

2021-01-28

EXPERIMENTAL INVESTIGATION ON PARTIAL REPLACEMENT OF CEMENT WITH WATER HYACINTH (EMBOCH) ASH IN CONCRETE

MIHIRET, ALEMU TAKAYE

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SCHOOL OF RESEARCH AND GRADUATE STUDIES

FACULTY OF CIVIL AND WATER RESOURCE ENGINEERING

**MSC PROGRAM IN CONSTRUCTION TECHNOLOGY AND
MANAGEMENT**

**EXPERIMENTAL INVESTIGATION ON PARTIAL REPLACEMENT OF CEMENT
WITH WATER HYACINTH (EMBOCH) ASH IN CONCRETE**

MIHIRET ALEMU TAKAYE

Bahir Dar Ethiopia

January 28, 2021

EXPERIMENTAL INVESTIGATION ON PARTIAL REPLACEMENT OF CEMENT WITH WATER HYACINTH ASH IN CONCRETE

MIHIRET ALEMU TAKAYE

A thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in partial fulfillment of the requirements for the degree of Master of Science in construction technology and management in civil and water resource engineering.

Advisor Name: Mitiku Damitie (Ph.D).

BahirDar, Ethiopia

January 28, 2021

DECLARATION

This is to certify that the thesis intitlled **Experimental investigation on partial replacement of cement with Water Hyacinth Ash in Concrete** submitted in partial fulfillment of the requirements for the degree of Master of Science in Construction Technology and Management under faculty of Civil and Water resource Engineering, Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this institution to get any other degree or certificate. The assistance and help I recived during the course of this investigation have been duly acknowledged.

Name of the candidate_____ Signature _____Date _____

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Approval of thesis defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of Student _____signature _____date_____

As member of board of examiners, we examined this thesis entitled **Experimental investigation on partial replacement of cement with Water Hyacinth Ash in Concrete by Mihiret Alemu.**

We hereby certify that the thesis is accepted for fulfilling the the requirements for the award of the degree of Masters of science in Construction Technology and Management under Civil and Water resource Engineering.

Board of examiners

Name of advisor	Signature	Date
_____	_____	_____
Name of External Examiner:	Signature	Date
_____	_____	_____
Name of Internal Examiner:	Signature	Date
_____	_____	_____
Name of chairperson	Signature	Date
_____	_____	_____
Name of chair Holder	Signature	Date
_____	_____	_____
Name of faculty dean	Signature	Date
_____	_____	_____

ACKNOWLEDGMENT

First of all, I would like to thank GOD for everything he did for me until the completion of my paperwork.

Second, my deepest gratitude goes to my advisor Dr. Mitiku Damtie and my Co-advisor Mr Habtamu Melaku for their uncountable knowledge share, advice, gentle comments, suggestion, and follow-ups during my study.

Third I would like to express my sincere appreciation to Bahir Dar Institute of Technology's faculty of civil and water resource engineering for joining this MSc program and for fully financing my final thesis work.

I am very grateful for the kind of teamwork and support provided by the staff from the construction Material Engineering laboratory of Bahir Dar Institute of Technology, Chemical Engineering laboratory also provided support in conducting tests.

I am glad to honor my family for their parental advice and guidance in my entire path. Special and earnest gratitude is for Kalkidan Adera and Tigst Alemu for their presence at every stage; which was adding incalculable energy in the entire endeavor of my study.

ABSTRACT

Nowadays concrete is the major construction material used in the booming Ethiopian construction industry. Keeping the concrete ingredient like cement, water and aggregate are essential in reducing the wastage and the cost incurred. currently, the availability of ingredients is limited and to overcome this problem, studies focus on some alternate materials in the concrete production process. Also, Incorporation of waste materials consumes less energy leading to the reduction of emission of greenhouse gases and global warming. The application of water hyacinth ash as a pozzolanic binder instead of cement finds extensive outcome in the manufacturing process of construction materials. In this research a detailed experimental investigation has been made to utilize WHA as a partial replacement material for ordinary Portland cement in the production of concrete. The properties of concrete are investigated with different proportion of cement replacement with WHA by 0%, 5%, 10% and 15% of the cement weight for a C-25 concrete. The main important parameters in concrete are workability, compressive strength, sulfate attack, water absorption of concrete and fourier transform infrared spectroscopy analysis. The concrete cubes casted and cured according to the specified standards. This study presents the result of an experimental investigation carried out to find the sustainability of WHA in concrete and compressive strength, is attained at the ages of 3, 7, 28, 56, and 91 days. The test result indicates that use of WHA in concrete has improved the performance of concrete in strength as well as in durability aspect. The cost optimization was found out by comparing one m³ of control mix concrete and concrete made with WHA. The result shows that the concrete made with WHA reduces the cost of concrete up to 5%.

Keywords: Water Hyacinth Ash, Cement, Workability, Concrete, and Compressive strength

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ACRONYMS

ACI –American Concrete Institute

BS –British Standard

ASTM –American Standard for Testing Materials

GHG-Green House Gass

OPC –Ordinary Portland Cement

WHA- Water Hyacinth Ash

XRD –X- Ray's Diffraction

RHPC-Rapid Hardening Portland Cement

SRPC- Sulfate Resisting Portland Cement

LHPC –Low Heat Portland Cement

C-S-H Calcium silicate hydrate

FTIR- Fourier Transform Infrared Spectroscopy

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Concrete is a stone-like hard mass used as a construction material because of its good compressive strength and durability. Nowadays, the cost of construction materials is increasing which needs to look at a way to reduce the cost of cement. The replacement of the materials of concrete with some other similar materials is greatly encouraged. The construction industry is looking for supplementary cementitious material with the aim of protecting the environment from carbon-dioxide emissions and cheap availability. Water hyacinth has acted as a good cement substitution material (Pandey and Mire, 2019). Concrete is one of the most widely used construction materials in the world. However, the production of Portland cement is an essential constituent of concrete, leads to the release of a significant amount of CO₂, greenhouse gas, and global warming. One ton of Portland cement clinker production creates one ton of CO₂ and other greenhouse gases (GHGs). Environmental issues play a leading role in the sustainable development of the cement and concrete industry in this century (Naik and Moriconi, 2005).

Concrete is an important construction material consisting of cement, aggregates, and water. Among these ingredients, cement is the major producers of carbon dioxide while manufacturing clinkers and contributing to global warming. Hence from past years itself, cement is partially or fully replaced by supplementary materials. In this experimental study, Water hyacinth which is a perennial aquatic plant and that can double its population within two weeks used as a supplementary cementitious material (Manoj, 2019).

Concrete is probably the most extensively used construction material in the world. The major ingredient in conventional concrete is Portland cement. The amount of cement production emits approximately an equal amount of carbon dioxide into the atmosphere. Cement production is consuming a significant amount of natural resources. That has brought pressure to reduce cement consumption by the use of supplementary materials. Water hyacinth (*Eichhornia crassipes*), an entirely free source of biomass is found unutilized as a supplementary cementitious material. It grows vigorously and richly to produce large biomass and doubles the population in two weeks. In this work, studies have been carried out to evaluate this bio-waste as cementitious material

and this will be beneficial for future application of Water hyacinth ash in cement concrete. (Dinesh and Murugesh, 2017). The study focuses on the workability, compression strength, microstructure and durability performance of the blended concrete containing different percentages of water hyacinth ash as a partial replacement of cement. Concrete is a composite material composed mainly of water, aggregate, and cement. Often, additives and reinforcements are included in the mixture to achieve the desired physical properties of the finished material. When these ingredients are mixed, they form a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix that binds the rest of the ingredients together into a durable stone-like material with many uses (Taylor, 1997). Water hyacinth is harmful to human health, aquatic life as well as the environment. Water hyacinth (*Eichhornia crassipes*); an entirely free source of biomass is found unutilized as supplementary cementitious material. It grows vigorously and richly to produce large biomass and doubles the population in two weeks (Dinesh and Murugesh, 2017). Using this harmful biological waste as a supplementary cementing material plays a great role in the reduction of demand for cement in the sector, ensuring the lake and aquatic life safe and making the environment eco-friendly.

Water hyacinth is a distinctive, free-floating plant known for its inflated leaf stalks and brightly colored flowers. The leaves and stalks are glossy and smooth to the touch. The spongy, inflated bases of the leaves help the plant float. A mass of dark, densely packed roots hangs beneath the plant, absorbing nutrients directly from the water. Water hyacinth can produce 8-15 large flowers which occur on a single spike. The flowers have 6 petals and are purple to white with a yellow spot on the top petal ('Aquatic Invasive Species Quick Guide Water Hyacinth (*Eichhornia crassipes*), 1884).

1.2 Statement of the Problem

Nowadays Ethiopia is one of the highly growing countries in the world. The recent growth rate according to African Development Bank report 11.2% per annum for the last 5 years. The critical reason which contributes to the speedy growth is the intension of the government to construct various infrastructures in the country like highway, buildings and waterworks and mega projects as the indication of past transformation plan. The construction industry covers the most of Ethiopian capital budget and is the major player in the Ethiopian economy increment which demands so many construction resources. The construction industry is one of the leaders in the deterioration of the environment by depleting resources and consuming energy. Also, a

considerable amount of emissions of greenhouse and acidifying gasses has the origin in the construction industry. Cement is one of the main construction materials which is used in the production of concrete. its production is increasing over the world. But the industry is an energy enormous intensive and produces many emissions, odors and noise. The emission from cement plants which cause the greatest concern and which need to be dealt are dust, carbon dioxide (CO₂), nitrogen oxides (NO₂) and Sulphur dioxide (SO₂). As a result of the increasing of these substances in the environment, the number of greenhouse gases increased and it leads to global warming. The production of one(1) ton of Portland cement releases approximately one ton of CO₂ into the atmosphere in the manufacturing process. The cement industry contributes about 5% of the total atmospheric CO₂ emissions globally. The current purchase price of 1 quintal of cement is 550 birr which increased by 54.54% from the last 2007 market price 250 birr. Moreover, to construct high-class or quality concrete structures with the specified budget and time. This problem directly affects the achievement of the proposed completion period and the quality of concrete structure when mega projects undertaken in our country Ethiopia. To fulfill the high demand for cement and to reduce its current market price, it's better to find out biological weed to produce concrete that is environmentally friendly and increased the quality of concrete in terms of mechanical properties and durability properties of concrete. This problem is very sensitive for the industry. It needs the great involvement of stakeholders in the sector.

1.3 Research Questions

- How evaluating WHA interms of its applicability in concrete structure
- What is the effect of WHA on the fresh and mechanical properties of concrete while replacing cement?
- What is the effect of Water Hyacinth Ash in the microstructure and durability properties of concrete?
- What is the optimum composition of concrete made with WHA and cement that could have a considerable positive effect on the properties of concrete?
- What is the economic benefit of WHA towards producing sustainable concrete production?

1.4 Objective of the study

1.4.1 General Objective

The main objective of this research is to investigate the properties of concrete with partial replacement of cement with water hyacinth ash.

1.4.2 Specific Objectives

- Evaluating WHA interms of its applicability in concrete structure
- To examine fresh and mechanical properties of concrete while partially replacing cement with WHA.
- To investigate the durability and microstructure properties of concrete with WHA to that of conventional concrete.
- To investigate the optimum quantity of WHA to partially replace cement in a C-25 concrete.
- To conduct cost comparisons between conventional concrete and concrete which is made with partially replaced cement with WHA.

1.5. Scope of the studies

This study mainly focuses on examining the appropriate quantity of water hyacinth ash which was collected from Lake Tana and prepared as ash to replace cement in concrete production. Since water hyacinth is aquatic Biological weed which is found in Lake Tana, Ethiopia. The study was limited to collect cement substitution samples from this lake. Whereas, the other concrete materials have been collected around Bahir Dar city.

1.6. Significance of the studies

This study targeted to find the biological waste materials as a cement substitution, to improve the strength and durability of concrete and to reduce the cost of ordinary Portland cement as well as reduction of the emission of greenhouse gases and global warming. It permits the participation of construction stakeholders like clients, contractors, and consultants to become cost-efficient and to produce improved quality concrete in the sector. This research to be used as a starting point for students, academicians, researchers and professional associations for further research in the area of supplementary cementitious materia

1.7 Research Organization

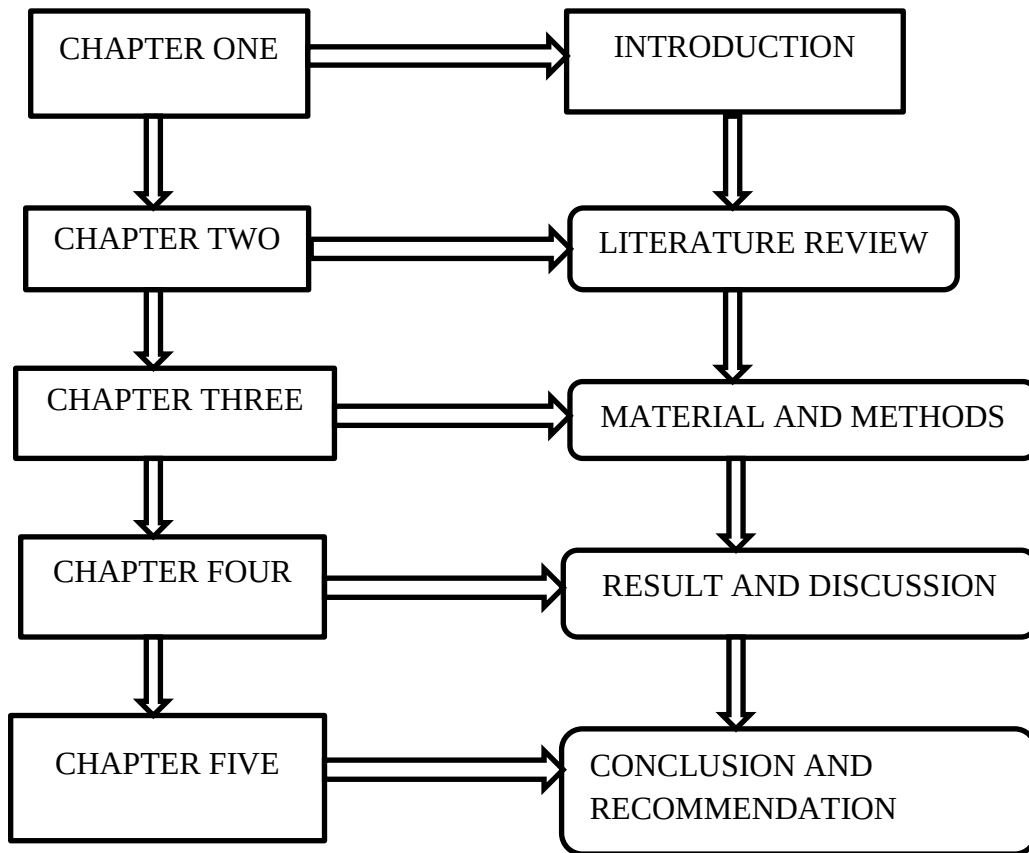


Figure 1.1 Research Organization Flow Chart

CHAPTER TWO

LITERATURE REVIEW

The literature review is carried out to find out the previous researchers work conducted in partial replacement of cement with a similar type of materials. the properties of concrete have been found. The available literature collected on this topic is as follows.

