to replace cement in terms of thermal conductivity, compressive strength, absorption of water, microstructure and the bulk density of the concrete is studied in this experiment. The incorporation woody ash to replace cement help to avoid negligible and huge needed for cement. Cement production will increase the emission of certain greenhouse gasses and will pollute the environment. Hence, by incorporation of wood ash will lead to less production of cement and more environmentally friendly.

2.2 Physical Properties of Woody Ash

The physical properties of wood ash can be classified by using combustion analysis. The physical properties are list below:

- Porosity
- Particle size
- Porosity
- Colour
- Density
- Bulk density

Wood ash particles different in sizes and shape. The wood ash waste has 1.81% of moisture content, 10.48 of pH, 10.46 of loss on ignition and a specified gravity of 2.43 (Udoeyoet al., 2006).

The wood ash is a heterogeneous mixture with varying size particle generally angular in shape which is partially burned or unburned wood and bark. The average amount of wood ash passing sieve (75 µm) is 50% and the percentage of ash retained on the sieve is (45 µm) 31 % (Naik, 1991). Table 2.1 shows the type of wood ash based on the bulk density.

Table 2.1: Average basic densities of wood types (Hakkila et al., 1978)

Wood type	Wood species	Basic density, kg/m^3
Round wood with bark	Scots pine	390
	Norway spruce	380
	Birch	490
	Alder	360
Whole tree from thinnings	Scots pine	385
	Norway spruce	400
	Birch	475
	Alder	370
Logging residue chips without needles/leaves	Scots pine	405
	Norway spruce	465
	Birch	500
Logging residue chips with needles	Scots pine	395
	Norway spruce	425
Residues from timber sawing, with bark	Coniferous tree	415
Stump and root wood	Scots pine	475
	Norway spruce	435

2.3 Chemical Characteristic of the Wood Ash

Based on Table 2.2, the type of wood ash being test can be identified. Different type of wood ashes has different chemical properties such as iron oxide (Fe_2O_3), silica (SiO_2), alumina (Al_2O_3) and quicklime (CaO). Lime ($CA(OH)_2$) and calcium silicate ($CaCO_3$) are the main components of wood ash.

Table 2.2: Chemical properties of the wood ash (Vassilevet al., 2010)

Biomass group, sub-group and variety	SiO_2	CaO	K_2O	P_2O_5	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	TiO_2
Wood and woody biomass										
Alder-fir sawdust	37.49	26.41	6.1	2.02	12.23	4.04	8.09	0.83	1.81	0.98
Balsam bark	26.06	45.76	10.7	4.87	1.91	2.33	2.65	2.86	2.65	0.21
Beech bark	12.4	68.2	2.6	2.3	0.12	11.5	1.1	0.8	0.9	0.1
Birch bark	4.38	69.06	8.99	4.13	0.55	5.92	2.24	2.75	1.85	0.13
Christmas trees	39.91	9.75	8.06	2.46	15.12	2.59	9.54	11.66	0.54	0.37
Elm bark	4.48	83.46	5.47	1.62	0.12	2.49	0.37	1	0.87	0.12
Eucalyptus bark	10.04	57.74	9.29	2.35	3.1	10.91	1.12	3.47	1.86	0.12
Fir mill residue	19.26	15.1	8.89	3.65	5.02	5.83	8.36	3.72	29.82	0.35
Forest residue	20.65	47.55	10.23	5.05	2.99	7.2	1.42	2.91	1.6	0.4
Hemlock bark	2.34	59.62	5.12	11.12	2.34	14.57	1.45	2.11	1.22	0.11
Land clearing wood	65.82	5.79	2.19	0.66	14.85	1.81	1.81	0.36	2.7	0.55
Maple bark	8.95	67.36	7.03	0.79	3.98	6.59	1.43	1.99	1.76	0.12
Oak sawdust	29.93	15.56	31.99	1.9	4.27	5.92	4.2	3.84	2	0.39
Oak wood	48.95	17.48	9.49	1.8	9.49	1.1	8.49	2.6	0.5	0.1
Olive wood	10.24	41.47	25.16	10.75	2.02	3.03	0.88	2.65	3.67	0.13
Pine bark	9.2	56.83	7.78	5.02	7.2	6.19	2.79	2.83	1.97	0.19
Pine chips	68.18	7.89	4.51	1.56	7.04	2.43	5.45	1.19	1.2	0.55
Pine pruning	7.76	44.1	22.32	5.73	2.75	11.33	1.25	4.18	0.42	0.17
Pine sawdust	9.71	48.88	14.38	6.08	2.34	13.8	2.1	2.22	0.35	0.14
Poplar	3.87	57.33	18.73	0.85	0.68	13.11	1.16	3.77	0.22	0.28
Poplar bark	1.86	77.31	8.93	2.48	0.62	2.36	0.74	0.74	4.84	0.12
Sawdust	26.17	44.11	10.83	2.27	4.53	5.34	1.82	2.05	2.48	0.4
Spruce bark	6.13	72.39	7.22	2.69	0.68	4.97	1.9	1.88	2.02	0.12
Spruce wood	49.3	17.2	9.6	1.9	9.4	1.1	8.3	2.6	0.5	0.1
Tamarack bark	7.77	53.5	5.64	5	8.94	9.04	3.83	2.77	3.4	0.11
Willow	6.1	46.09	23.4	13.01	1.96	4.03	0.74	3	1.61	0.06
Wood	23.15	37.35	11.59	2.9	5.75	7.26	3.27	4.95	2.57	1.2
Wood residue	53.15	11.66	4.85	1.37	12.64	3.06	6.24	1.99	4.47	0.57
Mean	22.22	43.03	10.75	3.48	5.09	6.07	3.44	2.78	2.85	0.29

2.4 Compressive Strength

Normal weight concrete can be tested by the compression strength test. This test is the easiest way to conduct for this study. The compression strength of control mixture and concretes mixed with the wood ash were 34 MPa and 33 MPa at 28^{th} days. The incorporation of wood ash increases the strength development of the concrete mix, although cement contains was reduced by 15 %. This is because of the attribute to the pozzolanic activity (Naik et al., 2002). There are many factors will affect the concrete strength and density such as:

- Shape and size of the specimen
- Loading direction
- Age
- Curing period
- Pore formation method
- Water content
- Particle size distribution and type of sand
- Cement sand and water cement ratios
- Characteristics of material used
- Curing method

There are two methods for testing the compressive strength which is destructive test and non destructive test.

2.5 Ordinary Portland Cement

Ordinary Portland cement is type 1 cement based on the ASTM C150. Nowadays, many developers or contractor will chooses the ordinary Portland cement as their first choices of cement because it suitable for general construction with the condition of the concrete did not vulnerability to sulfates in soil or groundwater (Neville, 2010).

Table 2.3: Physical properties of cement (Naiket al., 2003)

Test	Cement	ASTM C 150 specification for Type I cement
Compressive strength, MPa		
3-day	17.7	12.0
7-day	26.6	19.0
28-day	38.8	-
Autoclave expansion, %	0.06	within ± 0.80
Fineness, % (retained on 45-µm (No. 325 sieve)	4.0	-
Fineness, specific surface (air-permeability test), m^2/kg	340	280 min
Air content of mortar, %	11	12 max
Vicat time of setting, minutes		
Initial	275	45-375
Final	365	-
Specific gravity	3.15	-

Table 2.4: Chemical Properties of Portland Cement (Naiket al., 2003)

Analysis Parameter	Cement, %	ASTM C 150 specification for Type I cement, %
Silicon Dioxide, SiO_2	21.9	-
Aluminum Oxide, Al_2O_3	4.9	-
Iron Oxide, Fe_2O_3	3.0	-
Calcium Oxide, CaO	64.1	-
Magnesium Oxide, MgO	2.4	6.0 max
Titanium Oxide, TiO_2	0.0	-
Potassium Oxide, K_2O	0.5	-
Sodium Oxide, Na_2O	0.1	-
Sulfite, SO_3	1.4	3.5 max
LOI (1000°C)	1.7	3.0 max
Moisture	0.9	-
Available Alkali, Na_2O	0.88	-

2.6 Aggregate

An aggregate is a rock line material of different in shapes and size. The American Society for Testing Materials (ASTM) defines aggregate as granular material such as crushed stone, gravel, sand, cement, crushed stone used with a cementing medium to produce concrete. There are two sources of aggregate come from natural and manufactured. The natural form is taken from natural deposits without the change in their nature during production while manufacture form is included blast furnace slag, clay, and lightweight aggregate. There are two sizes for aggregate which are the fine aggregate and coarse aggregate.

2.6.1 Types of Aggregate Based on Specific Gravity

There are three types of aggregate which are

- Heavyweight aggregate
- Normal weight aggregate
- Lightweight aggregate

Lightweight aggregate used in manufacturing lightweight concrete, lightweight masonry block. It is produced by expanding some raw material in a rotary kiln on a sintering grate or by mixing them with water. It is also good thermal insulation and has a bulk density of less than 1200 kg/m³. Normal weight aggregate is obtained from the quarry, river and suitable for most construction. It has the density range of 2300 until 2500 kg/m³ and specific gravity in the range 2.5 until 3. Heavyweight aggregate usually using in the protection against the nuclear radiation. It has the density range of 4000 until 8500 kg/m³ and specific gravity in the range 4.5.

2.7 Thermal Conductivity

One part of body transfer of heat with each other call thermal conduction. Thermal conductivity λ is defined as an ability of a material to transmit heat and it is measured in watts per square meter of surface area for a temperature gradient of 1 K per unit thickness of 1 m. The thermal conductivity is not always constant. The moisture, density of the material and ambient temperature are the main factors affecting the thermal conductivity. The increases in the density of the concrete will also increase the thermal conductivity. Thermal conductivity is the property of material pertaining to heat conduction. Steady state and transient heat transfer are considered different heat transfer conditions across materials.

The partially replacing cement with wood ash in the concrete mixture produced a product with a lower density and a lower thermal conductivity than conventional concrete Density and thermal conductivity are often positively correlated (Bentz, 2007).