2.1 Water hyacinth

Water hyacinth (*Eichhornia crassipes*) is a hazardous and aggressive aquatic species, which has reaped global attention due to its rapid growth. It is a pandemic in most of the tropical and subtropical countries of the world. Its high water content (about 90%–95%) made management difficult and unprofitable, in such a way that millions of dollars have been spent every year on removing tons of biomass of this plant from bodies of water (Insulation and Board, 2019).

Water hyacinths are found in most of the tropical and subtropical countries of the world. Water hyacinth is a free gliding oceanic plant that develops in still or moderate moving crisp water bodies. Water hyacinth (*Eichhornia crassipes*), an altogether free wellspring of biomass is discovered unutilized as a supplementary cementitious material. The plant comprises long and stringy roots which might be up to three meters long and have sinewy stem. The normal length of the fiber is 1.604 mm and the normal measurement 5.5 microns. In research works, it is utilized as a substitute for cement in concrete to estimate the appropriateness and strength properties of water hyacinth as supplementary replacement material for cement (Abirami, Kayalvizhi and Pavithra, 2018).

Water hyacinth is a source of renewable energy and how it is utilized to reduce its harmful effects on the environment. Water hyacinth is considered an invasive aquatic plant species that proves to be a nuisance on water bodies. To utilize, its potential as partial cement replacement was investigated in this study (Mae *et al.*, 2015).

2.2 Characteristics of water hyacinth

Under favorable conditions, the population of water hyacinth doubles between 5 – 15 days. If completely undisturbed its biomass weighs 25kg per square meter or 400 tonnes per hectare. Each flower produces a seed pod that can contain up to 200 seeds. The seed can remain viable

for up to 15 years in water, silt or mud. The plant can also propagate vegetatively by sending out runners into the water which produces daughter plants that can reproduce at about the 2-week stage(Asmare, 2017).

Justifiably it is called one of the worlds worst aquatic weeds due to its impacts such as blockage of irrigation channels and rivers, destroying natural wetlands, restriction of livestock access to water, reducing gas exchange at the water surface, altering habitat of aquatic organisms, reducing aesthetic value of waterways, and it can also destroy fences, roads, and other infrastructure (Juanzon, 2017).

2.3 The effect of water hyacinth

The newly emerged water hyacinth becomes a big threat for Lake Tana in general and the fishers in particular. effects of water hyacinth are dependent on the extent of the invasion. the livelihood of subsistence fishers could be endangered because water hyacinth strongly reduces the efficiency of fishing. Unless a well-designed and organized preventive approach is followed, the expansion of water hyacinth could endanger not only fishers and the surrounding community but also the sustainability of the Lake. The local community around Lake Tana is at risk of losing their livelihood from fisheries following the infestation of the Lake by water hyacinth. Once water hyacinth has established, it is very difficult to eliminate hence, continuous monitoring is very important to decrease its rate of expansion (Asmare, 2017).

S. Dinesh, V. Murugesh (2017) conclude that tests conducted on the water hyacinth ash modified cement concrete mix, to ascertain the influences of water hyacinth ash on the characteristic strength of concrete, while water hyacinth ash is added in the concrete production,

As (Dinesh and Murugesh, 2017) report clearly show that the workability of concrete increase with increasing the amount of water hyacinth ash increase. The initial and final setting time of concrete also improves when the level of water hyacinth ash increases. (Dinesh and Murugesh, 2017) reveal that the compressive strength of concrete better improves when cement is replaced with water hyacinth ash up to 10% but when the dosage increases to 20%, strength of concrete slightly reduced. Replacement of water Hyacinth ash in the concrete mix significantly influenced the cracking behavior and ultimate strength of column (Dinesh and Murugesh, 2017).

S. Dinesh, V. Muruges (2017) slump test result has shown that all slumps were within the medium and high degree of workability and it tends to improve with a higher percentage of water Hyacinth ash in concrete as a result the workability of concrete increasing to the Water Hyacinth ash replacement. Based on S. Dinesh, V. Muruges (2017) graphical representation the water consistency indicates that the water required for normal consistency increased with the increase of cement replacement level and it is because of the high hygroscopicity nature of water hyacinth stem ash.

S. Dinesh, V. Muruges (2017) reported that strength increased with the curing age for all the samples. Control concrete gained 76% at day 7 and 88% after 14 days, 99% after 28 days of curing. The Water hyacinth blended concrete gained 50-66% at day7, 65-70% after 14 days, and 72-82% after 28 days of curing. It is clear from the observation that strength enhancement is lower than the cement concrete between 7 and 28 days. However, the 10% replacement of WHA to OPC can be considered as an optimal limit. According to S. Dinesh and V. Muruges (2017), the split tensile strength for control and Water Hyacinth blended concrete cubes with different ages. It can be seen that strength increased with the curing age for all the samples.

V.Muruges, N. Balasundaram, and T. Senthil Vadivel (2018): conclude that Saturated water absorption test indicates that water absorption is less for 10% replaced concrete which shows better durability compared to CC. The Chloride resistance test results indicate that 10% replaced concrete subjected to excellent chlorine resistance in 3.5% chloride solution is the best because the mass loss and strength loss were very less compared to CC. Compare to the normal concrete of M30 grade the 28 days strength is good and the required curing is normal. The optimum dosage for partial replacement of cement by WHA is 10%. After 28 days, the compression resistance strength of cube with WHA is better than normal conventional concrete (Muruges, Balasundaram and Vadivel, 2018).

V.Muruges, N. Balasundaram, and T. Senthil Vadivel in their study Experimental Studies on Durability Studies of Concrete with Partial Replacement of Cement by Water Hyacinth Ash concluded that 10% of cement replaced by water hyacinth ash to investigate the effects of WHA on durability and Strength in concretes better improve the durability of concrete. The Chloride resistance test results indicate that 10% replaced concrete subjected to excellent chlorine resistance in 3.5% chloride solution is the best because the mass loss and strength loss were very

less compared to CC. Based on these researchers' results at 28 days the compressive strength of concrete made with 10% Water hyacinth ash better than control mix concrete. N.Balasundaram, (2019). Density and workability of concrete didn't affect by water hyacinth substitution in concrete production. The compressive strength increased as the superplasticizer replacement was increased irrespective of the curing period and water permeability increased with an increase in the amount of water hyacinth extract. The optimum superplasticizer replacement was found to be 20%. (Okwadha and Makomele, 2018).

2.4 Cement

Cement is a finely ground powder of chemically combined argillaceous materials (silica and alumina) and calcareous materials (lime) with iron oxide, gypsum and small amount other ingredients. When mixed with water, cement sets and hardens into a solid mass. There are wide varieties of cement that should be used in the construction industries, or to solve distinct engineering problems. The chemical compositions of these types of cement can be quite different, but by far the huge amount of concrete used today is made with Portland Cements

Abebe Dinku, 2017. Conclude that Portland cement is one of the hydraulic cement which acts as a binder and used to chemically react with water for the reaction which is hydration for setting and hardening to produce a stone-like mass which is called paste. When the paste is combined with aggregate that is fine and coarse makes bond to form concrete. Portland cement is a mixture of calcium silicates and aluminum silicates that react with water to form a binder (Popovics, 1992).

The world's yearly cement production of 1.6 billion tons accounts for about 7% of the global loading of carbon dioxide into the atmosphere. Portland cement, the principal hydraulic cement in use today, is not only one of the most energy-intensive materials of construction but also is responsible for a large number of greenhouse gases (Mehta, 2001).

2.4.1 Production of Portland cement

Cement is made by heating a mixture of calcareous and argillaceous materials to a temperature of about 1450°C (Svinning and Høskuldsson, 2006). The calcareous material is calcium oxide (CaO), such as limestone, chalk, or oyster shells. Argillaceous materials are combination of silica (SiO₂) and alumina (Al₂O₃) that can be obtained from clay, shale, and slag (Mamlouk & Zaniewski, 2006). The calcareous and the argillaceous material are mixed in a grinding mill in an

appropriate proportion using either a wet or dry process. The process to be chosen depends on the nature of the raw materials used (Mark Bediako, 2015).

2.4.2 Chemical composition of Portland cement

Although most of the substances of which Portland cement is composed contain three or more elements in a state of combination, one may introduce a considerable simplification into their study by regarding them as being built up of the previously mentioned oxides.

Table 2. 1 Physical Characteristic of Cement Grades OPC (BIS Requirements) nevil, 2003

			Grade 33	Grade 43	Grade 53
Physical characteristics	Fineness[Sq.m/kg], min		225	225	225
	Soundness by	Lechatlir[mm] max	10	10	10
		AutoclaveMax [%]	0.8	0.8	0.8
	Setting Time	Initial[mts] Min	30	30	30
		Final[mts] Max	600	600	600
	Compressive Strength	3day Min [Mpa]	16	23	27
		7day Min [Mpa]	22	23	37
		28day Min [Mpa]	33	43	53

Table 2. 2 Chemical Characteristics of Cement Grades OPC (BIS Requirement) nevil, 2003

Chemical characteristics		Grade 33	Grade 43	Grade 53
	Lime Saturation Factor	0.8 Min 1.02 Max	0.8 Min 1.02 Max	0.8 Min 1.02 Max
	Alumina ratio, Min.	0.66	0.66	0.66
	Insoluble Residue [%] max	4	2	2
	MgO [%]Max.	6	6	6

	Max.Sulphuric anhydride	2.5% Max when C ₃ A is 5 or less Or 3%Max when C ₃ A is greater than 5	2.5% Max when C ₃ A is 5 or less Or 3%Max when C ₃ A is greater than 5	2.5% Max when C ₃ A is 5 or less Or 3%Max when C ₃ A is greater than 5
	Loss on Ignition [%] max	5	5	4

Table 2. 3 Approximate Oxide Composition of Portland Cement (Neville,2003)

No	Oxides	Oxide Content (%)
1	CaO	60 – 67
2	SiO ₂	17 – 25
3	Al ₂ O ₃	3 – 8
4	Fe ₂ O ₃	0.5 – 6
5	MgO	0.1 - 4
6	Alkalis	0.2 – 1.3

Table 2. 4 Main mineral compounds in Portland cement(Neville. 2003)

NO	Name of compound	Oxide composition	abbreviation	Scientific name
1	Tricalcium silicate	3CaOSiO ₂	C ₃ S	Alite
2	Dicalcium silicate	2CaOSiO ₂	C ₂ S	Belite
3	Tricalcium aluminate	3CaOAl ₂ O ₃	C ₃ A	Celite
4	Tetracalciumaluminoferrite	4CaOAl ₂ O ₃ Fe ₂ O ₃	C ₄ AF	Felite

2.4.3 Types of Portland cement

Cement varying chemical composition and physical characteristics exhibit different properties on hydration. The cement of desired properties can be produced by selecting a suitable mixture of raw materials. The various types of Portland cement used in the construction industry are Ordinary Portland Cement (OPC), Rapid Hardening Portland Cement (RHPC), Sulfate resisting Portland Cement (SRPC), and Low Heat Portland Cement (LHPC)(Yahaya et al., 2014).

The four major compounds found in cement clinker are:

1. Tri-Calcium Silicate (C_3S) . hydrates and hardens rapidly and is largely responsible for initial set and early strength. The tricalcium silicate (C_3S) compound constitutes about 50-70% by weight of Portland cement and remains the most important and abundant constituent of normal cement. It is important because the products after reaction contribute enormously to the setting and hardening of cement (Neville, 2003).

2. Di-Calcium Silicate (C_2S) which reacts more slowly and provides later-age strength gain, C_2S is the second most abundant constituent of clinker, and falls between 15% and 30% by weight of clinker. The reaction of C_2S is considerably slower than C_3S , produces less amount of $Ca(OH)_2$ and energy than C_3S . however, the C-S-H gel produced is similar to that of C_3S C-S-H gel (Neville, 2003).

3. Tri-Calcium Aluminate (C_3A) which reacts very rapidly generating heat and must be balanced in the cement with sulfate to prevent rapid stiffening, and (C_3A) constitutes 5-10% of most normal Portland cement clinker . C_3A reacts very quickly with water to form poorly crystalline calcium hydroalumunites or AFt phases generally described with the chemical formulae C_2AH_8 and C_4AH_{19} and releases a high heat of hydration (Neville, 2003).

4. Tetra Calcium Aluminoferrite (C_4AF) . Felite also known as calcium aluminoferrite (C_4AF) constitute 8-14% by weight of cement clinker. It was discovered as cement constituent some years after C_3S , C_2S , and C_3A have been known(Taylor,1997).The clinker is produced under tightly controlled conditions and is underground, usually with small amounts of a few additional components into a fine powder. AASHTO M85 and ASTM C150 are specifications for Portland cement AASHTO and ASTM work actively together to keep differences to a minimum. This is a fluxing agent that reduces the melting temperature of the raw materials in the kiln (from 3,000o F to 2,600o F). It hydrates rapidly but does not contribute much to strength of the cement paste.

By mixing these compounds appropriately, manufacturers can produce different types of cement to suit several construction environments.

The following types of Portland cement are commonly available and have different characteristics suited to be used for different purposes: There are five types of Portland cement (Types I, II, III, IV, V) each type is manufactured to meet certain physical and chemical requirements for specific purposes (ASTM C, 150).