Table 2.5: Material's thermal conductivity (Bentz, 2007)

Material	**Thermal conductivity** (W/mK)
air (dry and quiet)	0,023
PUR rigid foam	0, 02 – 0,04
expanded polystyrene	0,035 – 0,045
cellular glass	0,035 – 0,06
mineral or glass wool	0,04 – 0,08
particleboard	0,1 – 0,13
lightweight concrete	0,11 – 0,25
timber (pine)	0,14
water	0,60
brick	0,65 – 0,80
glass	0,6 – 1,38
concrete	1,2 –1,75
limestone	1,50
granite	2,80
steel	43-58
aluminium and light alloys	125 – 200
copper	386

2.8 Water Absorption

Absorption is the presence of water in the pores of the material followed by an increase in the mass, but excluding the water adhering of the particle at external surface. The absorption value is considered the properties of aggregate. It displays the pore size and porosity (Yzenas, 2006). Similarly, water absorption can be regarded as an indirect measure of the permeability of an aggregate which can also connect physical properties such as mechanical durability, shrinkage and strength. (Smith & Collins, 2001).

2.9 Scanning Electron Microscope of Concrete

This is another alternative method to determine the strength of the concrete. A Hitachi VP SEM S3400 machine is used to capture the images of the specimens. By using this, it is able to observe micro crack behavior and the bonding between the particles.

2.10 X-Ray Diffraction

Fluids, powders and crystal can be analyzed by using X-ray diffraction which is a non destructive tool. It is an indispensable method to identify the material characteristics and crystalline phases. X-ray diffraction techniques are superior in elucidating the three dimensional atomic structure of crystalline solids. The crystal structures will affect the properties and function of the material. X-ray diffraction techniques have been widely used as an indispensable means in materials research, development and production.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In chapter 3, it was discussed the test methods, materials used and mixing procedure for this study. There had total of six tests were conduct which are compressive strength test, thermal conductivity test, water absorption, scanning electron microscope, x-ray diffraction test and density. The raw materials used in this experiment are cement, water, fine aggregate, coarse aggregate and wood ash.

3.2 Raw Material Use

The ingredients used to produce a wood ash concrete consists of five types of raw material; water, ordinary portland cement, coarse aggregate, wood ash and fine aggregate.

3.2.1 Water

The water must be clear and should not contain any impurities because it will affect the hydration process of the specimens. According to ASTM C 1602, the source of water comes from water mixing, non-potable, potable water, and combined water. The tap water is selected to mixing the specimens.

3.2.2 Woody Ash

Woody ashes have been assembled from the factory. The wood ash is sieved through 300micron sieve and stored in the air tight container before tested.

3.2.3 Cement

There are more than 7 types of cement being manufactured throughout worldwide. Ordinary Portland cement is chosen as the cement that will use to produce a normal weight concrete. The clinker of hydrated cement particle can be removed by sieve through 300 μm sieve, then placed inside the container to prevent the cement to absorb the air moisture because it will easily be hydrated (Neville, 2010).

Figure 3.1: Ordinary Portland cement of "ORANG KUAT"

3.2.4 Fine Aggregate

Fine aggregate was the raw material to manufacture the concrete. Fine aggregate was an aggregate entirely passing the 10 mm sieve with more than 85 % of its weight passing the 5 mm sieve. The sand particle sizes used for the fine sand was below 4.75 mm size particles because it was within an acceptable range and more easygoing to be obtained. According to ASTM C128 07a, the fine aggregate is placed on the pan and oven dry at temperatures of 110 °C ± 5 °C. The impurities of the aggregates were removed by sieved through a 600 micron sieve.

3.2.5 Coarse Aggregates

Coarse aggregate was the raw material to manufacture the concrete. Coarse aggregate was an aggregate passing 85 % of its weight retained on 5 mm sieve. There were various sizes of aggregate obtained from the supplier. The aggregate was directly supplied from the quarry for the study used. Two different ranges of size are needed for the concrete mixing in this study. The finer coarse and coarse aggregate size range is from 5 mm to 20 mm. The coarse aggregate required passing through a washing process at the first stage. This was to remove the dust particles which stain on the coarse aggregate. Without the washing process, the dust stains will affect the cohesiveness of the aggregator uses. Next, the cleaned coarse aggregate will be placed under the hot sun and dried up by using the temperature of the sun. The duration of the drying process uses less than 24 hours to wipe out the moisture content for the coarse aggregate particles until it reaches the saturates surface dried. Afterwards the aggregate was dried, it will pass through a sieve size about 20 mm, 10 mm, 5 mm and a pan and the sieve size shown in Figure 3.2. Next, Figure 3.3 showed that the coarser aggregate retains on (10 mm - 20 mm) and fine aggregate will retain on (5 mm - 10 mm). The purpose of this method is to remove other sizes of the particles that not use in this study. After all the sieving process, the aggregate will keep in the container shown in Figure 3.4.

Figure 3.2: Sieve Size with 20 mm, 10 mm, 5 mm, and pan

Figure 3.3: Coarse aggregate retain on sieve size

Figure 3.4: The aggregates keep on the container

3.2.6 Mould

Throughout this project, only one type of mould will be used in the casting process. According to the BS code, the dimension of 50 mm × 50 mm × 50 mm of the mould is chosen for the test. The mould are coated a layer of oil before the concrete mixture is poured inside the mould and being tight. By doing this way, it will make the demould step more easily after the concrete mixture is hardened.

Figure 3.5: A view of mould

3.3 Concrete Mix Design

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the objective of producing concrete of certain minimum strength as economically as possible. In this experimental study, there are four different percentages of the wood ash replaced the cement in order to manufacture the concrete. The cement will partially replaced by 0 %, 10 %, 20 % and 30 % of wood ash in the mixing. The control specimen will have 0 % replacement for the cement. The dry design density of concrete is 2200 kg/m^3, target strength of the concrete is 30 MPa with water cement ratio of 0.6.

Table 3.1: Mix ratio for concrete

Material	Proportions (Kg/m³)
Fine aggregate	701
Coarse aggregate	1052
Water	205
Cement	342

3.4 Mixing of Concrete

Initially the cement, sand and wood ash weight by weighting machine and mixed by the concrete mixer until uniformly mixing under a dry condition as shown in Figure 3.6. Next, pour in the water cement ratio required for dry mixture. The wet mixture is mixed manually until uniformly mix before casting. Before casting of specimens, the workability is measured by conduct the slump test based on the ASTM C1611.

Figure 3.6: Concrete mixer

3.5 Casting of Concrete

The concrete was transferred to an oiled cube mould. The mould was coated with a thin layer of machine oil inside for easy removal afterwards. The mould was put in the vibrator machine to vibrate until the concrete is compacted fully without pore.

Figure 3.7: A view of cast cubes

3.6 Curing of Concrete

After the casting of specimens, the specimens are air dried for 24 hours before submerging in the tank. The water curing method is conducted after the air curing method is done. Water curing of the specimens is a significant process to obtain the target strength because the hydration process is complete. The specimens are submerged in the water for 7th and 28th day. The optimum temperatures for water curing the specimens are in the range of 25 °C to 28 °C. Figure 3.10 shown the concrete specimens arrange in water tank and the water level is fully covered all the specimens.

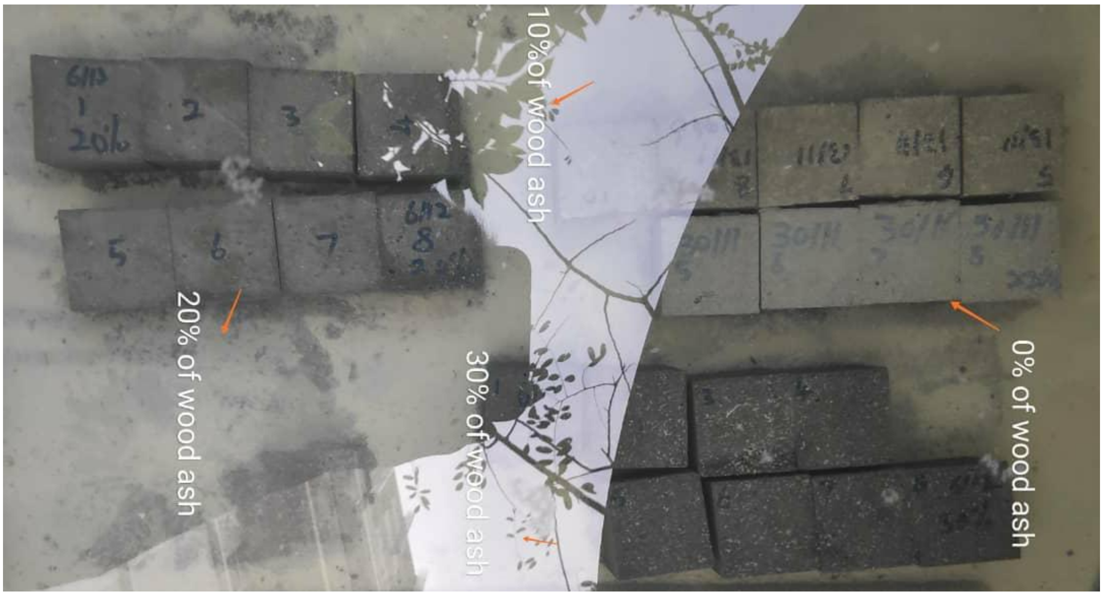

Figure 3.8: Water cures for 7th and 28th days

3.7 Testing of Cubes for Compression Strength

The compressive strength machine will be used to test the concrete properties by following the BS EN 123903. A constant axial compression loads with 0.02 mm/s applied to the 50 mm × 50 mm × 50 mm cubes concrete until failure occurs in the specimen. This test was repeated for three times for each mix ratio and the average value of the result will be recorded in this study. The dimensions of specimens are measured by using the digital vernier calliper before the test was carried out. The concrete cube put at the center of bronze plate under the testing machine. The axial compression load will subject to the flat surface of the specimens with 0.02 mm/s loading until the concrete cube cracked is shown. The maximum compression loading is recorded and repeat for three times for each mix ratio. Equation 3.1 shown the formula to calculate the compressive strength.

$$F = \frac{P}{A} \tag{3.1}$$

where:

A = Cross Sectional area, m^2

F = Compressive Strength of the concrete, Mpa

P = Maximum compressive load, N

Figure 3.9: Measure the cube by vernier caliper

Figure 3.10: INSTON 5582 Testing Machine

3.8 Thermal Conductivity

The ability to transfer heat though it is called thermal conductivity. Electrical resistance is analogous to thermal resistance in that inversely proportional to the heat flow. The thermal conductivity can be determined by the steady state box method refer to system's energy evaluation. The concrete is placed between the hot and cold chamber as is Figure 3.13. The air temperature difference between two chambers is to calculate the k value. In accordance with BS EN 12664 (BSI, 2001), thermal conductivity test is conducted to estimate the tendency of the specimens to resist the heat transfer. Use the equipment for this test is guarded box, data logger, chillier and an electrical control box. The specimen is put as below Figure 3.13. The remaining side surface of the concrete is insulated by the rock wool to prevent the heat loss. The specimen is put on the machine for 20 - 24 hours and temperature; current changes will save the data logger. The thermal conductivity is calculated by using equation 3.2.