Type I cement is general-purpose cement. It is suitable for all uses when the special properties of the other types are not required.

Type II cement is used when sulfate concentrations in groundwater are higher than normal. Type II will usually generate less heat at a slower rate than Type I or Normal cement. Therefore, it may be used in structures of considerable mass, such as large piers, heavy abutments, and heavy retaining walls. Its use will minimize temperature rise, which is especially important in warm weather(Neville,2003).

Type III cement is high-early-strength cement that will develop higher strength at an earlier age. It is used when early form removal is desired. Richer mixes (higher cement content) of types I and II may be used to gain early strength. The principal reason for the use of type III cement is when formwork is to be removed early for re-use where sufficient strength for further construction is required quickly.

Types IV cement are used in massive structures, such as dams. This type of cement is used where the heat generated during hardening is critical.

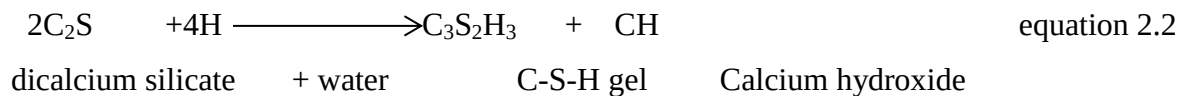
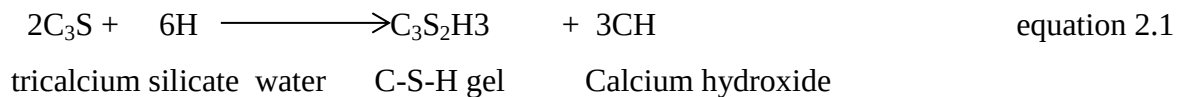
Type V cement is used in concrete exposed to severe sulfate action and is used mainly in the western section of the United States(Frqvwlwxwhv *et al.*, no date).

2.4.4 Blended hydraulic cement

ASTM C 1157 a hydraulic cement consisting of two or more inorganic ingredients that contribute to the strength-gaining properties of the cement, with or without other ingredients, processing additions, and functional additions. According to ASTM C 219 hydraulic cement consisting of two or more inorganic constituents (at least one of which is not portland cement or portland cement clinker) which separately or in combination contribute to the strengthening properties of the cement, (made with or without other constituents, processing additions and functional additions, by grinding or another blending).

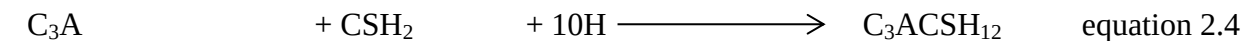
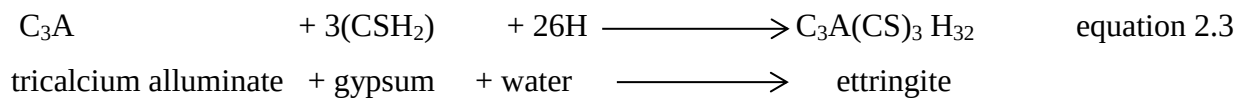
2.4.5 Reaction of cement components

Ordinary Portland Cement (OPC) is a product of four principal mineralogical phases. These phases are Tricalcium Silicate- C_3S ($3CaO.SiO_2$), Dicalcium Silicate – C_2S ($2CaO.SiO_2$), Tricalcium Aluminate- C_3A ($3CaO.Al_2O_3$), and Tetracalcium alumino-ferrite – C_4AF ($4CaO.Al_2O_3.Fe_2O_3$). The setting and hardening of the OPC take place as a result of reaction between these principal compounds and water(Neville,2003). The reaction between these compounds and water are shown as under:



The hydration products from C_3S and C_2S are similar but the quantity of calcium hydroxide (lime) released is higher in C_3S as compared to C_2S (Taylor,1997).

The reaction of C_3A with water takes place in presence of sulfate ions supplied by dissolution of gypsum present in OPC. This reaction is very fast and is shown as under:



Tetracalcium alumino-ferrite forms a hydration product similar to those of C_3A , with iron substituting partially for alumina in the crystal structures of ettringite and monosulpho-aluminate hydrate. The above reactions indicate that during the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. This leached out surplus lime renders deleterious effect to concrete such as make the concrete porous, give chance to the development of micro-cracks, weakening the bond with aggregates and thus affect the durability of concrete(Taylor.Emeritus, 1997)

2.4.6 Fineness of cement

The term fineness or fineness of grinding refers to the average size of the cement particles. A higher fineness means a more finely ground cement, smaller particles. The significance of fineness lies in the fact that it affects several technically important properties of cement and concrete. For instance, the higher the fineness, the higher the compressive strengths are developed at an early age. The fineness of cement affects heat released and the rate of hydration.

Greater cement fineness increases the rate at which cement hydrates and thus accelerates strength development(Husk and Replacement, 2015).

2.4.7 Consistency of Portland cement

The quality of Portland cement, such as in the soundness, time of setting, and tensile strength tests, the amount of mixing water specified is related to the water content needed to bring the paste to a standard condition of wetness, is referred to as normal consistency. There are no requirements specified for the water content at normal consistency. The usual values range from about 22 to 28% for commercial Portland cement, somewhat higher for Portland cements with natural pozzolans, and lower for high alumina cement.

2.4.8 Setting time of Portland cement

When cement is mixed with water of around 20-35%, the result is a paste. This paste displays considerable plasticity and maintains it for a period called the dormant period. After a while, however, the paste starts stiffening, less and less plasticity can be observed, and finally, all the plasticity is gone: that is the paste becomes brittle, although it is still without any sizable strength. This stiffening process is called the setting(Neville 2004).

Hydration reactions of cement-based materials are characterized by having initial and final setting times. The duration of the setting is dependent on the chemical compositions and fineness of the binder and additives and the ambient temperature(Taylor 1997).

2.4.9 Soundness of cement

It refers to the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion. The destructive expansion is caused by an excessive amount of free lime (CaO), (SO_3) or magnesia (MgO).Whereas Unsoundness is the harmful property that occurs when the hardened cement paste develops an undue expansion that is manifested by cracking of the mass.

2.4.10 Heat of hydration of Portland cement

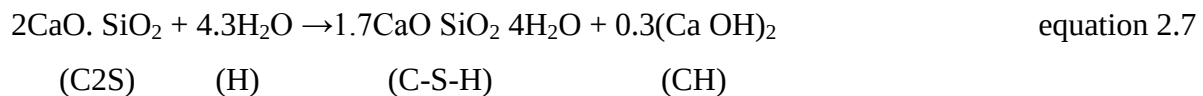
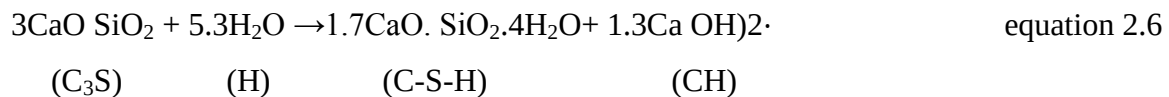
The heat of hydration of the Portland cement compound is exothermic. In which heat is given off during hydration. The amount of heat liberated may reach up to 500 joules per gram or 120 Cal/gram(Neville, 2004). hydration of the individual constituents of the cement is exothermic and liberates a considerable amount of heat (heat of hydration) (Durdzi, 2016). Heats of hydration of

the pure constituents of the cement imply that cement rich in tricalcium silicate and tricalcium aluminate will be characterized by high heat of hydration. and is made use of in the production of low heat Portland cement, cement which are characterized by a low heat of hydration. The heat of hydration of cement equals the weighted average of the heat of hydration of the individual components and can be calculated from the equation(Neville, 2003).

$$QH = a(C_3S) + b(C_2S) + c(C_3A) + d(C_4AF) \quad \text{equation 2.5}$$

The heat of hydration is the heat generated when cement and water react the amount of heat generated is dependent chiefly upon the chemical composition of the water-cement ratio fineness of cement and temperature of curing also are factors(Neville,2003).

The hydration of cement is initiated by the presence of water. The role of cement hydration is to bind aggregates together to produce concrete. The two calcium silicates provide the driving force behind the hardening and strength development of cement and their chemical hydration reactions are shown(Tran, 2007).



According to (Tran, 2007) The physical properties of Portland cement include color, fineness and specific gravity. Portland cement has a grayish color with fineness between 3.0 m²/kg and 3.5 m²/kg, and a specific gravity from 2.8 - 3.0 (Tran, 2007).

I Calcium silicate hydrate (C-S-H) gel

The structures of all the calcium-silicate hydrate have many features in common. They are characterized by sheet-like structure Ca(OH)₂ layers sandwiched by silicate(Emeritus,1997). The C-S-H gel is a mixture of poorly crystallized particles with different morphology and chemical composition that are not sharply defined by their stoichiometric composition(Chen, 2003). The C-S-H gel fills in all capillary space and provides a bond between the original cement grains, which appear to be joined at the contact surface. C-S-H gel in the solid paste of Portland cement contains the bulk of micro-porosity. The gel pores give the hydrated paste a high surface area and largely control the sorption properties of cement paste(Chen, 2003).

2.5 Aggregate

The aggregate for concrete consists of coarse aggregate and fine aggregate. The fine aggregate has a grading of size between 150 μm to 4.75 mm whereas coarse aggregate has a larger size than fine aggregate, up to the size of 63 mm (ASTM C 33-03) (Of and By, 2014). Aggregate covers the largest proportion which is three fourth of concrete by volume. Hence it has great importance on the quality of concrete, especially on strength. This is because good aggregate is known to have well-crushing strength and better resistance to effect. Not only that aggregates affect the strength of concrete, but the proper bonds of aggregates such as their size and shape affect the durability and structural performance of concrete(Production, Control and Building, 2005). Aggregates must conform to certain requirements and should consist of clean, hard, strong, and durable particles free of chemicals, coatings of clay, or other fine materials that may affect the hydration and bond of the cement paste. The characteristics of the aggregates influence the properties of the concrete(Frqvwlwxwhv et al.,).

2.6 Water

The function of water in the concrete is for chemical reaction with Portland cement that enables setting and hardening to attain minimum design compressive strength of concrete. The water for concrete should be the water for drinking; the quality of the water plays an important role in the preparation of concrete. Impurities in water may interfere with the setting of the cement and may adversely affect the strength and durability of the concrete also(Neville, 2003). The chemical constituents present in water may actively participate in the chemical reactions and thus affect the setting, hardening, and strength development of concrete(Neville, 2004). In addition to that, health issues related to the safe handling of such water must be considered. The suitability of water can be identified from past service records or tested to performance limits such as setting times and compressive strength and durability tests. Therefore the water we use in concrete production should be free from any chemical impurity and pollution('Quality of Water for Making Concrete, 2015). Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement (Committee et al, 2005).

2.7 Pozzolanic material

Pozzolanas are defined as a siliceous or alumino-siliceous material, which in itself possesses little or no cementitious value but will, in finely divided form and the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (ASTM C618-03). The term pozzolana originated from the United States implication of “pozzolana” which evolves from the location “Puzzouli, Italy”. At this location the Romans, who were also the superpower of the world discovered this reactive silica-based material of volcanic origin.

2.7.1 Benefit of using pozzolanic material

The benefit of using pozzolanic material in the construction industry is well understood by fresh and mechanical properties of concrete. Different scholars have seen that in various categories technical, environmental and ecological, and economic benefits (Bediako et al, 2012). The technical benefits show that pozzolana utilization in mortars and concretes improves workability, reduces permeability and voids, minimizes micro cracking and early cement shrinkage, increases compressive strength, heat of hydration and sulfate attack (Kumar et al, 2012).

2.8 Properties of Water Hyacinth Ash

2.8.1 Physical properties

I Color of WHA

N.Balasundaram,2019, conducted Experimental Behaviour of Water Hyacinth Ash as Partial Replacement of Cement on Short Column to determine the physical properties of water hyacinth

II Specific gravity of WHA

The specific gravity of WHA was found to be 1.72 while its water absorption was 5.62%the properties were used in determining the amount of WHA that were needed in each mixture of the different treatment as well as in obtaining the right amount of water to achieve aw/c ratio (A.San Antonio, 2015). The color of water hyacinth ash seems like grey (Shyam Krishnan. S, 2017)

Table 2. 5 Physical properties of water hyacinth ash

Physical properties	S. Dinesh, V. Murugesh (2017)	Neelu Das (2015)	Shyam Krishnan.s (2018)	Das and Singh, 2016
Specific gravity	2.12	2.168	2.12	2.168
Setting time 10% 20%	Intial =140min Final =300min Intial =220min Final =360min	140min-220min 230min-320min for all percentage	-	-
Consistency	10% =35% 20%=37%	Increasing (30%-40%)	-	-
Fineness	Less than 150 micron	87%	10	87%

2.8.2 Oxides of Water Hyacinth Ash

Ahmed Shaban, (2015) conclude in his study calcium and silcon are the major oxides present in Water Hyacinth Ash. A study conducted by (Mae *et al.*, 2015) reported that High-calcium (> 20% CaO) may be produced from lignite or sub-bituminous coals and are comprised of calcium-alumino-silicate glass and a wide variety of crystalline phases in addition to those found in Water Hyacinth Ash. This WHA will react and harden when mixed with water due to the formation of cementitious hydration products(ASTM C311).

According to (Mae *et al.*, 2015) CaO also known as lime and known as one of the four major oxide composition (60-67%) which secure the sand and water together. When CaO is mixed with water, it forms calcium hydroxide that reacts faster with carbon dioxide, producing a mortar that hardens more quickly. It is the major constituent of cement that controls the strength and soundness where the exact proportion is important. The right proportion makes cement sound and strong otherwise making the cement unsound and causing the cement to expand and disintegrate(Mae *et al.*, 2015). As clearly seen in table, 2.6 major chemical compounds and alkalis are described by different scholars in various years of study.

Table 2. 6 Chemical Composition of Water Hyacinth Ash

Chemical compounds	Ahmed Shaban (2015)	Neelu, Das (2016)	G.W.MBu GuA(2014)	Neelu (2016)
SiO ₂	23.3	24.4	-	55.39
Al ₂ O ₃	4.23	2.2	1	16.07
Fe ₂ O ₃	5.98	1.27	1.8	13.05
CaO	17.4	22.61	27	6.33
MgO	4.45	14	-	5.48
SO ₃	5.06	-	-	1.17
Na ₂ O	1.49	0.35	-	1.59
K ₂ O	7.43	14.82	35.8	-

2.9 Properties of concrete Affected by WHA

2.9.1 Fresh concrete

2.9.1.1 Workability of concrete

The workability of fresh concrete depends on its stability, segregation, viscosity, cohesion, bleeding, and internal friction of the plastic stage of concrete. This rheological behavior is defined by two characteristics of the concrete, i.e. yield stress and plastic viscosity. Yield stress is the effort needed to initiate movement of the fresh concrete and correlates well with a slump. Plastic viscosity is the flow characteristics of the concrete while moving and for low stiffness concretes can be determined by various rheometers currently available. According to S. Dinesh (2017), N.Balasundaram (2019), U. Abirami (2018) Water hyacinth ash has its effect on the fresh properties of concrete. As most scholars conclude in table, 2.7 of their study water hyacinth ash improves the workability of concrete.

Table 2. 7 Slump result characteristics of water hyacinth ash in different ratio

% WHA replacement	S. Dinesh (2017)	N.Balasundaram (2019)	U. Abirami (2018)	V. Muruges (2017)
	Slump (mm)	Slump (mm)	Slump (mm)	Slump (mm)
0	45	96	90	40
5	-	-	93	-
10	95	94	95	90
15	-	-	98	-

20	130	92	102	140
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2.9.1.2 Factors affecting the workability of concrete

Consistency

Consistency is the fluidity or degree of wetness of concrete. It is generally dependent on the shear resistance of the mass. It is a major factor in indicating the workability of freshly mixed concrete. The ability of a freshly mixed cement paste or mortar to achieve relative mobility is known as consistency. Consistency in mortar and concrete can be related to workability. For cement paste, the Vicat apparatus is used whilst the flow table is usually used for mortar. The consistency of cement is influenced normally by the water-to-cement ratio(Neville, 2003).

Setting time

Setting times characterize the transformation of cement paste into a hardened state. It also determines whether the cement is undergoing hydration. Usually, two sets are defined with binders and they are the initial and the final setting times. The initial setting time is the time from mixing dry cement with water till the starting of binder gel interlocking with each other (Taylor, 1997)

Segregation

Segregation refers to a separation of the components of fresh concrete, resulting in a non-uniform mix. The primary causes of segregation are differences in specific gravity and size of constituents of concrete. Moreover, improper mixing, improper placing, and improper consolidation also lead to segregation.

Bleeding

Bleeding is the tendency of water to rise to the surface of freshly placed concrete. It is caused by the inability of solid constituents of the mix to hold all of the mixing water as they settle down.

Water cement ratio

Water-cement-ratio is a relevant factor that affects the quality of fresh and hardened concrete. The water-cement-ratio plays a great role in the workability and compressive strength of concrete. When the amount of water in the mix becomes maximum, the workability of the freshly mixed concrete will be increased on the other hand the strength of concrete after setting and hardening will be reduced. The effect of water-cement-ratio on workability of concrete, hydration process and in brief overview of the effect of w-c ratio on the porosity and gel pores.

Furthermore, concrete with the lower w/c ratio has low capillary voids and the effect of water-cement ratio on the strength of the concrete ('Determination of water - cement-ratio of concrete', 2018).

2.9.2 Hardened concrete

2.9.2.1 Compressive strength

The compressive strength of concrete is one of the most convenient properties of concrete. In most structural applications, concrete is engaged primarily to resist compressive strength stresses. In the case where strength in tension or shear is of primary importance, the compressive strength is frequently used as a measure of these properties. Therefore the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used in a qualitative measure for other properties of hardened concrete. The compressive strength is determined by testing cubes or cylinders in the laboratory. The strength of concrete is its resistance to rupture(Neville, 2003). It can be measured in several ways: strength compression in tension, shear or flexures. The cohesion and internal friction developed by concrete in resisting failure are related to the water-cement ratio, the design constituents, the mixing, placement and curing methods employed(Yahaya *et al.*, 2014).

Compressive strength is an important material property of concrete and is often related to the quality of the concrete. Compressive strength is commonly used in the material specification as it can be easily tested and other properties of concrete can be correlated to the compressive strength(Pickel, 2014).

A similar study by (U.Abirami 2018), (Murugesh, 2017), (Manoj, 2019) reported that Water hyacinth ash greatly affects the mechanical properties of concrete like compressive strength, split tensile strength and flexural strength of concrete. As researchers report on their result as cement is substituted by WHA in the ratio of 0%, 5%, 10%, 15%, and so on in the production of concrete. Table 2.8 shows how water hyacinth ash affects the mechanical properties of concrete in different scholars.

Table 2. 8 Effects of water hyacinth ash on mechanical properties of concrete U.Abirami 2018, Muruges, 2017, Manoj 2019

Addition of WHA to cement(%)	Compressive strength of concrete (map) age in days			Split tensile strength of concrete (map) Age in days		
	U.Abirami 2018					
	7	14	28	7	14	28
0	16	24.5	25	2.36	-	2.92
5	17.2	25	25.2	2.41	-	3.12
10	18.35	25.2	26	2.68	-	3.23
15	19.7	26.8	27.12	2.74	-	3.46
20	13.8	19.6	22.6	1.95	-	2.32
	Muruges, 2017			-	-	-
0	70-75%	80-85%	90-100%	-	-	-
10	50-65%	65-70%,	72-82%	-	-	-
	Manoj 2019					
0	21.15	27.64	30.22	2.48	2.67	2.97
5	21.76	27.91	30.98	2.635	2.965	3.235
10	22.36	28.18	31.91	2.75	3.26	3.5
15	21.0	26.13	29.51	2.35	2.95	2.97
0	21.2	27.7	30.43	2.48	-	2.97
10	22.39	28.19	31.9	2.75	-	3.5
20	19.76	24.14	27.13	1.95	-	2.44

2.9.2.2 Factors affecting compressive strength of concrete

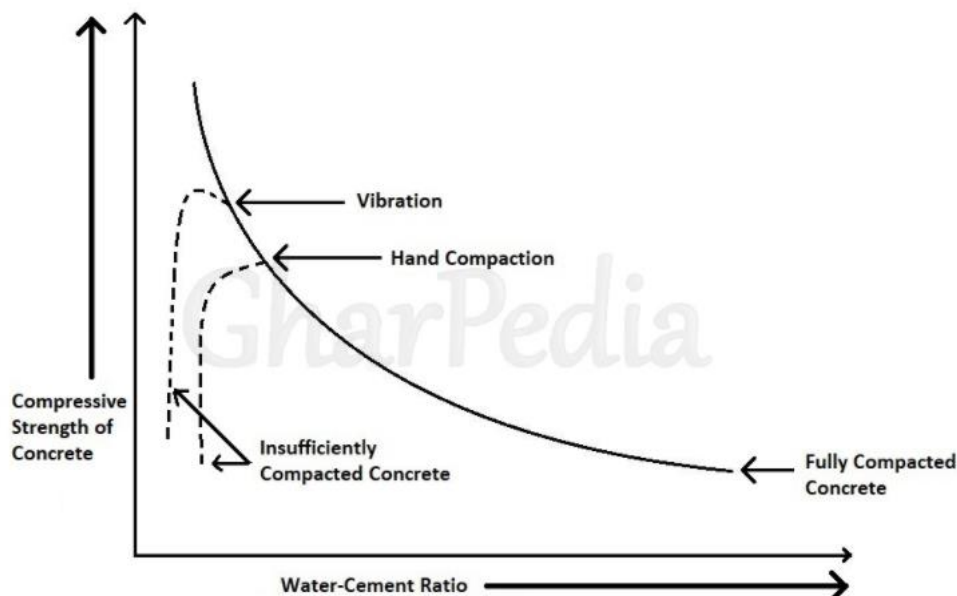
Ingredients of concrete

The main ingredients of concrete are cement, sand, aggregate, and Water. quality of each material affect the strength of the concrete. All materials, therefore, should fulfill the standard criteria for use in concrete(Hemali Pate, 2018).

Water-to-cement ratio

The ratio of the weight of water to the weight of cement is called the Water-Cement ratio. It is the most important factor for gaining the strength of concrete. The lower w-c ratio leads the higher strength of concrete(Neville. 2003). Generally, the water-cement ratio of 0.45 to 0.60 is used. Too much water leads to segregation and voids in concrete. The water-Cement ratio is inversely proportional to the strength of concrete. As shown in the chart below when the w-c ratio has increased the strength of concrete gets decreases and when w-c ratio is decreased then the strength of concrete increases (Hemali Pate, 2018).

Water to cement or binder ratio (w-c) is an important parameter worth considering since it affects the strength of cement-based materials. High strength is achievable in mortar and concrete with minimum cement content and an appropriate w-c ratio.



Compressive Strength of Concrete vs Water-Cement Ratio

Figure 2. 1  **Relationship of compressive strength and water-cement ratio (Hemali Pate, 2018).**

Compaction of Concrete

Compaction of concrete increases the density of the concrete because it is the process in which air voids are removed from freshly placed concrete which makes the concrete compact and

dense. The presence of air voids in concrete greatly reduces its strength(Neville. 2003). Approximately 5 % of air voids can reduce the strength by 30 to 40 %. As we can see in the above chart, even at the same water-cement ratio strength is different with different compaction accuracies. In the fully compacted concrete, strength is higher than the insufficiently compacted concrete (Hemali Pate, 2018).

Curing of Concrete

Curing of concrete is the most essential to prevent plastic shrinkage, temperature control, strength development, and durability. Curing provides the desired moisture and temperature at the depth and near the surface after placing and finishing concrete for development of strength. In other words, curing provides sufficient water to concrete for completing the hydration process without interruption which is important for strength development. Commonly 7-day curing corresponds to 70 % of compressive strength(Neville, 2003). The curing period depends on the types of cement and the nature of work. Generally, it's about 7 to 14 days for Ordinary Portland Cement. There are many methods of curing like Ponding and immersion, Spraying and fogging saturated wet coverings (Hemali Pate, 2018).

Weather Condition

According to (Hemali Pate, 2018) Weather condition also affects the strength of concrete due to different reasons. In a cold climate, exterior concrete is subjected to repeated freezing and thawing action due to the sudden change in weather. It produces deterioration in concrete. With the change in moisture content, materials expand and contract. It produced cracks in concrete (Hemali Pate, 2018).

Temperature

As (Hemali Pate, 2018) illustrated that the certain degree of temperature increase, the rate of hydration process increases in it which, it gains strength rapidly. Sudden temperature changes create a thermal gradient, which causes cracking and spalling of concrete. So that, the final strength of concrete is lower at a very high temperature (Hemali Pate, 2018).

Age of Concrete

Based on (Hemali Pate, 2018) conclude that increase in age of concrete, the degree of hydration would be more. The hydration process is the chemical reaction of water and cement. Hydration produces the gel which plays a significant role in the bonding of particles of the concrete ingredients. Therefore, the strength of concrete increases with its age (Hemali Pate, 2018).

2.10 Durability of Concrete

Durability is the property of resistance of concrete against chemical attack, and environmental pollutants (Muruges, Balasundaram, and Vadivel, 2018). A durable concrete is the one that will withstand in a satisfactory degree, the effects of service conditions to which it will be subjected. As per IS 456: 2000, Durable concrete is one that performs satisfactorily in the working environment during the anticipated exposure conditions and during its service life. It is the ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration which will alter the original form and quality.

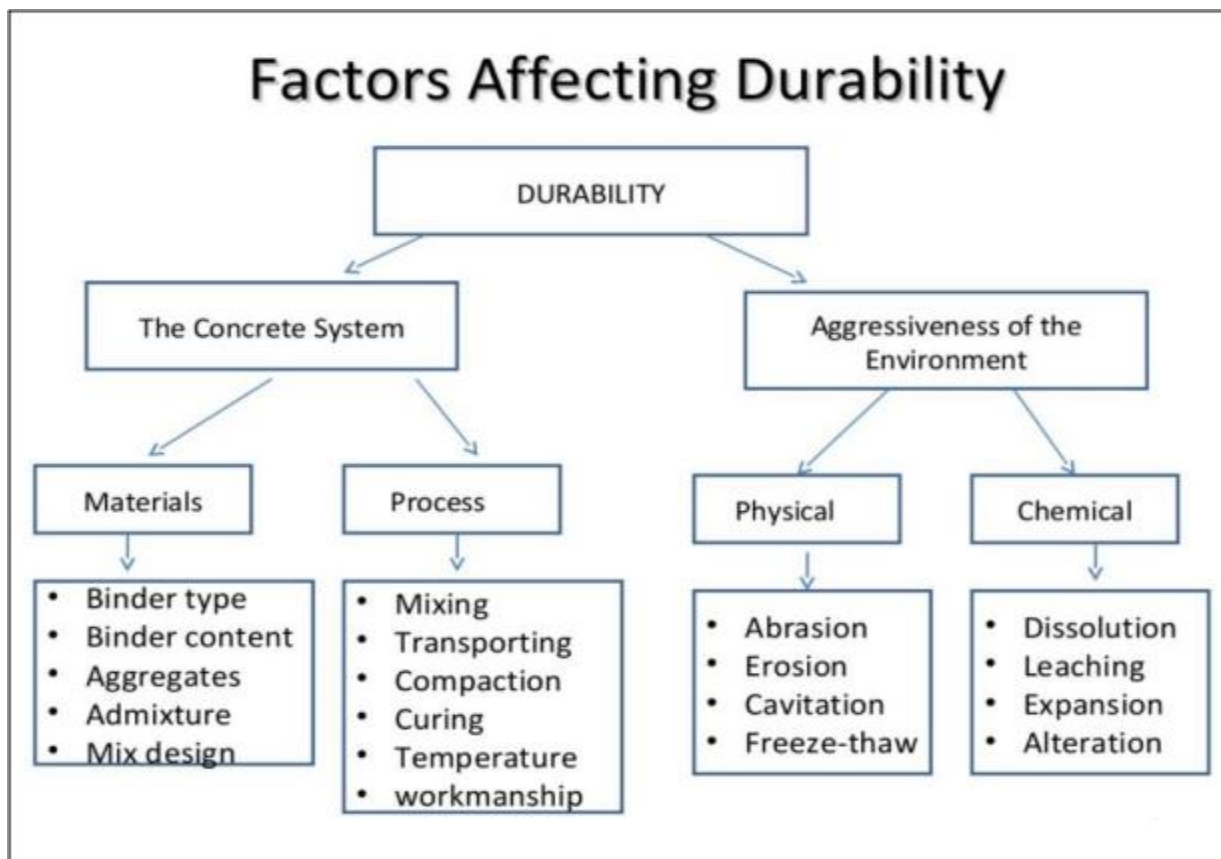


Figure 2. 2 Factor affecting the durability of concrete (Fahim Al-Neshawy & Esko Sistonen 2015)

2.10.1 Sulfate attack

Sulfate ions in the pore solution of concrete can react with certain cement hydrates, particularly the calcium aluminates, causing damage to the matrix. mostly this occurs when the concrete will be exposed in service to soils or water containing sulfate (sulfate attack Edition, 2013).