$$Thermal\ conductivity = \frac{QxL}{Ax\Delta T} \qquad (3.2)$$

where:

Q =Heat flow (W)

L =Thickness (mm)

A =Area (m²)

ΔT=Average temperature different (K)

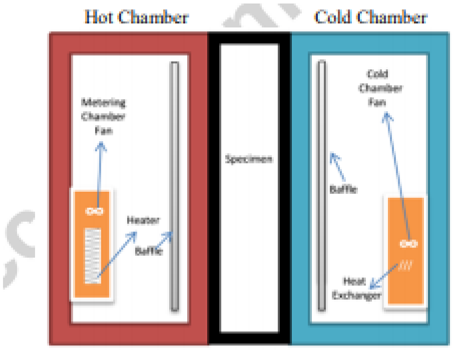

Figure 3.11: The schematic of the box method

3.12 Water Absorption Test

This test is applicable for the cube concrete with dimension of 50 mm × 50 mm ×50 mm based on the ASTM C642. The weight of the specimen before and after the curing is weight and record. Equation 3.3 shows the formula to calculate the water absorption.

$$\text{Water absorption} = \frac{W_{sat} - W_{dry}}{W_{dry}} \text{ X } 100\% \quad (3.3)$$

where:

W_{dry} = The weight of the specimens before curing process

W_{sat} =The weight of the specimens after curing process

3.9 Scanning Electron Microscope (SEM)

This test requires prepared a sample, of the test according to ASTM C 856 14 with the suitable dimensions (10 X 10 X 10) mm. All specimens were dried in the oven prior to testing at 60 °C for 7 days to avoid disturbance. The next step involves immersion of the sample in a low viscosity epoxy resin. The epoxy was cured at 40 °C for at least 24 h. Before the specimen put into the Scanning electron microscope, it will coating with a thin film of conductive material (Liquid gold) at sputter coater to prevent the build up of electric charge when the electron beam scans the specimen.

Figure 3.12: Sputter coater

Figure 3.13: Scanning electron microscope

3.10 X-Ray Diffraction

The powder was put at the plated and compacted tightly shown in Figure 3.14 before put into the machine with the slope of 2°. The scan range is from 0 to 60 with the speed of 2 m/s.

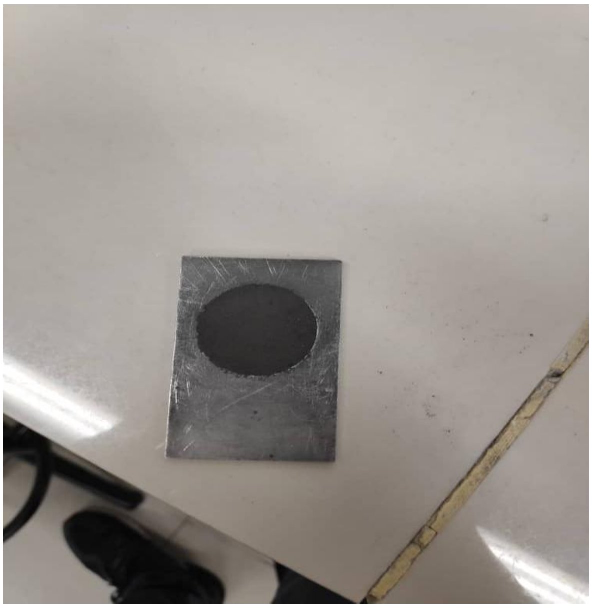

Figure 3.14: The specimens is compacted

Figure 3.15: The specimens in the X-Ray Diffraction machines

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The result of the test carried out on the normal concrete incorporated with the wood ash as a partial cement replacement was obtained and be discussed in chapter four. There was a total of six tests conducted such as compressive strength test, density test, scanning electron microscope test, water absorption test, x-ray diffraction test, and thermal conductivity test. The concretes were cured for 7^{th} and 28^{th} days of age at the water tank with tap water before testing.

4.2 Mix Proportion

Tables 4.1 and 4.2 shown the design ratio of different proportions of the concrete specimens.

Table 4.1: Design ratio of the proportion of the control sample

Material	**Proportions (Kg/m³)**
Cement	342
Water	205
Fine aggregate	701
Coarse aggregate	1052

The purpose of the NW-W0 concrete casting is acting as a control mixture. The water cement ratio is 0.6. There had 96 of specimens were cast with a dimension of 50 mm × 50 mm × 50 mm in order to accomplish both the aim and objectives.

Table 4.2: Design ratio proportions with wood ash

Specimen	**Materials (Kg/m³)**				
	Water	**Cement**	**Fine Aggregate**	**Coarse Aggregate**	**Wood ash**
NW-W0	205	342.0	701	1052	0.0
NW-W10	205	307.8	701	1052	34.2
NW-W20	205	273.6	701	1052	68.4
NW-W30	205	239.4	701	1052	102.6

where:

NW-W0 = concrete with 0 % wood ash replacement

NW-W10 = concrete with 10 % wood ash replacement

NW-W20 = concrete with 20 % wood ash replacement

NW-W30 = concrete with 30 % wood ash replacement

4.3 Water Absorption Test

There was a total of four batches of concrete mix with wood ash with a different ratio ranging from 0 % to 30 % with an incremental of 10 % each as a partial cement replacement. Figure 4.1 shown an example of concrete specimens immersed in the water tank. The effects of water absorption properties are observed. It is shown that the higher percentage of the wood ash replaced the cement, the darker the concrete. Mostly because the wood ash absorbed the water faster than the cement. On the other hand, Tables 4.3, 4.4 and 4.5 show the saturated weight, oven dry weight and the water absorption of the concretes.

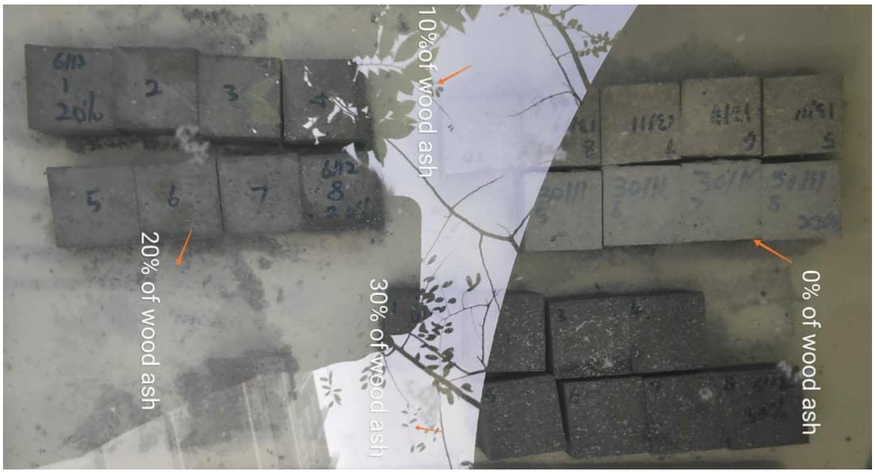

Figure 4.1: The concrete mix in the water tank

Based on Figure 4.2, the water absorption of the concrete mix is directly proportional to the incorporation wood ash as a partial cement replacement. The water absorption at 7th day is slight increases from 6.49 % to 7.58 % with regards to the cement replacement from 0 % to 30 %. The water absorption at 28th day is slight increases from 6.2 % to 7.14 % with the increased proportion of the cement replacement from 0 % to 30 %. The more wood ash is added the more unburn carbon will lead to the excessive absorption of water and free water availability was reduced in the specimens. Both on the water absorption level are showing positive results because it was below the acceptable value of the construction material which is 10 %. The absorption rate at 28th day is lower than all specimens in 7th day because of the formation of the C-S-H gels. It forms a continuous layer that binds together the original cement particles into a cohesive whole. This greatly decreases the permeability of the cement paste, meaning that it is more difficult for liquid water and dissolved ions to move through the pore system.

Table 4.3: Saturated weight of the concrete mix

Saturated Weight						
Specimen	7th day curing period			28th day curing period		
	Concrete 1 (g)	Concrete 2 (g)	Concrete 3 (g)	Concrete 1 (g)	Concrete 2 (g)	Concrete 3 (g)
NW-W0	293.79	293.99	293.77	294.85	294.73	295.19
NW-W10	292.70	295.24	293.50	293.15	294.43	294.84
NW-W20	295.73	294.57	294.49	294.60	294.21	295.20
NW-W30	295.19	295.54	296.00	292.90	295.10	296.18

Table 4.4: Oven dry weight of the concrete mix

Oven dry weight						
Specimen	7th day curing period			28th day curing period		
	Concrete 1 (g)	Concrete 2 (g)	Concrete 3 (g)	Concrete 1 (g)	Concrete 2 (g)	Concrete 3(g)
NW-W0	275.73	276.54	275.52	277.22	277.33	278.60
NW-W10	274.20	277.01	275.20	276.10	276.50	277.00
NW-W20	276.57	274.51	274.95	275.80	275.40	276.40
NW-W30	274.30	274.52	275.45	272.93	275.64	276.72

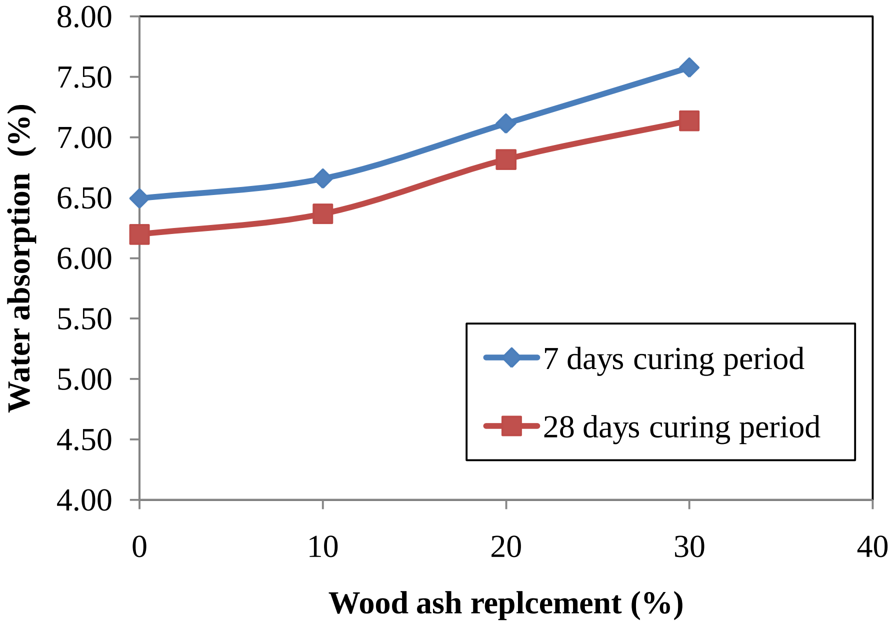

Figure 4.2: Water absorption on 7th days and 28th day

4.4 Oven Dry Density

The oven dry density of the concrete mix at 7th and 28th day was shown in Figure 4.3. The oven dry density at 28th day is denser than 7th day, although the concrete mixtures are different. When the water was added to the concrete mix at low moisture content, the particles are easier to move freely and the particle will become closer indirectly the void will also reduce. As the excess waters were filled up the void that should be filled by another particle. It will reduce the dry unit weight of the concrete because the void was occupied by excess water. The higher the oven dry density, the lesser the void in the concrete. The oven dry density for the different mixtures at 7th and 28th day fall between the acceptable range for the normal weight concrete which is between 2000 - 2600 kg/m^3.

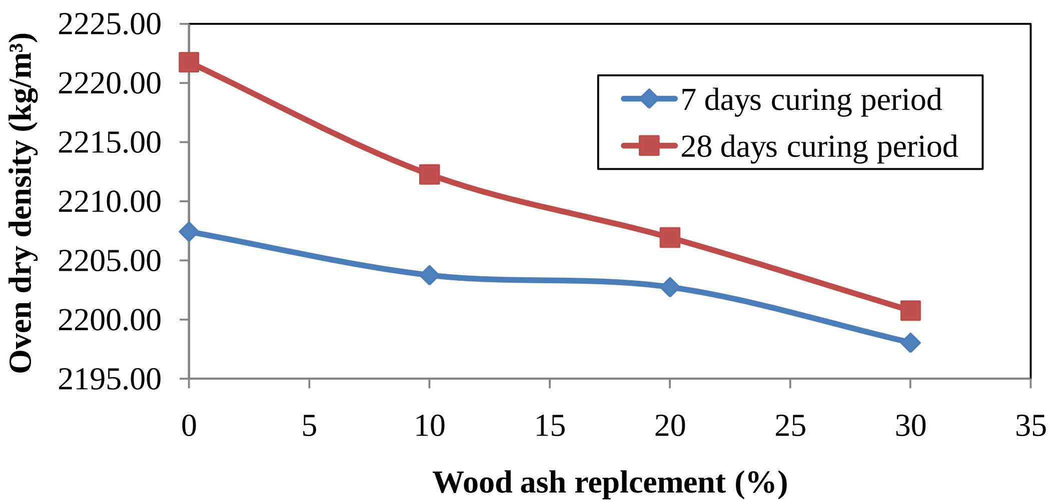

Figure 4.3: Oven dry density at 7th and 28th day

4.5 Compression Test

The compression strength development of specimens comprising different percentages of wood ash is shown in Figure 4.3. It was found that the control specimens (NW-W0) reached an average of 28.8 MPa of the compressive strength on 7th day and increased 37.1 % (39.5 MPa) on 28th day. Meanwhile, specimens with 10 % of wood ash (NW-W10) exhibited almost the same value with the control specimen which is 28.4 MPa on 7th day and increase 24.6 % (35.4 MPa) on 28th day. In addition, specimens with 20 % of wood ash (NW-W20) showed a reduction of 10 % as compared with the (NW-W10) which is 26.4 MPa on the 7th day and increase 12.1 % (32.2 MPa) on 28th day. The specimens with 30 % of wood ash (NW-W30) gave the lowest value at 7th and 28th when compared to the specimens with 0 %, 10 % and 20 % of wood ash that are 23.71 MPa and 29.03 MPa respectively.

Overall, the incorporation of the wood ash as a partial cement replacement will inversely proportional to the 7th and the 28th compression strength of the concretes. It shown the wood ash replacement would result in lower compression strength of concrete because wood ash will not self-cementing or possesses of pozzolanic effect. This was again further reduced cementitious materials content in the mixture and lead to decrease on compression strength. All the specimens are higher than the target strength of 30 MPa except the NW-W30 which is 29.03 slightly below the target strength at 28th day.

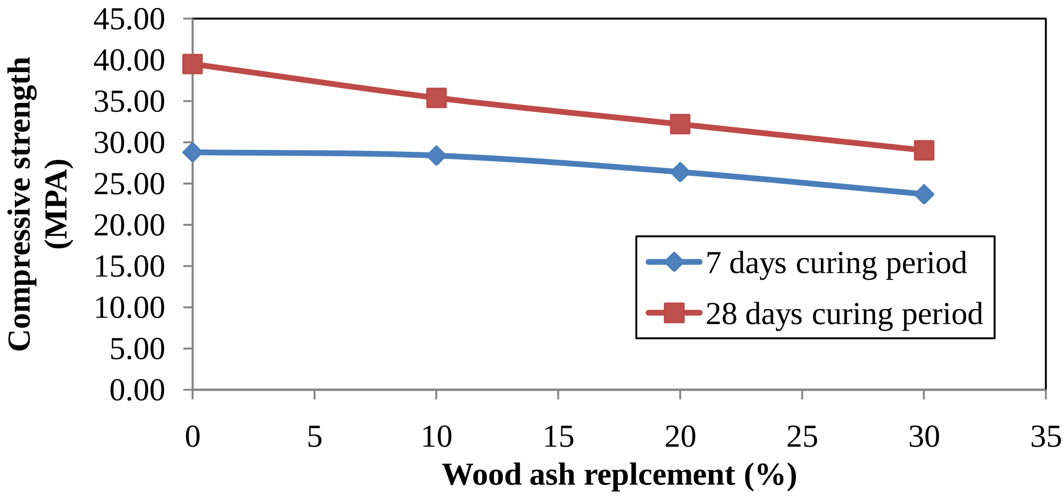

Figure 4.4: Average compression strength at 7th and 28th day

4.6 Thermal Conductivity of the Concrete

As it can be seen from Figure 4.5, the highest value of the thermal conductivity of concrete is obtained for the specimens with 0 % replacement of cement which is 1.4149 W/MK at 28th day. The lowest thermal conductivity at 28th day is NW-W30 which is 1.1443 W/MK. Moreover, the graph declines slightly with the increases used of wood ash for a replacement for the cement due to the amorphous structure of the mineral. Wood ash contains the amorphous silica. Since the crystalline silica was 15 times as the amorphous, so it is natural for the concrete with amorphous silica had the lower conductivity. The lower the thermal conductivity means had a better thermal insulation.

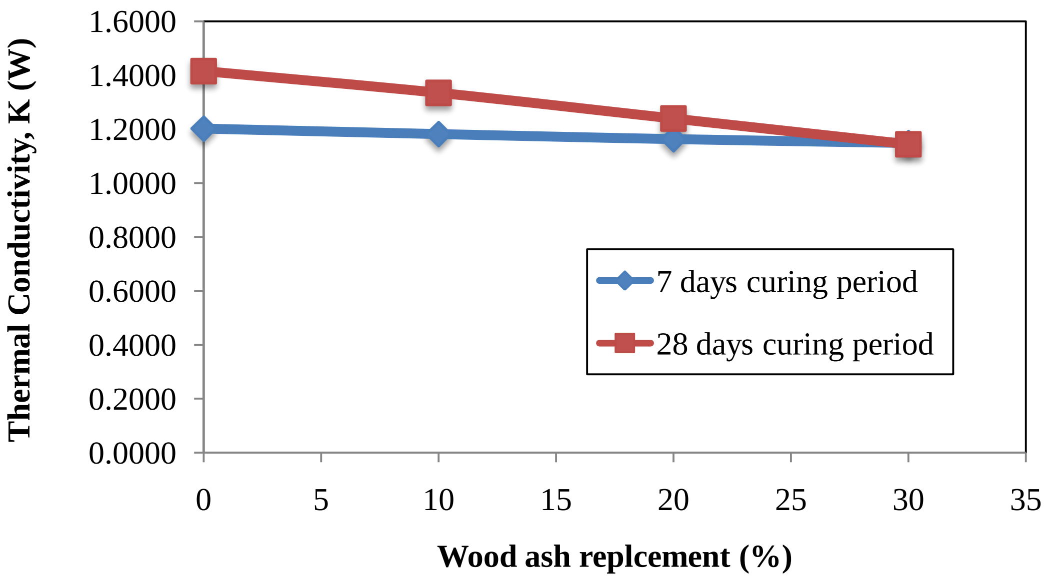

Figure 4.5: Thermal conductivity of concrete mix at 7th and 28th day

4.7 XRD

The mineralogical analysis of wood ash was observed by using the x-ray diffraction (XRD). Some crystalline phases were found in the wood ash. The Table 4.15 had shown the result of the chemical properties of wood ash.