Sulfate attacks in concrete occur due to reaction between sulfate from external origins or atmosphere with surplus lime leads to formation of ettringite, which causes expansion and results in volume destabilization of the concrete. An increase in sulfate resistance of water hyacinth ash concrete is due to the continuous reaction between water hyacinth ash and leached out lime, which continues to form additional C-S-H gel. This C-S-H gel fills in capillary pores in the cement paste, reducing permeability and ingress of sulfate ions(Ash production, 2012). Naturally occurring sulfates of sodium, potassium, calcium, or magnesium are sometimes found in soil or dissolved in groundwater. Sulfates can attack concrete by reacting with hydrated compounds in the hardened cement. These reactions can induce sufficient pressure to disrupt the cement paste, resulting in loss of cohesion and strength. Calcium sulfate attacks calcium aluminate hydrate and forms ettringite. Sodium sulfate reacts with calcium hydroxide and calcium aluminate hydrate forming ettringite and gypsum. Magnesium sulfate attacks similar to sodium sulfate and knowledge ettringite, gypsum, and brucite (magnesium hydroxide). Brucite forms primarily on the concrete surface, consumes calcium hydroxide, lowers the pH of the pore solution, and then decomposes the calcium silicate hydrates(Deterioration of concrete, 2004).

Sulfate attack is the more regular type and typically occurs where water containing dissolved sulfate penetrates the concrete. Before the sulfate attack, the concrete of reinforced concrete structures is regularly seen in cleaned segments typically

2.10.2 Water absorption of concrete

The main important parameters for the durability of concrete are water absorption which tends to corrode the reinforcement bars in the concrete structures(Muruges, Balasundaram and Vadivel, 2018). The process in which molecules of substances adhere to the concrete surface either by physical bonds or as a result of chemical bonds is called adsorption(Mohammadi, 2013)

Concrete cubes of size 150x150x150mm were cast and cured for 28 days. After 28 days of curing the cubes were taken out and dried. The initial dry weight of the cubes was found. The chloride solution has been prepared by adding 3.5 % sodium chloride (NaCl) in distilled water and stirred well. The salts get dissolved into the solution. Specimens were engrossed for 28 days in a chloride solution. Then the cubes are taken out from solution and dried at room temperature. The weight of the specimens is noted as final dry weight. The differences between initial and final dry weight of the specimen were found(Muruges, Balasundaram and Vadivel, 2018).

2.11 Microstructure of Concrete

2.11.1 X-ray Fluorescence

The purpose of X-ray fluorescence, XRF, is to both qualitatively and quantitatively determine the chemical elements present within a substance. The basis for XRF is based on the emission of energy from an atom. If an electron of an inner shell is knocked out of the atom by the irradiation of energy, an electron from a higher shell falls into this resultant “hole” which releases energy. This energy is released as an x-ray, the wavelength of this x-ray is characteristic of the element that emits higher energy, this is the characteristic of x-ray fluorescence (Torrens-martín, Fernandez-Carrasco, and Martinez-Ramirez).

2.11.2 X-ray Diffraction

X-ray diffraction, XRD, is used in the qualitative identification of crystalline phases by their diffraction pattern. Crystals are made up of arrangements of atoms/molecules that create a lattice. Within this lattice is repetitious parallel planes, called lattice planes, the distance between these planes is called the lattice plane distance, d . When parallel x-rays strike a pair of parallel lattice planes, every atom within the planes acts as a scattering center and emits a second wave (Vo *et al.*, 2021).

2.11.4 Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) is one of the two vibrational spectroscopies (infrared and Raman) techniques that are widely used in industry. FTIR provides qualitative (through fingerprinting), semi-quantitative, and quantitative information on chemical structures and physical characteristics. Solid, liquid, or gas samples can be analyzed in bulk or thin-film forms. Accessories are available to investigate materials properties at different temperature

2.12 Environmental impacts

The main environmental issues associated with cement production are consumption of raw materials and energy use as well as emissions to air (Stajanca M., Ettokova A, 2012). Wastewater discharge is usually limited to surface runoff and cooling water only and causes no substantial contribution to water pollution. The storage and handling of fuels is a potential source of contamination of soil and groundwater. Additionally, the environment can be affected by noise and odors (Stajanca M., Ettokova A, 2012). The key polluting substances emitted into the air are dust, carbon oxides nitrogen oxides (NO_x) sulfur dioxide (SO_2). Carbon oxides,

polychlorinated dibenzo-p-dioxins and dibenzofurans, total organic carbon, metals, hydrogen chloride and hydrogen fluoride are emitted as well. The type and quantity of air pollution depend on different parameters. Cement production needs a very high amount of energy. Energy cost represents 40% of total production costs involved in producing of 1 tone of cement (Stajanca M., Ettokova A, 2012). Cement is produced by utilizing an extensive amount of raw materials treated and reacted at extreme conditions such as high temperatures. The high-temperature processes are called pyro- processing processes where raw materials are heated at high temperatures for solid-state reactions to take place, which utilize fuel sources such as coal, fuel oil, natural gas, tires, hazardous wastes, petroleum coke, and anything combustible (Mehta, 2001).

Cement in- industry contributes to a significant extent of anthropogenic carbon dioxide emissions, which is in the range of 5–7% of total anthropogenic carbon dioxide emissions In the clinker burning process, to produce 1 tonne of clinkers, 1.52 tonnes of raw materials are used on average(A M Neville, 2011). The balance of 0.52 tonne of raw materials is converted mainly to carbon dioxide by the processes such as $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$. This is a serious global environmental problem since increase in carbon dioxide in the atmosphere has direct consequences on global warming. It has been recognized that cement industries release different gases to the atmosphere including greenhouse gas emissions, Dioxin, NO_2 , SO_2 , and vibration during operating machinery and blasting in quarries. However, there are strategies for the reduction of carbon dioxide which are aimed at lowering emissions per ton of cement, even though there is inherent emission of carbon dioxide during chemical breakdown of the limestone in cement kilns during production of Portland cement clinker (Stajanca M., Estokova A, 2012).

One of the strategies of decreasing CO_2 emission is integrating supplementary cementitious material which is water hyacinth ash with Portland cement which offers key advantages in reduction of CO_2 emissions, climate change, economic and technical benefit(Stajanca M, Estokova A, 2012).

2.13 summary of literature review

Table 2. 9 summary of the literature review

Water hyacinth ash as a cement replacement in concrete					
year	Title	Author	Replaceme nt In (%)	Test conducted	Finding
2015	Impact of water hyacinth on Properties of concrete made with various gravel to dolomite ratios	Ahmed Shaban Abdel hay and Yasser Abdel ghany fawzy	0.5,1,2,5	Fresh properties ✓ Slump test Mechanical properties ✓ Compressive strength ✓ splitting tensile strength mass transport by ✓ Isat microstructure test by ✓ XRD and thermal gravimetric analysis (TGA)	✓ Introducing W-H in a concrete mix up to 2 by mass of cement not affected the slump ✓ Mechanical properties of concrete developed at 2% W-H for different gravel/ dolomite ratios ✓ Mass transport properties of concrete enhanced at 2% ratio of W-H. ✓ Introducing W-H in concrete mix decreased C-H, developed new, bound water, %.
2014	effectiveness of water hyacinth ash as partial cement replacement in load bearing masonry	Angela Mae A. San Antonio Maureen Joy A. Iligan	10,15,20,25	✓ Compressive strength test ✓ Density of concrete	✓ As the replacement ratio increases the compressive strength decrease ✓ Also the density of load-bearing masonry decrease as the WHA ratio increase ✓ The optimum replacement was 10%

	blocks	Zyra Jane Z. Salao			
2016	Evaluation of water hyacinth stem ash as pozzolanic material for use in blended cement	Neelu Das, Shashikant Singh	10,15, 20,25	✓ Chemical and mineralogical composition of the material ✓ Consistency and setting time of blended cement ✓ Compressive strength of blended cement ✓ Water absorption and sorptivity	✓ The chemical composition test reveals silica as the minor constituent and also has other compounds of Ca, Mg, K and S. ✓ Initial and final setting time becomes longer as the WHA replacement increase. ✓ Mortar specimen with WHA resulted in lower water absorption and sorptivity at ages of 28 days than a conventional sample. ✓ 10% replacement provides the best compressive strength.
2017	Experimental behavior of WHA as the Partial replacement of cement in concrete	S. Dinesh, V. Murugesh	10,20	✓ Consistency test of WHA ✓ Setting time test ✓ Slump test for workability ✓ Compressive strength ✓ Split tensile strength	✓ Normal consistency increase as WHA increase ✓ Initial and final setting time of WHA increase as a % replacement increase. ✓ The workability of concrete increases with increase WHA replacement. ✓ At 20% replacement both compressive and split tensile strength decrease. ✓ 10% replacement was the optimum dosage.
2017	Experimental studies	K. Akil, P.	2,4,6,8	✓ Compressive strength	All strength properties increase as WHF increases

	on the properties of cement concrete with water hyacinth fibers	Parthasarathy & D. Siva Shankar		✓ Flexural strength ✓ Split tensile strength	up to 4% replacement. Further addition of WHF reduces strength.
2017	Experimental investigation on water hyacinth ash as the partial Replacement of cement in concrete	V. Murugesh	10,20	✓ Consistency test ✓ Setting time test ✓ Slump test ✓ Compressive and split tensile strength test	✓ As the mix ratio of WHA in cement increases, then the setting time also gets increased. ✓ Normal consistency increase as the WHA ratio increase ✓ Workability of concrete increase as WHA replacement increase ✓ If 20% replacement of cement by water hyacinth ash will affect the strength of concrete. ✓ The optimum quantity of WHA to replace cement was 10%
2018	Experimental Studies on Durability Studies of Concrete with Partial Replacement of Cement by Water Hyacinth Ash	V.Murugesh, Dr. N. Balasundaram and Dr. T. Senthil Vadivel	10	✓ Water absorption test ✓ Chloride resistance test	✓ Saturated water absorption test indicates that water absorption is less for 10% replaced concrete which shows better durability compared to CC ✓ 10% replaced concrete subjected to excellent chlorine resistance in 3.5% chloride solution is the best because the mass loss and strength loss were very less compared to CC ✓ The optimum dosage for partial replacement of

					cement by WHA is 10%.
2018	Experimental Study on Behavior of Concrete Replaced with Water Hyacinth Ash	U. Abirami K. Kayalvizhi	5,10,15,20	✓ Slump test for workability ✓ Compressive strength ✓ Split tensile strength	✓ As the ratio increases the workability increase ✓ The compressive and split tensile strength increase up to 15% WHA replacement but at 205 it slightly decreases ✓ The optimum replacement ratio was 15%
2019	Experimental Investigation on Water Hyacinth Ash As a Supplementary Cementing Material	Ashima Manoj Aleena Eldho Saju Sujitha S	5,10,15		✓ The standard consistency of cement is increased with increase in % addition of water hyacinth ash. ✓ Setting time of cement is increased with an increase in % addition of water hyacinth ash. ✓ Workability of concrete increase with the increase in % addition of water hyacinth ash ✓ Compressive and splitting tensile strength increases up to 10% beyond that ratio the strength decrease. ✓ The optimum dosage was 10%
2019	Experimental behavior of water hyacinth ash as partial replacement of	N.Balasundaram, V.Muruges	10,20	✓ Setting time test ✓ Compressive strength test ✓ Load-deflection	✓ The setting time of concrete is delayed due to addition of WHA in concrete. ✓ The addition of WHA in RCC short column results in an increase in ultimate buckling load

	cement on short column			behavior	for 10% of WHA replacement of cement ✓ The compression strength of the short column increases by 10% replacement of WHA than conventional concrete. Further addition of WHA will reduce the potency of concrete
	The Study on Effect of Lightweight Concrete Block by Water Hyacinth Adding	Prang subpar-asa, Laemthong laokongthavorn, shigeyuki Date	2.5,5, 7.5,10	✓ Dry density test ✓ Water absorption test ✓ Compressive strength test	✓ The density of the concrete decrease as the WHA replacement increase ✓ The water absorption of concrete increase as the percent replacement increase ✓ The compressive strength increases up to 5% replacement after that decrease ✓ The optimum quantity was 10%
2018	experimental study on strength of water hyacinth ash as partial replacement of cement in concrete	Shyam Krishnan.s, Murugesh. V	10,20	✓ Workability test ✓ Split tensile strength ✓ Compressive strength	✓ The optimal dosage for the partial alternative of cement by water hyacinth ash is 10%. ✓ The compressive strength of concrete. decreases, when the addition of dosage is more than 10%.The results show if 20% ✓ Due to the high absorptivity of ash in water hyacinth, the setting time of the cement gets increased. ✓ The workability of the concrete increases based on the percentage of replacement of water

					hyacinth ash
Water hyacinth ash as fine aggregate replacement in concrete					
year	Title	Author	Replacem ent %	Test conducted	Findings
2017	Incorporation of Water Hyacinth in Concrete	Juby Mariam Boban, Parvathy V Nair, Shinoy T Shiji, Sneha Elsa Cherian	0.5,1,1.5,2	✓ Compressive strength test ✓ Split tensile strength test ✓ Water absorption test ✓ Sorptivity test	✓ 0.5% provide best compressive strength ✓ WHF in concrete has reduced water absorption characteristics ✓ Using WHF enhanced durability and improved compressive strength at a higher temperature
2019	Some mechanical characteristics of concrete	C.K. Kiptum, L.Rosasi, O. Joseph and E.Odhiambo	0.1,0.2,0.3	✓ Compressive strength ✓ Split	✓ As the water hyacinth stem increases the compressive strength slightly decreases. ✓ The tensile strength of concrete increase at 1%replacement beyond that slightly decrease

	reinforced With dried water hyacinth and quarry dust as fine Aggregates			tensile strength	
Water hyacinth ash an admixture replacement					
year	Title	Author	Replacemen t %	Tests conducted	Findings
2018	Evaluation of water hyacinth extract as an admixture in concrete production	G.D.O. Okwadha1, D.M. Makomele	10, 15, 20 , 25	✓ Consistency and setting time test ✓ Workability ✓ Compressive strength	✓ Mortar setting time increased with an increase in the amount of Water hyacinth extract ✓ Slump flow increased with an increase in the amount of Water hyacinth extract. ✓ Compressive strength increased with an increase in replacement up to 20% replacement. ✓ Water hyacinth extract can be used as a superplasticizer in SCC production.
2017	performance evaluation of water hyacinth fiber reinforced self-	Roma Jill Pastrana Abion Brent Harley Matienzo DABU Maritel Alohae Alanis hernaez	0.4 WHF with 10,20, 30, WHA	✓ Workability test ✓ Compressive strength test ✓ Flexural strength test	✓ Workability of SCC decrease as the percentage increase ✓ Flexural strength is maximum at 10% replacement ✓ Compressive strength is best at 10% replacement.