Table 4.5: Chemical properties of wood ash

SiO_2	Silicon oxide (Quartz)
CaO	Calcium oxide (lime)
$CaCO_3$	Calcium carbonate (calcite)
Al_2O_3	Aluminium oxide
Ca_2SiO_4	Calcium Silicate
$CaOSiO_2H_2O$	Calcium Silicate hydrate
$Ca_3Al_2O_6$	Tricalcium Aluminate

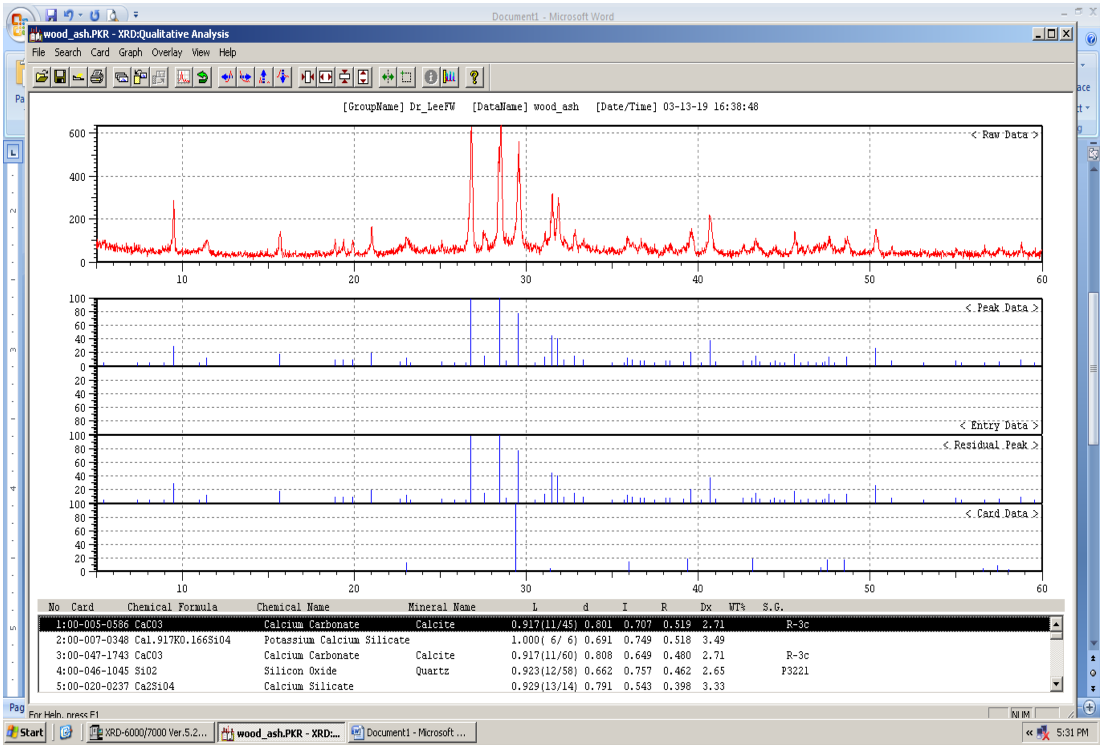

Figure 4.6: Result for wood ash contain calcium carbonate and silicon oxide

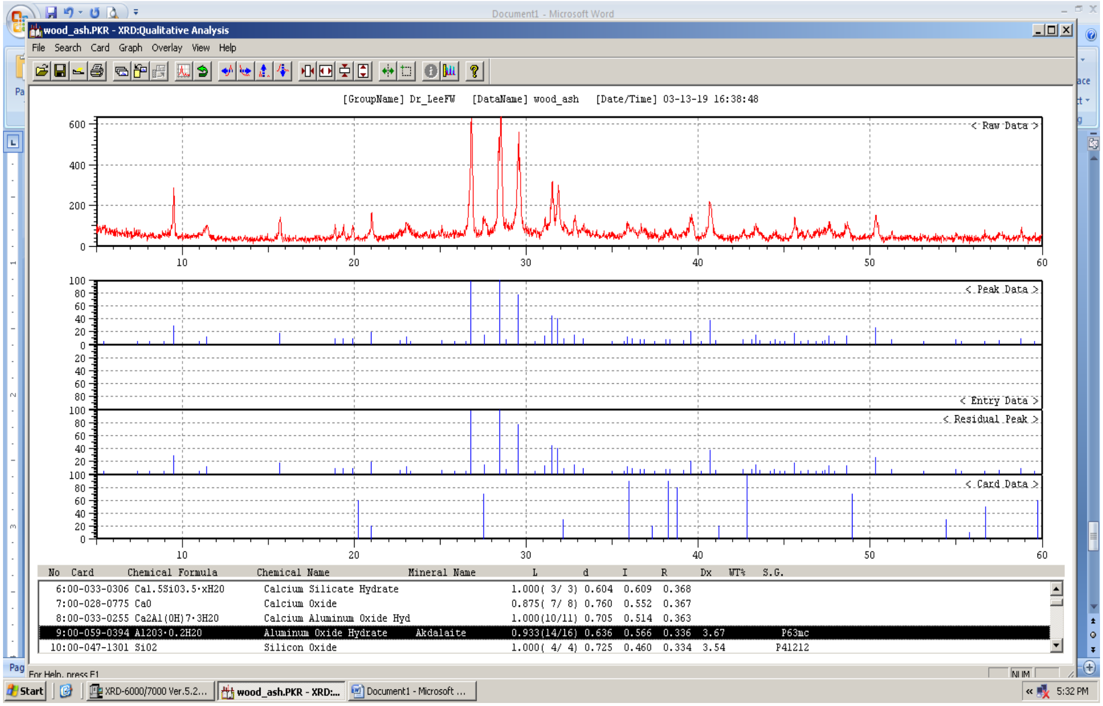

Figure 4.7: Result for wood ash contain aluminium oxide and calcium silicate hydrate

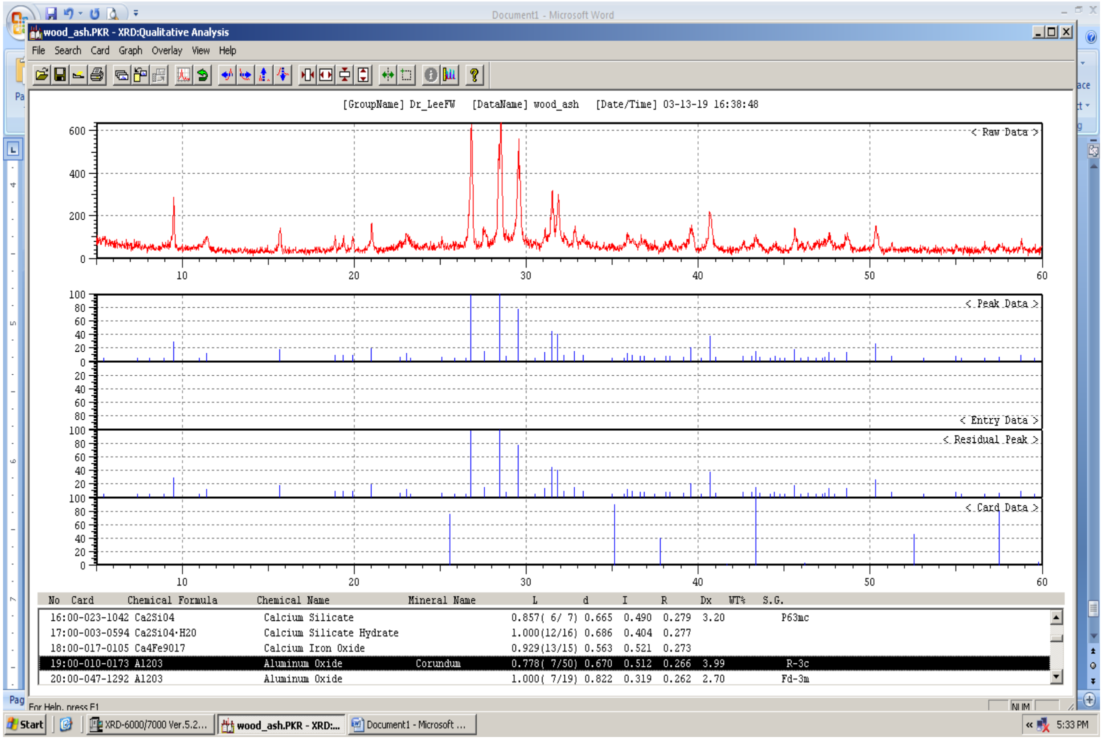

Figure 4.8: Result for wood ash contain aluminium oxide and calcium silicate

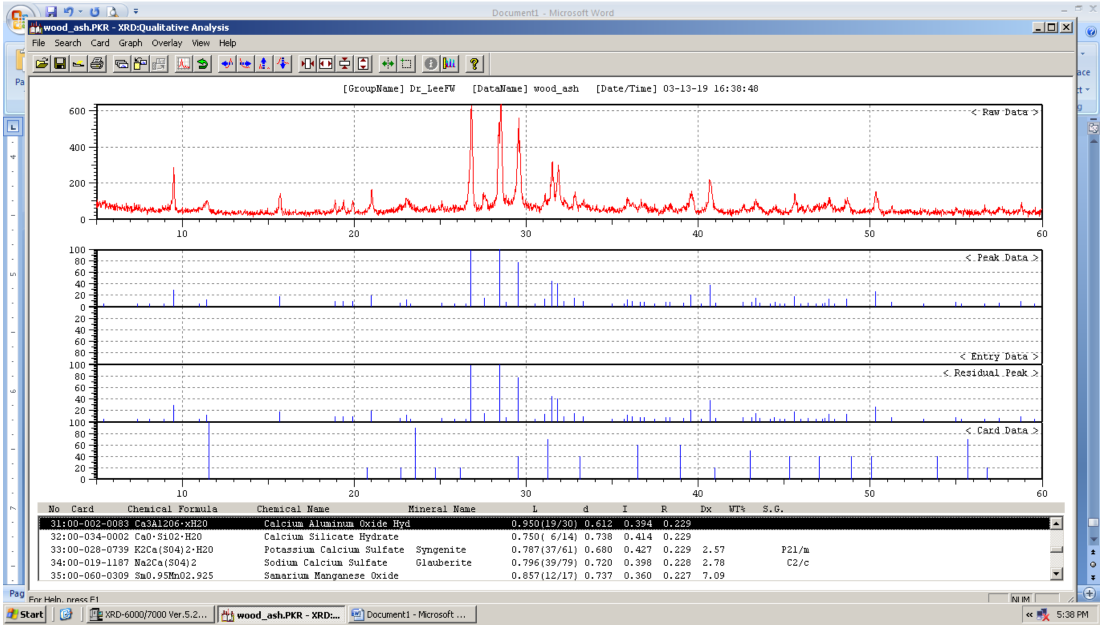

Figure 4.9: Result for wood ash contain tricalcium aluminate

4.8 Scanning Electron Microscope

The Figure 4.10 showed that the wood ash as a heterogeneous mixture of particles of varying size that are generally angular in shapes. The wood ash particles found in porous agglomerated particles due to the unburnt or partially burnt wood chips.