	compacting concrete using varied rice hull ash as admixture				
2019	A review for the use of water hyacinth in concrete as an admixture	Mutahar Ali Fareed Ahmed Memon Sammar Hussain Rizivammaar Noor Memon Naseeb Ullah Menga		✓ Workability test ✓ Compressive strength test	✓ Water hyacinth has certain compounds such as lignin which can be used admixture in concrete. ✓ Use of water hyacinth as admixture increase workability ✓ Increase compressive strength ✓ Water hyacinth also has pozzolanic properties hence it can also be used as cement replacement

Gap identification of the studies

From the summary of literature of review I have tried to identify the of gap researchers study. Most of the researchers focus on their research regards with cement substitution with Water Hyacinth Ash by checking the workability and compressive strength of concrete. But in this study I have tried to check the properties of concrete by incorporating Water Hyacinth Ash.

- ✓ Checking the durability properties of concrete using water absorption of concrete
- ✓ Compressive strength of concrete in the addition of sodium sulfate

- ✓ Investigating the microstructure of concrete using FTIR analysis

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

Bahir Dar is the former capital of Gojjam province and the current capital of the Amhara Regional State in Ethiopia. The City lies at 1797m above sea level. Bahir Dar's climate is classified as warm and temperate. The summers here have a good deal of rainfall, while the winters have very little. In Bahir Dar, the average annual temperature is 19.6 °C. The maximum area of the lake is covered by the aquatic weed which is water hyacinth. Studies show that 20 ha of the lake totally covered by the weed. Lake Tana is geographically located in the north-western part of Ethiopia, between latitude 10°58'–12°47'N and longitude 36°45'–38°14'E. It has a surface area of 3,200 sq km, a mean depth of 8 meters and maximum depth of 14 meters with fluctuations due to increasing siltation levels.

3.2. Materials selection

The objective of this study is to determine the effectiveness of water hyacinth ash to replace cement in the production of a C-25 concrete as well as to quantify the optimum dosage of WHA. The materials used for this study were ordinary Portland cement, fine aggregate of river sand, coarse aggregate, treated municipal water, and Water Hyacinth which was collected from Lake Tana.

3.2.1 Cement

The cement used for this study is an Ordinary Portland Cement (OPC) of grade 42.5 produced by Derba. Because of time and financial constraints only Ordinary Portland Cement was used. Testing this cement is not mandatory because there is a shortage supply of cement in the current market rather than accumulate for long period in the store. the following specification of ordinary portland cement which is manufactured by Derba was used throughout the study.

Table 3. 1 Specification for Derba CEM I cement

Parameters	EN 197:1:200 specification	Standards
Compressive Strength (2) days (Mpa)	≥ 25 Mpa	Ethiopian Standard ES 1177-1:2005

Compressive Strength (28 days)(Mpa)	$\geq 42.5\text{Mpa}$	Cement Type: CEM I Class of strength 42.5N
Soundness expansion (%)	0.80	
Setting time initial	30mm	
Final	60mm	
Specific gravity	3.15	

3.2.2 Fine aggregate

Fine aggregate is materials passing through an IS sieve that is less than 4.75mm. Standard Specification for concrete aggregate (ASTM C 33). There are different types of fine aggregate in our country but for the desired study, river sand was used and its fineness modulus was in the range of 2.3 and 3.1. The fine aggregate used for the current study was free from injurious amounts of organic impurities.

3.2.3 Coarse aggregate

According to ASTM C 33 Standards, Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic-cement concrete. The aggregate used for this study is coarse aggregate which has a maximum size of 25 mm. The important parameters of coarse aggregate that influence the performance of concrete are its shape, texture, maximum size and it forms the main matrix of the concrete.

3.2.4 Water hyacinth ash

For the present study, Water hyacinth ash is an alternative material for cement. It can be visible on lakes and ponds. Water hyacinth used for the study was collected from nearby lake tana. Then The collected samples were washed and cleaned with potable water to remove dirt and impurities, the samples were cut uniformly into smaller pieces and were dry for over a week. WHA was produced after burning the water hyacinth under controlled temperature. The burning process is held using a Muffle Furnace at 800°C for 6 hours and cooled to room temperature for 24hr to convert the organic matter into an inorganic substance. Then the samples were ground by a milling machine. The grounded sample was passed through a sieve of size 150-micron. The sample collected from the 150-micron sieve will be used as the replacement material for cement.



(a) Natural water hyacinth



(b) Clean harvested water hyacinth



(c) Sun-dried water hyacinth ash



(d) Burnt WHA in furnace



(e) WHA before milling



(f) WHA after milling

Figure 3. 1 water hyacinth ash production process

The main physical properties of Water Hyacinth Ash are color, consistency, setting time, soundness, fineness, and specific gravity. Figure 3.2 shows that the WHA has gray color. so it complies with the requirement of cement color in concrete production.

Table 3. 2 Percent replacement of Cement with WHA

No	Ratio of WHA	Ratio of cement
1	0%	100%
2	5%	95%
3	10%	90%

4	15%	85%
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3.2.5 Water

Water used in mixing concrete was clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement. **Almost any treated municipal** water that is drinkable and has no pronounced taste or odor is satisfactory as mixing water for making concrete as per ACI 318.

3.3 Methodology

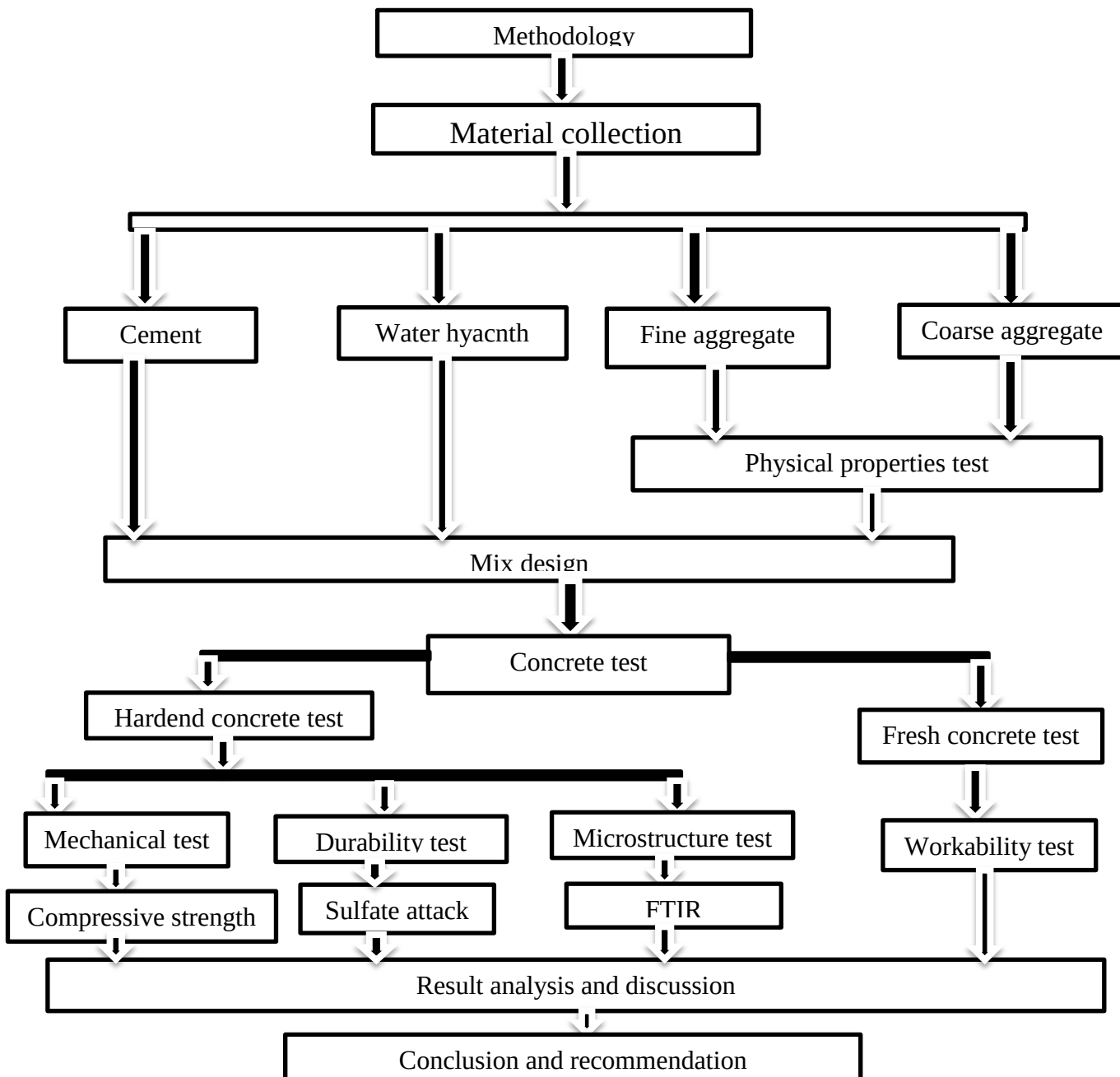


Figure 3. 2 methodology flow chart

To investigate the use of water hyacinth ash as a cement replacing material in concrete. The experiment was done using control mixes made with OPC. Consequently, the next sections are telling us all the properties of materials and specifications used throughout the study.

I Fine aggregate

As specified in ASTM C 33 fine aggregate is defined as aggregate in which its particle size is less than 4.75mm. for the current study clean river sand was used throughout all experimental investigations different fine aggregate tests were conducted to check the quality of the sand before casting concrete samples based on ASTM standard.

Table 3. 3 Physical properties of fine aggregate ASTM test methods

No	Parameters	Standard test method
1	Silt content	ASTM C117
2	Fineness modulus	ASTM C 136
3	Specific gravity	ASTM C 128
4	Moisture content	ASTM C128
5	Absorption capacity	ASTM C128
6	Unit weight	ASTM C 29

II Coarse aggregate

As specified in ASTM C-33 coarse aggregate is an aggregate in which size larger than 4.75 mm. in this study well-graded crushed stone coarse aggregate was used throughout the experiment. Different physical tests were conducted for checking the quality of the coarse aggregate.

Table 3. 4 Physical properties of the coarse aggregate ASTM test methods

No	Physical properties	Standard
1	Unit weight	ASTM C 29
2	Specific gravity	ASTM C 128
3	Moisture content	ASTM C 128
4	Absorption capacity	ASTM C128

3.4 Concrete specimens

The concrete specimens have dimensions of 150mm x150mm x150mm cubes for compressive strength test, before casting the concrete sample in the cubical mold it's better to clean the internal part of the mold and check the tightness of the mold to prevent the flow of cement paste.

Table 3. 5 Standards of ASTM tests for different item of work

No	Tests conducted	Standards
1	Workability slump test	ASTM C 143/C 143M
2	Compressive strength	ASTM C109/C109M
3	Sulfate resistance	ASTM C1012/C1012M
4	Water absorption	ASTM C1585/C1585M

3.5 Chemical test

A chemical test was conducted to determine the mineralogical content of cement substitute material which WHA and the chemical composition.

Table 3. 6 Oxide composition of Water Hyacinth Ash

	Oxides	Water hyacinth ash	Oxides	Water hyacinth ash	Remarks
1	SiO ₂	23.06	K ₂ O	34.04	✓
2	Al ₂ O ₃	2.52	MnO	0.4	✓
3	Fe ₂ O ₃	1.56	P ₂ O ₅	2.11	✓
4	CaO	62.74	Ti ₂ O	0.11	✓
5	MgO	6.42	H ₂ O	0.55	✓
6	Na ₂ O	1.40	LOI	13.91	✓

As shown from table, 3.6 the chemical test result analysis of Water Hyacinth Ash achieves 62.74% Calcium content was good result compared with Previous studies as it was shown in table, 2.6.

3.6 Mix design

Mix proportion was done based on ACI 211.1 mix design standard. All mixes of concrete were designed to meet the C-25 grade of concrete with a target mean strength of 33.25 MPa. A cement quantity of 360 kg/m³, the water-cement ratio for the current study was 0.49 and the range of

slump for the targeted mix design was 25mm to 50mm used throughout the experiment to meet the stated target mean strength and to achieve good workability and better compressive strength. For half of the mixes, sodium sulfate solution was used to conduct concrete sulfate attack by measuring the compressive strength in the specified curing date, the amount of Na_2SO_4 was 5% of the amount of water **was compared with** the control mix compressive strength. Detail mix design calculations are included in Appendix B.