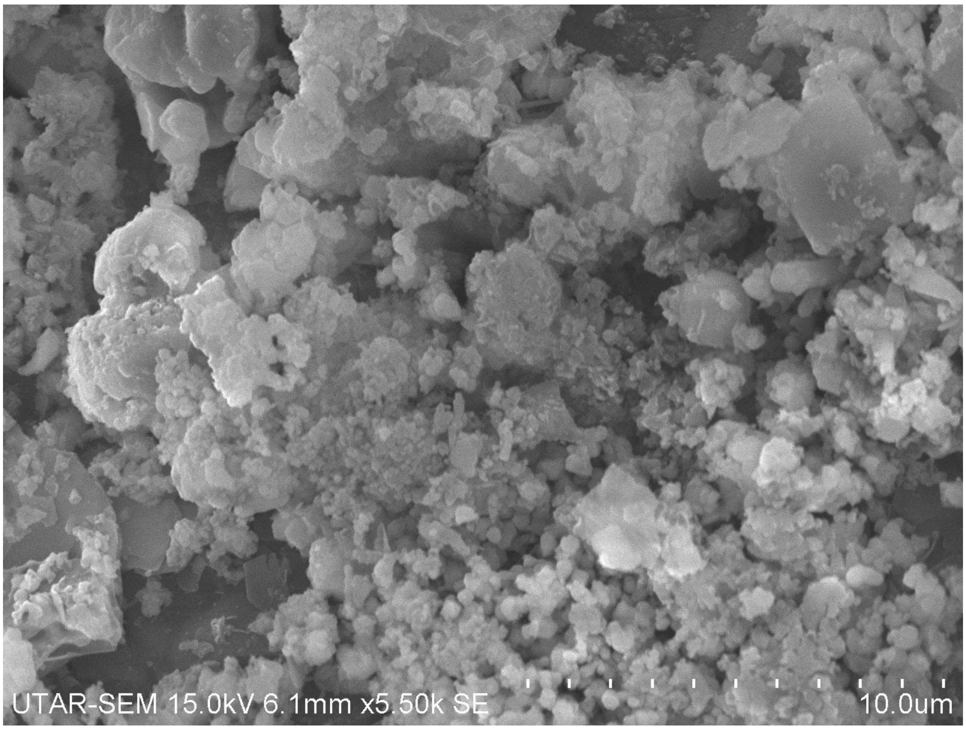

Figure 4.10: Example of wood ash properties

Based on the Figures 4.11, 4.12 and 4.13, we found that the concrete with 0 % of wood ash is more compacted, denser and less pore compare to the other. The ettringite needles are replaced by voluminous CSH structure that indicates the higher degree of hydration. This observation was well in line with the compressive strength observations. The specimens with added wood ash show the less crystalline structure and more void between the particles.

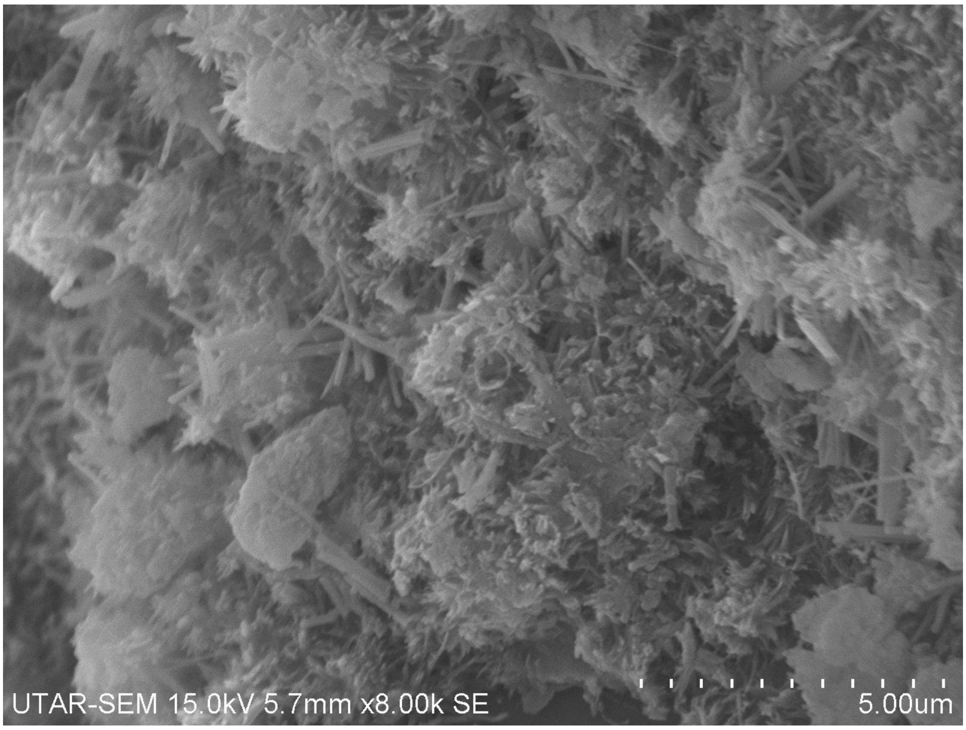

Figure 4.11: SEM image of concrete with wood ash 0 % replacement of cement at 28th day

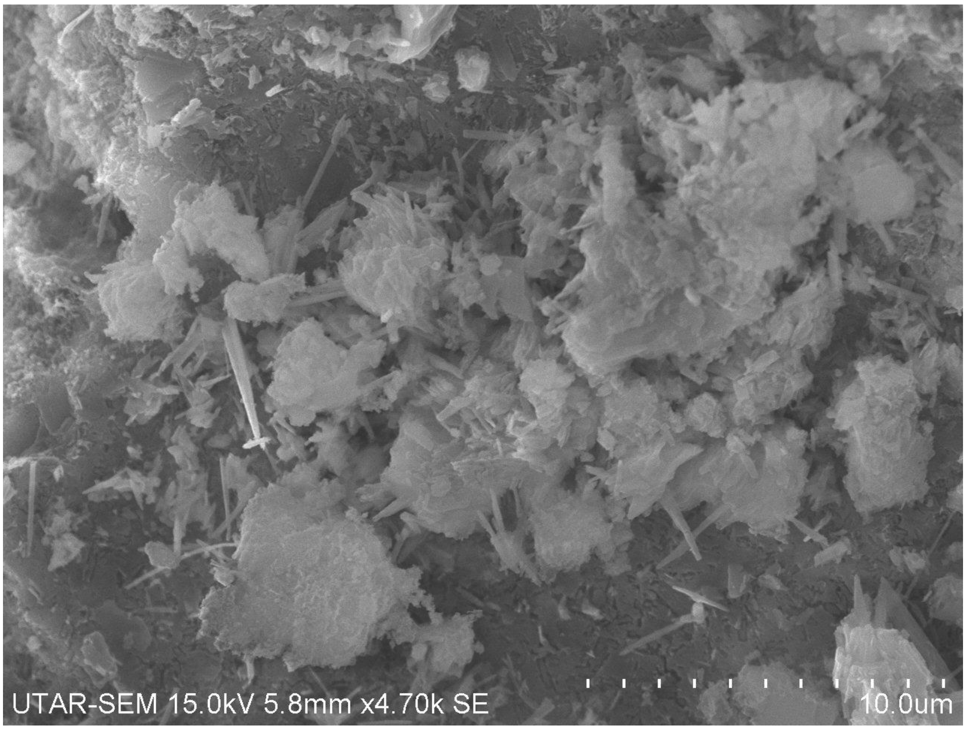

Figure 4.12: SEM image of concrete with wood ash 20 % replacement of cement at 28th day

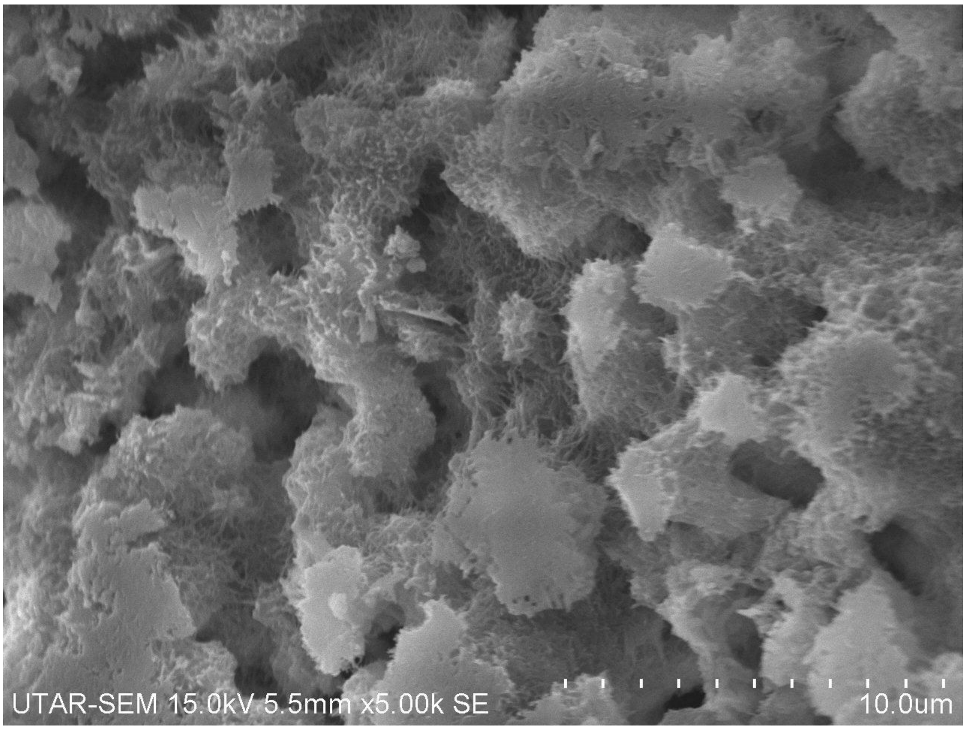

Figure 4.13: SEM image of concrete with wood ash 30 % replacement of cement at 28th day

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim of this study is to investigate the characteristic of concrete fabricated by replacing Ordinary Portland cement (OPC) with wood ash at different weight ratios. Several conclusions can be drawn corresponding to the objectives that listed out in Chapter 1 of this study.

The first objective of this study is to produce 30 MPa target strength of concrete by using the wood ash as cement replacement. Based on Table 4.6, all the specimens are higher than the target strength of 30 MPa except the NW-W30 which is 29.03 slightly below the target strength at 28^{th} day.

The second objective is to study the mechanical properties in the concrete by incorporate of the wood ash to replace the cement in terms of thermal conductivity, compressive strength, absorption of water, microstructure and density of the concrete.

i. Incorporation of wood ash as a partial cement replacement slight declined in the thermal conductivity of concrete as the wood ash replacement increases.
ii. Incorporation of wood ash as a partial cement replacement decreased in the compression strength of concrete as the wood ash replacement increases.
iii. Incorporation of wood ash as a partial cement replacement slight increases water absorption of concrete as the wood ash replacement increases.
iv. Incorporation of wood ash as a partial cement replacement steadily declines on the dry density concrete as the wood ash replacement increases.

The third objective is to figure out the maximum replacement of wood ash from 0 % to 30 % of 10 % incremental. Based on the studied, NW-W20 is the optimum replacement of wood ash. It's achieved the target strength of 30 MPa and had a lower thermal conductivity than NW-W0 and NW-W10 which is 1.239 W/MK on 28^{th} but higher than NW-W30 (1.114W/MK). The oven dry density for the different mixtures at 7th and 28th days fall between the acceptable range for the normal weight concrete which is between 2000 until 2600 kg/m³.The water absorption level is showing positive results because it's below the acceptable value of the construction material which is 10 %. Thus, the use of wood ash in concrete helps to transform it from environmental concern to a useful resource for the production of a highly effective alternative cementing material.

5.2 Recommendations for Future Work

The study of incorporating wood ash as partial cement replacement in concrete is still fresh and limited in this field. Upon the completion of this study, some recommendation needs to consider for improving the limitation of the test:

i. Study the mechanical properties and impact of concrete by using different curing method.
ii. By using incremental of 5 % of replacement of wood ash instead of 10 % replacement and study the mechanical properties.
iii. The specimens use must big enough so that the result will more accurate.
iv. By using the different water cement ratio with a smaller interval in order to get a better result.

REFERENCE

Abdullahi, M., 2006. Characteristics of wood ash/OPC concrete. *Leonardo Electronic Journal of Practices and Technologies*, *8*, pp.9-16.

Ali, N., Din, N., Khalid, F.S., Shahidan, S., Abdullah, S.R., Samad, A.A.A. and Mohamad, N., 2017, November. Compressive strength and initial water absorption rate for cement brick containing high-density polyethylene (HDPE) as a substitutional material for sand. In *IOP Conference Series: Materials Science and Engineering* (Vol. 271, No. 1, p. 012083). IOP Publishing.

Batt, A.S. and Garg, A., 2017. Partial Replacement of Wood Ash with Ordinary Portland Cement and Foundry Sand as Fine Aggregate. *Journal of Civil & Environmental Engineering*, *7*(2).

Bostanci, L. and Sola, O.C., 2018. Mechanical Properties and Thermal Conductivity of Aerogel-Incorporated Alkali-Activated Slag Mortars. *Advances in Civil Engineering*, *2018*.

Hakkila, P., Kalaja, H., Salakari, M. and Valonen, P., 1978. *Whole-tree harvesting in the early thinning of pine* (Vol. 333, p. 58). Metsäntutkimuslaitos.

Kucche, K.J., Jamkar, S.S. and Sadgir, P.A., 2015. Quality of water for making concrete: a review of literature. *International Journal of Scientific and Research Publications*, *5*(1), pp.1-10.

Naik, T.R., 1999. Tests of wood ash as a potential source for construction materials. *Report NoCBU-1999-09. Milwaukee: UWM Center for By-products utilization, Department of Civil Engineering and Mechanics*, *University of Wisconsin-Milwaukee*, p.61.

Naik, T.R., 2008. Sustainability of concrete construction. *Practice Periodical on Structural Design and Construction*, *13*(2), pp.98-103.

Naik, T.R., Kraus, R.N. and Siddique, R., 2002. Demonstration of manufacturing technology for concrete and CLSM utilizing wood ash from Wisconsin. *UWM Centre for By product Utilization*.

Ramme, B.W., Wen, H., Naik, T.R. and Kraus, R.N., 2005. Center for By-Products Utilization.

Neville, A. M., 2010. *Properties of Concrete (Vol.4). London: Pearson, pp. 10-17, 65-71, 83-86, 598-599, 688.*

Nevillee, *Properties of Concret, Longman scientific & Technical publication, 1994, pp 10-87.*

Ottosen, L.M., Hansen, E.Ø., Jensen, P.E., Kirkelund, G.M. and Goltermann, P., 2016. Wood ash used as partly sand and/or cement replacement in mortar. *International Journal of Sustainable Development and Planning*, *11*(5), pp.781-791.

Udoeyo, F.F., Inyang, H., Young, D.T. and Oparadu, E.E., 2006. Potential of wood waste ash as an additive in concrete. *Journal of materials in civil engineering*, *18*(4), pp.605-611.

Ukrainczyk, N., Vrbos, N. and Koenders, E.A., 2016. Reuse of woody biomass ash waste in cementitious materials. *Chemical and biochemical engineering quarterly*, *30*(2), pp.137-148.

Sebastian, A., Manapurath, A.S., Balachandran, D., Sebastian, D.M. and Philip, D., 2016. Partial Replacement of Cement with Wood Ash. *Ijste—International Journal of Science Technology & Engineering*, *2*.

Taoukil, D., Sick, F., Mimet, A., Ezbakhe, H. and Ajzoul, T., 2013. Moisture content influence on the thermal conductivity and diffusivity of wood–concrete composite. *Construction and Building Materials*, *48*, pp.104-115.

Thomas,J.2019. *Calcium-Silicate-Hydrate (C-S-H) gel*. [online] Available at:<http://iti.northwestern.edu/cement/monograph/Monograph5_4_2.html> [Accessed 7 Apr. 2019].

Valore, R.C., 1954, May. Cellular concretes Part 1 composition and methods of preparation. In *Journal Proceedings* (Vol. 50, No. 5, pp. 773-796).

Vassilev, S.V., Baxter, D., Andersen, L.K. and Vassileva, C.G., 2010. An overview of the chemical composition of biomass. *Fuel*, *89*(5), pp.913-933.

West, G., Fookes, P.G., Lay, J., Sims, I., Smith, M.R. and Collis, L., 2001. Aggregates: Sand, Gravel and Crushed Rock Aggregates for Construction Purposes (Geological Society Engineering Geology Special Pub. No. 17)(p. 360). In *Geological Society of London*.

Yang, Z., Huddleston, J. and Brown, H., 2016. Effects of Wood Ash on Properties of Concrete and Flowable Fill. *Journal of Materials Science and Chemical Engineering*, *4*(07),p.101.

APPENDIX

APPENDIX A: Absorption of the concrete mix

Absorption								
Specimen	**7^{th} day curing period**				**28^{th} day curing period**			
	Concrete 1 (g)	**Concrete 2 (g)**	**Concrete 3 (g)**	**Average (g)**	**Concrete 1 (g)**	**Concrete 2 (g)**	**Concrete 3 (g)**	**Average (g)**
NW-W0	6.55	6.31	6.62	6.49	6.36	6.27	5.95	6.20
NW-W10	6.75	6.58	6.65	6.66	6.18	6.48	6.44	6.37
NW-W20	6.93	7.31	7.11	7.11	6.82	6.83	6.80	6.82
NW-W30	7.62	7.66	7.46	7.58	7.32	7.06	7.03	7.14

APPENDIX B: Compression strength on 7^{th} and 28^{th} day

Compressive strength								
Specimen	**7^{th} day curing period strength (MPA)**				**28^{th} day curing period strength (MPA)**			
	Concrete 1	**Concrete 2**	**Concrete 3**	**Average**	**Concrete 1**	**Concrete 2**	**Concrete 3**	**Average**
NW-W0	28.87	29.04	28.50	28.80	39.15	40.00	39.35	39.50
NW-W10	28.30	28.50	28.40	28.40	35.80	35.10	35.30	35.40
NW-W20	26.10	26.30	26.80	26.40	32.10	32.70	31.80	32.20
NW-W30	23.84	23.62	23.68	23.71	28.80	29.30	29.00	29.03

APPENDIX C: Thermal conductivity with 0% replacement of cement with wood ash at 7th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/K·M)
1	1.114	39.63	22.50	17.13	0.0025	0.050	1.3007
2	0.540	39.61	22.41	17.20	0.0025	0.050	0.6273
3	1.637	39.57	22.37	17.19	0.0025	0.050	1.9043
4	1.100	39.54	22.34	17.20	0.0025	0.050	1.2783
5	1.124	39.52	22.33	17.19	0.0025	0.050	1.3073
6	1.117	39.51	22.34	17.17	0.0025	0.050	1.3009
7	1.116	39.61	22.38	17.24	0.0025	0.050	1.2951
8	0.544	39.56	22.36	17.20	0.0025	0.050	0.6327
9	0.588	39.54	22.37	17.17	0.0025	0.050	0.6846
10	1.128	39.55	22.37	17.18	0.0025	0.050	1.3125
11	1.138	39.63	22.36	17.27	0.0025	0.050	1.3181
12	0.561	39.61	22.36	17.25	0.0025	0.050	0.6504
13	0.554	39.58	22.37	17.21	0.0025	0.050	0.6439
14	0.566	39.55	22.37	17.18	0.0025	0.050	0.6588
15	1.112	39.60	22.38	17.22	0.0025	0.050	1.2915
16	1.674	39.63	22.37	17.27	0.0025	0.050	1.9392
17	1.698	39.60	22.37	17.24	0.0025	0.050	1.9694
18	0.577	39.58	22.36	17.22	0.0025	0.050	0.6703
19	1.697	39.55	22.36	17.19	0.0025	0.050	1.9742
20	1.113	39.63	22.36	17.27	0.0025	0.050	1.2890
AVG		39.58	22.37				1.2024

APPENDIX D: Thermal conductivity with 10 % replacement of cement with wood ash at 7th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/KM)
1	1.114	40.88	22.67	18.21	0.0025	0.05	1.2233
2	0.540	40.12	22.60	17.52	0.0025	0.05	0.6158
3	1.637	40.13	22.58	17.54	0.0025	0.05	1.8665
4	1.100	40.29	22.57	17.72	0.0025	0.05	1.2409
5	1.124	40.23	22.57	17.66	0.0025	0.05	1.2722
6	1.117	40.20	22.59	17.61	0.0025	0.05	1.2682
7	1.116	40.24	22.64	17.60	0.0025	0.05	1.2682
8	0.544	40.28	22.63	17.65	0.0025	0.05	0.6165
9	0.588	40.33	22.64	17.69	0.0025	0.05	0.6646
10	1.128	40.37	22.64	17.74	0.0025	0.05	1.2714
11	1.138	40.35	22.64	17.71	0.0025	0.05	1.2854
12	0.667	40.33	22.64	17.69	0.0025	0.05	0.7537
13	0.622	40.30	22.65	17.64	0.0025	0.05	0.7054
14	0.566	40.13	22.65	17.48	0.0025	0.05	0.6476
15	1.112	40.15	22.66	17.48	0.0025	0.05	1.2723
16	1.674	40.42	22.65	17.77	0.0025	0.05	1.8842
17	1.698	40.20	22.65	17.55	0.0025	0.05	1.9344
18	0.577	40.05	22.65	17.40	0.0025	0.05	0.6633
19	1.697	40.35	22.65	17.70	0.0025	0.05	1.9168
20	1.113	40.16	22.65	17.51	0.0025	0.05	1.2714
AVG		40.28	22.63				1.1821