Table 3. 7 Summary of mix proportion of concrete for the different ratio of WHA

summary of mix proportion of concrete for different percentage of WHA for C-25 concrete							
Percent replacement	WHA kg/m^3	Cement kg/m^3	Fine agg kg/m^3	Coarse agg kg/m^3	Water kg/m^3	W/C ratio	Slump (mm)
Con mix	0	360	818.58	1098.43	197.00	0.49	25-50
5%WHA	18	342	818.58	1098.43	197.00	0.49	25-50
10%WHA	36	324	818.58	1098.43	197.00	0.49	25-50
15%WHA	54	306	818.58	1098.43	197.00	0.49	25-50

3.7 Curing of concrete

After casting the concrete specimen in the proper concrete mould **it was kept in a** controlled environment for 24 hours and were removed from their molds and immersed into a water pond until the intended days **of** testing concrete compressive strengths, that is, 3rd, 7th, 28th, 56th and 91st days. Then record the compressive strength result at the end of specified curing dates.

3.8 Sulfate attack

Sulfate attack is one of the most important matters concerning the durability of concrete structures. The resistance of concrete to sulfate attack is determined by several factors, such as water/cement, permeability, and cement properties, which include fineness and cement composition (Sancak and Özkan, 2015).

A concrete sulfate attack test was conducted using sodium sulfate (Na_2SO_4) solution. **Sodium** sulfate reacts with calcium hydroxide to form Calcium sulfate (gypsum). **This** reaction proceeds to a greater or lesser extent, depending on the **conditions**, in flowing water, with a constant supply of sodium sulfate and removal of calcium hydroxide, the reaction may eventually continue to completion, i.e. leaching of all calcium hydroxide (Neville, 2004). The experiment

was performed by curing the concrete cube specimens in Na_2SO_4 for different periods of 3, 7, 28, 56, and 91 days with the addition of 5% sodium sulfate (Na_2SO_4) to the amount of curing water. The response of Na_2SO_4 attack on water hyacinth ash concrete for various percentages was studied by a loss in compressive strength.

3.9 Water absorption

The main important parameter for the durability of concrete is water absorption which tends to corrode the reinforcement bars in the concrete structure. Three concrete cubes from each specimen after 7 and 28 days of curing were dried in an oven at 105°C for 24 hours to obtain the dry weight. The concrete was weighted using digital balance and their weights are taken as dry weight (A) of specimen. Then they were again submerged in water for 24 hours and this weight was taken as wet weight (B). Then water absorption was calculated as a percentage of mass (Murugesh, Balasundaram, and Vadivel, 2018).

$$\text{Absorption (\%)} = \frac{(B-A)}{A} * 100 \quad 3.1. (\text{ASTM C 642})$$

3.10 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier transform infrared spectroscopy (FTIR) in a reflectance mode was used to record the absorption spectra of the bonds in the range of 400 to 4000 cm^{-1} . The KBr pellet method was used to prepare the samples. The samples were taken out and immersed in acetone for 24 h to stop the reaction. The samples were then dried at 60°C in an electric oven. Dry samples were crushed and powdered to $100\text{ }\mu\text{m}$ (Tome *et al.*, 2018).

CHAPTER FOUR

RESULT AND DISCUSSION

In this chapter, the results of the mechanical tests and durability tests are given and potential reasons for these behaviors are discussed. For the investigation of the effect of the water hyacinth ash on strength of concrete, microstructural test results are also presented.

4.1 Fine aggregate

As specified in ASTM C 33 fine aggregate is defined as aggregate which its particle size is less than 4.75mm. for the current study clean river sand was used throughout all experimental investigations different fine aggregate tests were conducted. Among these tests silt content, fineness modulus, specific gravity, moisture content and absorption capacity were conducted to check the quality of the sand before casting concrete samples based on ASTM standard.

Table 4. 1 Fineness modulus of fine aggregate concerning ASTM limit

Sieve size (mm)	Weight of Sieve	Weight of Sieve and weight of the sample	Weight retained Sample (gm)	Percentage Retained sample (%)	Cumulative Retained coarser (%)	Cumulative pass (%)	ASTM limits	
							Min	Max
9.5	702.4	702.4	0	0.00	0.00	100	100.00	100.00
4.75	738.3	772.4	33.8	3.38	3.38	96.62	95.00	100.00
2.36	736.2	793.2	57.0	5.70	9.08	90.92	80.00	100.00
1.18	611.6	771.2	159.6	15.96	25.04	74.96	50.00	85.00
0.6	607.2	878.9	271.7	27.17	52.21	47.79	25.00	60.00
0.3	582.5	910.5	328.0	32.80	85.01	14.99	10.00	30.00
0.15	572.7	659.2	86.5	8.65	93.66	6.34	2.00	10.00
0.075	540.4	589.9	49.5	4.95	98.61	1.39	00	5.00
Pan	413.5	427.5	14	1.4	100	0.00		
			1000		268.38			
					100			

					F.M=2.68			
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$$FM = \frac{\Sigma \text{Comulative coarser}(\%)}{100} = 268.38 = \mathbf{2.68}$$

Table 4. 2 **Physical properties of fine aggregate**

No	Parameters	test method	Results	ASTM limit	Remark
1	Fineness modulus	ASTM C117	2.68	2.3 to 3.1	✓
2	Specific gravity	ASTM C 136	2.71	2.4 to 2.9	✓
3	Absorption capacity	ASTM C128	2.45%	0.2% to 2%	✓
4	Moisture content	ASTM C 128	1.8%	-	

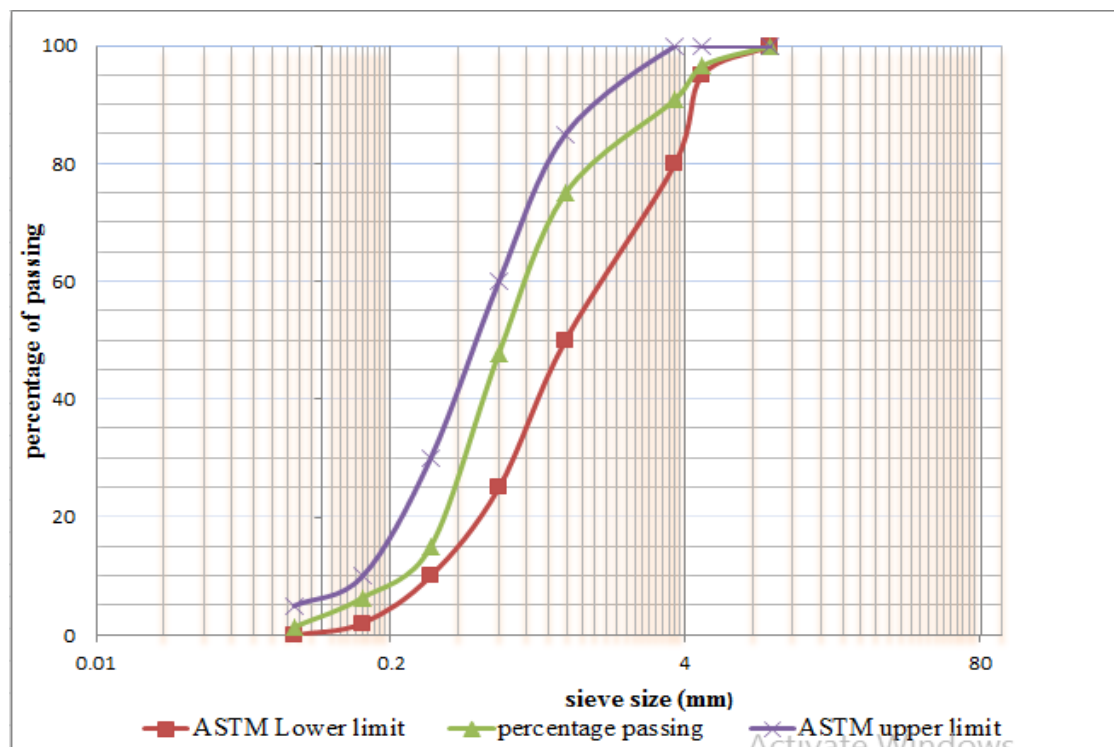


Figure 4. 1 **Fine aggregate gradation curve with ASTM lower and upper limits**

4.2 Coarse Aggregate

As specified in ASTM C-33 coarse aggregate is an aggregate in which size larger than 4.75 mm. in this study well-graded crushed stone coarse aggregate was used throughout the experiment. Different physical tests were conducted for checking the quality of the aggregate. the unit weight

of coarse aggregate was 1594.56 kg/m^3 and the other properties experimental result was recorded in table 4.4.

Table 4. 3 Gradation of coarse aggregate with respect to ASTM limits

Sieve size	Weight of Sieve	Weight of sieve & sample weight	Weight retained (gm)	% weight retained(%)	Cumulative % retained (gm)	Cumulative % pass	ASTM limits	
							min	max
37.5	712.00	712.00	0	0	0	100%	100%	100%
25	701.00	846.00	145	7.25	7.25	92.75%	90%	100%
19	724.00	1584.00	860	43.00	50.25	57.00%	50%	80%
12.5	682.50	1204.50	522.0	26.10	76.35	23.66%	20%	60%
9.5	702.46	897.46	195.0	9.75	86.10	13.91%	10%	40%
4.75	737.70	865.20	127.5	6.37	92.47	7.54%	5%	10%
2.36	736.20	877.20	141.0	7.05	99.52	0.49%	0%	5%
pan	412.00	422.00	10.0	0.5	100	0.00%	0%	0%

Table 4. 4 Physical properties of coarse aggregate used for all experiment

No	Physical properties	Test method	Result	ASTM requirement	Remark
1	Unit weight	ASTM C 29	1594.56 kg/m^3	1200 to 1750 kg/m^3	✓
3	Specific gravity	ASTM C 128	2.75	2.4 to 2.9	✓
4	Moisture content	ASTM C128	1.01%	-	✓
5	Absorption capacity	ASTM C128	1.41%	0.2% to 4%	✓
6	Nominal aggregate size	-	25mm	-	✓

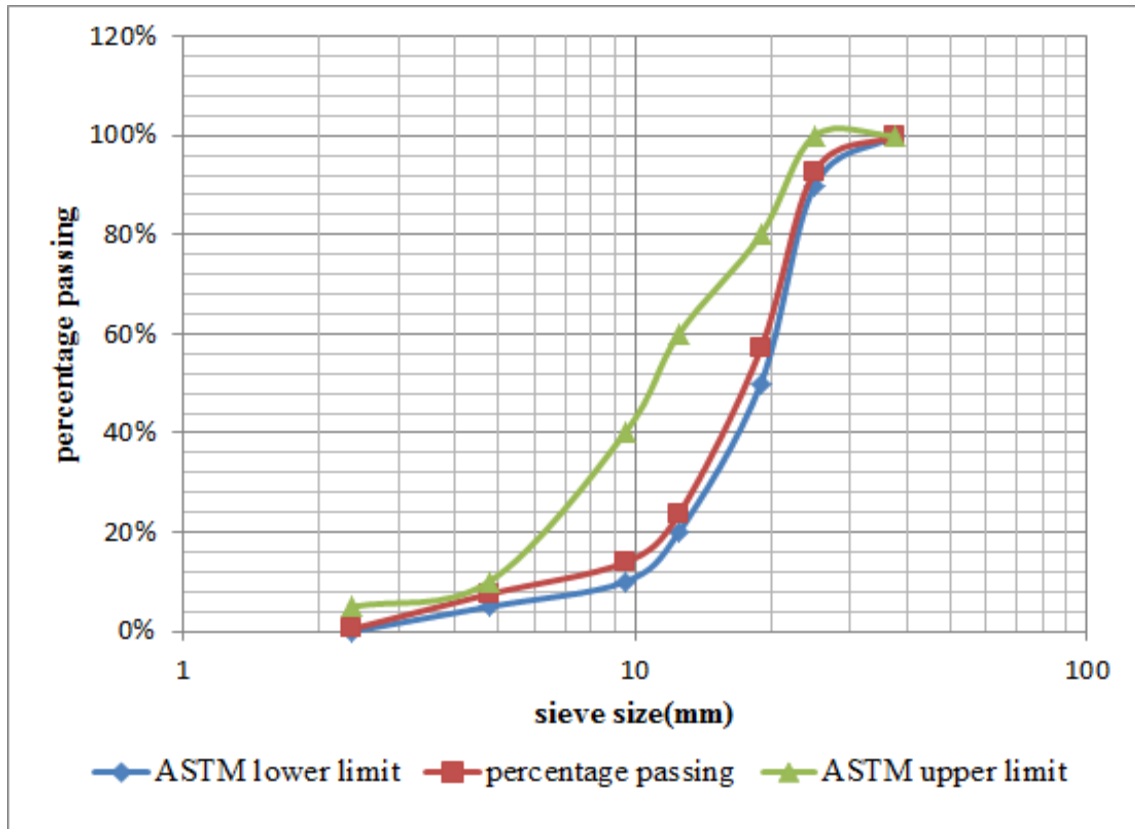


Figure 4. 2 Particle size distribution of coarse aggregate of the current study

Mix design

Table 4. 5 Summary of mix proportion of concrete for the different ratio of WHA

summary of mix proportion of concrete for different percentage of WHA for C-25 concrete							
Percent replacement	WHA kg/m ³	Cement kg/m ³	Fine agg kg/m ³	Coarse agg kg/m ³	Water kg/m ³	W/C ratio	Slump (mm)
Con mix	0	360	818.58	1098.43	197.00	0.49	25-50
5%WHA	18	342	818.58	1098.43	197.00	0.49	25-50
10%WHA	36	324	818.58	1098.43	197.00	0.49	25-50
15%WHA	54	306	818.58	1098.43	197.00	0.49	25-50

4.3 Workability of Concrete

4.3.1 Slump test

Fresh concrete was tested using slump cone test to find the workability of control mix concrete and concrete of WHA with partial replacement of cement. Workability of the concrete is considered as the placement of the concrete without segregation and bleeding. The workability of concrete is one of the functions of the comparative magnitudes of several concrete mix ingredients. the slump test is one of the fresh concrete test which measures the workability of concrete, the apparatus used for slump test was slump cone which has a dimension of 300mm*200mm*100mm. Before casting the concrete it's a must to check the workability of concrete. based on slump test result, C-25 concrete was poured into three layers and each layer was compacted 25 times in a metal rod. The top layer was leveled by trowel. Then elevate the cone loaded up with cement. Then measure the distinction between the highest point of the sample and mould.