APPENDIX E: Thermal conductivity with 20 % replacement of cement with wood ash at 7th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/KM)
1	1.102	39.83	23.37	16.46	0.0025	0.05	1.3391
2	1.111	39.83	23.31	16.51	0.0025	0.05	1.3459
3	0.267	39.83	23.33	16.51	0.0025	0.05	0.3231
4	1.654	39.78	23.38	16.40	0.0025	0.05	2.0167
5	0.575	39.79	23.37	16.41	0.0025	0.05	0.7007
6	1.134	39.90	23.37	16.52	0.0025	0.05	1.3721
7	1.110	39.86	23.37	16.49	0.0025	0.05	1.3469
8	1.685	39.82	23.38	16.45	0.0025	0.05	2.0493
9	0.556	39.80	23.38	16.42	0.0025	0.05	0.6772
10	1.657	39.88	23.37	16.51	0.0025	0.05	2.0073
11	1.130	39.88	23.37	16.51	0.0025	0.05	1.3686
12	1.090	39.86	23.37	16.49	0.0025	0.05	1.3213
13	0.444	39.86	23.37	16.48	0.0025	0.05	0.5393
14	0.667	39.83	23.38	16.45	0.0025	0.05	0.8104
15	1.116	39.93	23.37	16.56	0.0025	0.05	1.3476
16	0.549	39.90	23.36	16.54	0.0025	0.05	0.6644
17	1.108	39.87	23.36	16.51	0.0025	0.05	1.3426
18	0.548	39.89	23.37	16.51	0.0025	0.05	0.6634
19	0.567	39.97	23.37	16.60	0.0025	0.05	0.6832
20	1.118	39.95	23.36	16.59	0.0025	0.05	1.3482
AVG		39.86	23.37				1.1634

APPENDIX F: Thermal conductivity with 30 % replacement of cement with wood ash at 7th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/KM)
1	1.63	40.30	21.89	18.41	0.0025	0.05	1.772
2	1.67	40.31	21.87	18.44	0.0025	0.05	1.813
3	1.12	40.34	21.89	18.45	0.0025	0.05	1.215
4	0.55	40.32	21.92	18.40	0.0025	0.05	0.603
5	0.56	40.34	21.93	18.41	0.0025	0.05	0.603
6	1.12	40.34	21.94	18.40	0.0025	0.05	1.221
7	1.11	40.33	21.93	18.40	0.0025	0.05	1.211
8	0.57	40.33	21.94	18.39	0.0025	0.05	0.615
9	1.14	40.36	21.95	18.42	0.0025	0.05	1.235
10	1.11	40.40	21.95	18.45	0.0025	0.05	1.206
11	1.67	40.39	21.95	18.45	0.0025	0.05	1.813
12	0.56	40.40	21.94	18.46	0.0025	0.05	0.604
13	1.12	40.39	21.95	18.44	0.0025	0.05	1.215
14	0.56	40.40	21.95	18.45	0.0025	0.05	0.609
15	1.12	40.38	21.95	18.43	0.0025	0.05	1.219
16	0.56	40.38	21.94	18.44	0.0025	0.05	0.604
17	2.19	40.31	21.89	18.42	0.0025	0.05	2.375
18	0.56	40.39	21.94	18.45	0.0025	0.05	0.611
19	1.67	40.45	21.93	18.52	0.0025	0.05	1.809
20	0.58	40.47	21.94	18.53	0.0025	0.05	0.626
AVG		40.37	21.93				1.149

APPENDIX G: Thermal conductivity with 0 % replacement of cement with wood ash at 28th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/KM)
1	2.181	40.02	22.88	17.14	0.0025	0.05	2.545
2	0.584	39.96	22.62	17.34	0.0025	0.05	0.673
3	1.121	39.93	22.58	17.34	0.0025	0.05	1.293
4	0.566	39.91	22.57	17.34	0.0025	0.05	0.653
5	1.677	39.90	22.57	17.34	0.0025	0.05	1.935
6	1.104	39.88	22.54	17.33	0.0025	0.05	1.274
7	1.117	39.87	22.57	17.31	0.0025	0.05	1.291
8	1.642	39.85	22.59	17.26	0.0025	0.05	1.903
9	0.556	39.86	22.60	17.26	0.0025	0.05	0.644
10	0.561	39.86	22.61	17.25	0.0025	0.05	0.650
11	0.444	39.86	22.61	17.25	0.0025	0.05	0.515
12	1.130	39.93	22.62	17.31	0.0025	0.05	1.305
13	1.677	39.90	22.62	17.28	0.0025	0.05	1.941
14	1.695	39.91	22.63	17.28	0.0025	0.05	1.962
15	1.130	39.91	22.63	17.28	0.0025	0.05	1.308
16	1.115	39.91	22.62	17.28	0.0025	0.05	1.290
17	1.664	39.90	22.63	17.27	0.0025	0.05	1.927
18	1.110	39.91	22.62	17.28	0.0025	0.05	1.284
19	1.688	39.90	22.63	17.27	0.0025	0.05	1.955
20	1.682	39.90	22.62	17.28	0.0025	0.05	1.947
AVG		39.90	22.62				1.415

APPENDIX H: Thermal conductivity with 10 % replacement of cement with wood ash at 28th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/KM)
1	1.130	39.78	22.23	17.56	0.0025	0.05	1.287
2	1.121	39.77	22.18	17.58	0.0025	0.05	1.275
3	0.018	39.77	22.18	17.59	0.0025	0.05	0.020
4	1.681	39.75	22.17	17.58	0.0025	0.05	1.913
5	1.107	39.73	22.16	17.56	0.0025	0.05	1.261
6	1.113	39.74	22.18	17.56	0.0025	0.05	1.268
7	1.660	39.74	22.23	17.51	0.0025	0.05	1.896
8	1.095	39.71	22.22	17.48	0.0025	0.05	1.253
9	0.561	39.75	22.23	17.51	0.0025	0.05	0.641
10	0.444	39.73	22.24	17.49	0.0025	0.05	0.508
11	1.124	39.74	22.24	17.50	0.0025	0.05	1.284
12	1.683	39.73	22.24	17.49	0.0025	0.05	1.925
13	1.689	39.72	22.25	17.47	0.0025	0.05	1.934
14	1.130	39.71	22.24	17.47	0.0025	0.05	1.293
15	0.557	39.78	22.24	17.54	0.0025	0.05	0.636
16	1.665	39.76	22.24	17.52	0.0025	0.05	1.901
17	1.122	39.79	22.24	17.54	0.0025	0.05	1.279
18	1.686	39.79	22.24	17.54	0.0025	0.05	1.922
19	1.666	39.78	22.25	17.53	0.0025	0.05	1.901
20	1.134	39.77	22.24	17.53	0.0025	0.05	1.294
AVG		39.75	22.22				1.334

APPENDIX I: Thermal conductivity with 20 % replacement of cement with wood ash at 28th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/KM)
1	1.631	39.02	21.93	17.08	0.0025	0.05	1.909
2	1.672	39.02	21.92	17.10	0.0025	0.05	1.955
3	1.120	39.05	21.93	17.12	0.0025	0.05	1.309
4	0.554	39.09	22.00	17.09	0.0025	0.05	0.649
5	0.555	39.09	22.00	17.09	0.0025	0.05	0.650
6	1.123	39.07	22.00	17.07	0.0025	0.05	1.316
7	1.114	39.09	22.00	17.09	0.0025	0.05	1.304
8	0.565	39.07	22.00	17.07	0.0025	0.05	0.662
9	1.137	39.07	22.00	17.07	0.0025	0.05	1.333
10	1.112	39.05	22.00	17.05	0.0025	0.05	1.304
11	1.672	39.05	22.00	17.05	0.0025	0.05	1.961
12	0.558	39.10	22.00	17.09	0.0025	0.05	0.653
13	1.120	39.11	22.01	17.10	0.0025	0.05	1.310
14	0.562	39.11	22.01	17.10	0.0025	0.05	0.657
15	1.124	39.10	22.01	17.09	0.0025	0.05	1.316
16	0.557	39.10	22.01	17.09	0.0025	0.05	0.652
17	2.188	39.08	21.93	17.14	0.0025	0.05	2.552
18	0.564	39.10	22.02	17.08	0.0025	0.05	0.660
19	1.675	39.10	22.02	17.08	0.0025	0.05	1.961
20	0.580	39.14	21.97	17.17	0.0025	0.05	0.676
AVG		39.08	21.99				1.239

APPENDIX J: Thermal conductivity with 30 % replacement of cement with wood ash at 28th day

Hours	Heat Flow, Q (W)	Avg Hot Plate Temp	Avg Cold Plate Temp	Avg Temp Different, ΔT (K)	Area, A (m2)	Thickness, L (m)	Thermal Conductivity, K (W/KM)
1	0.563	39.92	22.76	17.16	0.0025	0.05	0.6559
2	0.550	39.85	22.75	17.10	0.0025	0.05	0.6428
3	1.663	39.74	22.78	16.96	0.0025	0.05	1.9620
4	1.111	39.86	22.84	17.01	0.0025	0.05	1.3061
5	1.648	39.80	22.83	16.96	0.0025	0.05	1.9431
6	1.122	39.75	22.85	16.91	0.0025	0.05	1.3269
7	1.119	39.88	22.85	17.03	0.0025	0.05	1.3141
8	1.665	39.76	22.86	16.90	0.0025	0.05	1.9702
9	0.565	39.82	22.87	16.95	0.0025	0.05	0.6663
10	1.138	39.83	22.87	16.96	0.0025	0.05	1.3416
11	1.113	39.77	22.88	16.89	0.0025	0.05	1.3181
12	0.561	39.80	22.88	16.92	0.0025	0.05	0.6636
13	0.018	39.84	22.88	16.96	0.0025	0.05	0.0212
14	1.114	39.76	22.88	16.88	0.0025	0.05	1.3198
15	0.444	39.81	22.88	16.93	0.0025	0.05	0.5250
16	0.561	39.84	22.89	16.95	0.0025	0.05	0.6616
17	0.563	39.94	22.76	17.18	0.0025	0.05	0.6554
18	1.657	39.76	22.89	16.86	0.0025	0.05	1.9654
19	1.118	39.83	22.89	16.94	0.0025	0.05	1.3202
20	1.115	39.90	22.83	17.08	0.0025	0.05	1.3059
AVG		39.82	22.85				1.1443