Table 4. 6 Workabilities of concrete from slump test

No	Percentage replacement	Water/cement ratio	Slumpresult (mm)
1	0% WHA	0.49	35
2	5% WHA		48
3	10% WHA		65
4	15% WHA		92

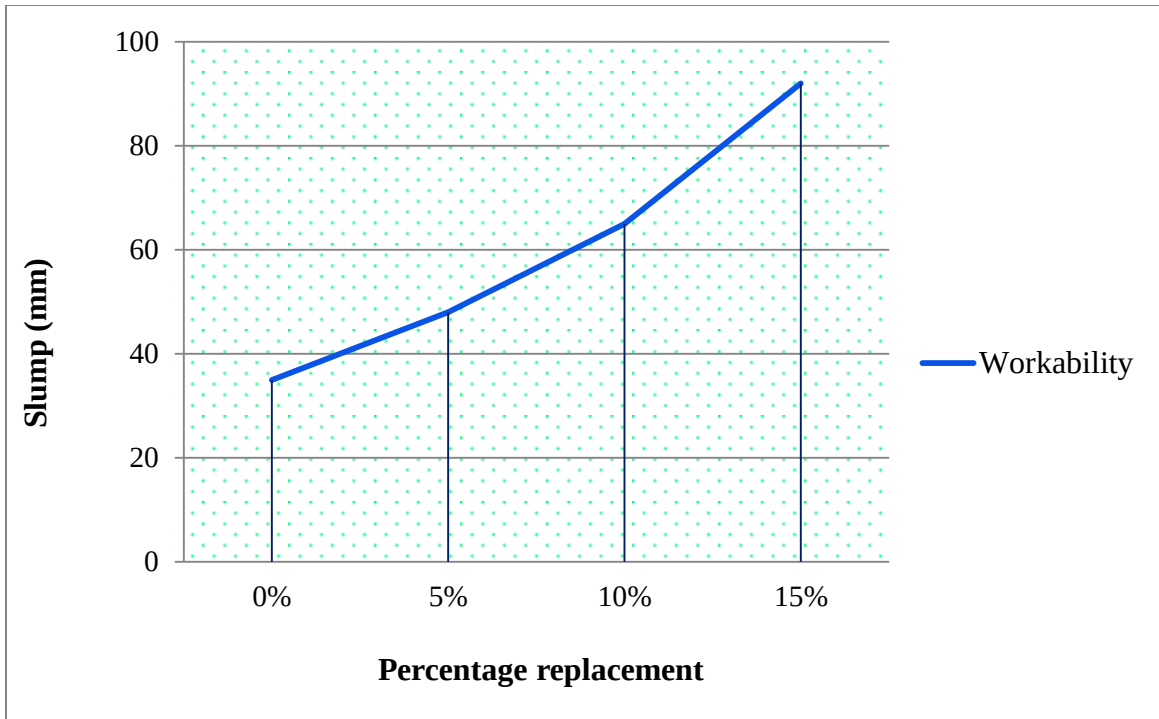


Figure 4. 3 Workability of concrete for the various percentage of WHA

As shown in Figure 4.3 the improvement in workability of concrete. WHA content in the replacement of cement rises for concretes made with a constant w/c ratio of 0.49. It was observed that WHA significantly increases the workability of concrete up to 37.14% as compared to control mix concrete. The higher the percentage of WHA in the replacement of cement, the better the workability of concrete it behaves. Because WHA has a smooth surface, spherical shape, and lowers specific surface area than ordinary Portland cement(Hwang and Thi, 2020).

4.4 Compressive Strength

The result of compressive strength of concrete for control mix and various percentage of water hyacinth ash replacement level presented in table, 4.7. The concrete pastes involve two hydration processes, first one is due to the hydration of included OPC which produces C-S-H and calcium hydroxide. The second one is due to the reaction of the produced calcium hydroxide with the water hyacinth ash to produce more hydration products which increase the compressive strength(Hegazy and Khalil, 2019).

Table 4. 7 Average compressive strength of concrete for different curing ages and WHA(%)

Percentage of replacement	Average Compressive strength of C-25 concrete				
	3 rd day (Mpa)	7 th day (Mpa)	28 th day (Mpa)	56 th day (Mpa)	91 st day (Mpa)
0% WHA	17.3	26.2	33.1	35.2	41.5
5 % WHA	18.6	27.7	34.5	37.8	43.6
10% WHA	19.8	29.3	35.7	41.3	46.5
15% WHA	16.2	25.2	32.0	34.6	40.1

The compressive strength of the hardened concrete immersed in pure water, up to 56 days, was graphically plotted, as a function of curing time, in figure 4.4. Among 56-day strength enhancements obtained from a concrete containing WHA, a remarkable enhancement of 42% in reference to the control mix was obtained for w/c ratio of 0.49 and 10% WHA addition. This enhancement could be related to higher amount of C-S-H formed as a consequence of WHA addition. The main reason for the improvement of concrete compressive strength is the pozzolanic reaction from WHA and calcium hydroxide, which promotes the formation of hydrated calcium silicate. However, concrete without WHA can only rely on cement to hydrate to a small amount of calcium silicate hydrate. Hydrated calcium silicate is one of the important elements that provide strength. Therefore, the compressive strength of concrete without WHA is lower than concrete made with a replacement of cement up to 10% by WHA.

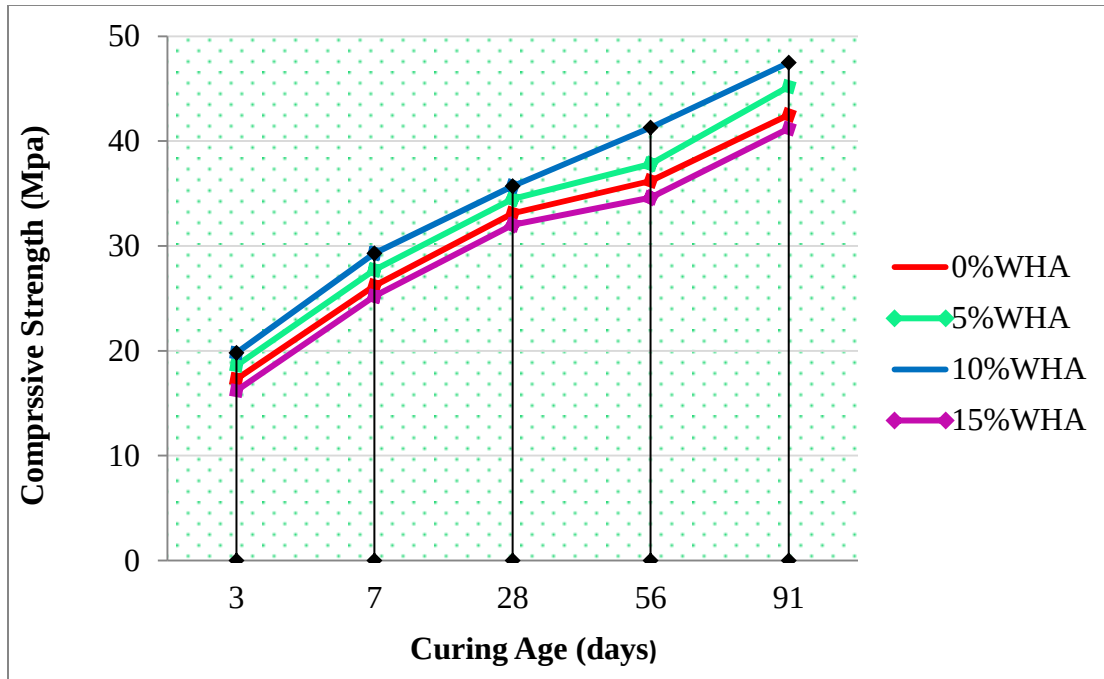


Figure 4. 4 Compressive strength of concrete for different curing ages

As shown in figure 4.4 in general, curing age plays the main role in the development of compressive strength of concrete. As the age of concrete increase or becomes harder, the compressive strength of concrete significantly increase. The compressive strengths obtained in this study were more than 34.5 Mpa and 35.7 Mpa at 28th day, 37.8 Mpa and 41.3 Mpa at 56 days 43.6 Mpa and 46.5 Mpa at 91st for 5% and 10% respectively in replacement of cement with water hyacinth ash; Figure. 4.4 represent the strength of the cubes at 3, 7, 28, 56, and 91 days for both control mix concrete and replacement of cement in concrete by different percentage of Water Hyacinth Ash. Pozzolanic materials hydrate slowly after the release of Ca(OH)_2 during cement hydration. Most researchers confirm that replacing cement with water hyacinth ash in concrete improves the compressive strength(Manoj, 2019). As shown in figure 4.4, the compressive strength of concrete improves from control mix up to 10% replacement.

4.5 Sulfate attack

Table 4. 8 Average compressive strength result 5% sodium sulfate solution

Percentage of replacement	Compressive strength of concrete in Na_2SO_4 solution				
	3 rd day (Mpa)	7 th day (Mpa)	28 th day (Mpa)	56 th day (Mpa)	91 st day (Mpa)
0% WHA	16.1	25.6	31.42	34.2	41.4
5% WHA	18.0	27.3	33.8	36.7	44.3
10% WHA	17.1	26.2	32.9	35.4	43.7
15 % WHA	15.1	24.5	30.5	33.2	40.1

Figure 4.5 show that the compressive strength of concrete significantly increases as the curing age increases. Because of the sulfate (Na_2SO_4) attack, the compressive strength of concrete is reduced as the percentage of WHA increase in concrete production. As observed in table 4.8 the compressive strength of concrete at 28 days, 56 days and 91 days were 33.8 Mpa, 36.7 Mpa and 44.3 Mpa respectively in 5% replacement of cement with water hyacinth ash. At 5% replacement the concrete shows a slight increase in compressive strength. But further increase in percentage of WHA in concrete under sulfate solution get a slight reduction in compressive strength. As the age of concrete increases, the sulfate solution has a significant effect on the compressive strength. In comparison, Concrete cured in pure water with that of concrete cured under sodium sulfate (Na_2SO_4) solution, the former achieves better compressive strength. On the other hand the color of concrete cured in water which incorporate sodium sulfate affected due to sulfate attack.

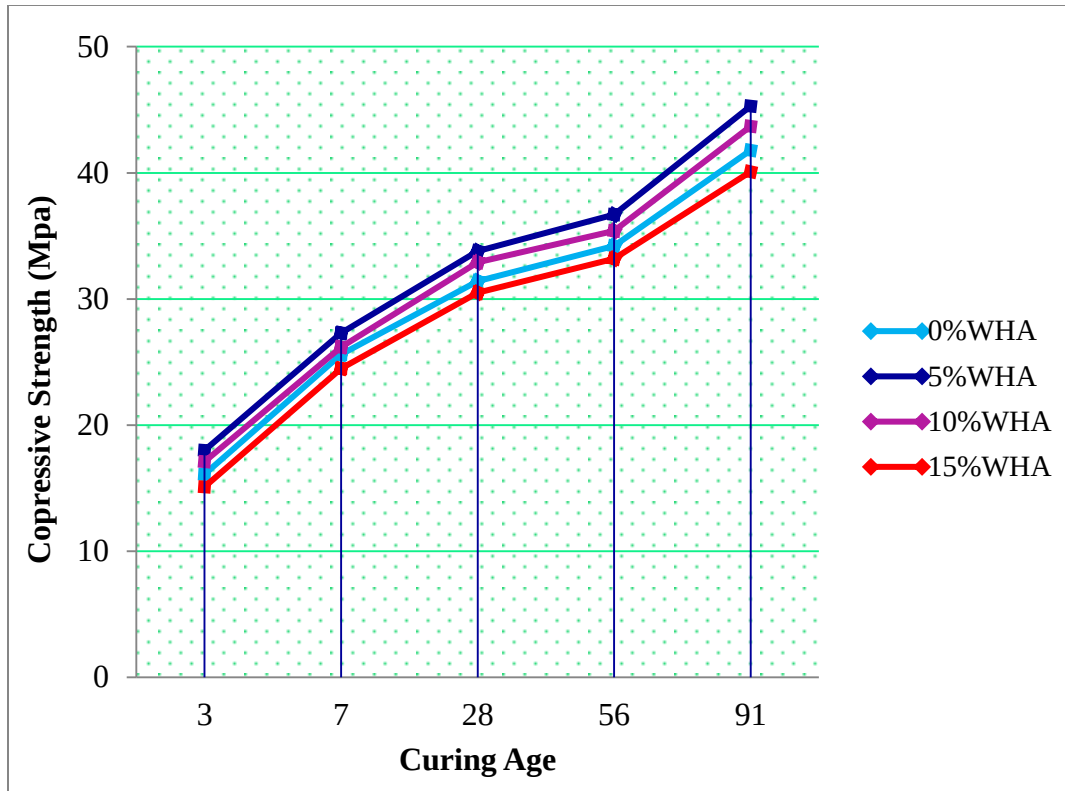


Figure 4. 5 Average compressive strength of concrete following sulfate attack

The compressive strength of the hardened concrete made with 0%, 5%, 10%, and 15% WHA immersed in 5% Na_2SO_4 solution, up to 91 days, are graphically plotted, as function of curing time, from figure, 4.5 it is clear that the compressive strength of the concrete increases with aging due to the increase of the hydration products especially C-S-H which is the main source for the strength. The concrete made with 0%, 5%, 10% and 15% WHA involve two hydration processes, first one is due to the hydration of included OPC which produces C-S-H and calcium hydroxide. The second one is due to the reaction of the produced calcium hydroxide with WHA to produce more hydration products which increase the compressive strength as confirmed by (Hegazy and Khalil, 2019). 5% replacement of cement with WHA achieves 33.8Mpa, 36.7 Mpa, and 44.3Mpa in 28 days, 56 days, and 91days of curing. Higher relative strength indicates greater resistance to sulfate attack(Zhang and Zong, 2014). So in this study 5% replacement better resists the sulfate attack.

A research program conducted by Emre Sancak and Fukru Ozkan (2015) as the amount of C3A reduces, C3S/C2S ratio increases and as this ratio increases, the amount of calcium hydroxide

(CH) produced by the hydrolysis of these two compounds increases. CH reacts with the sulfates attacking concrete producing gypsum. The produced gypsum will cause expansion and strength reduction over time in the hardened concrete.

Comparing concrete cured in pure water and in sulfate (Na_2SO_4) solution, the former achieves better compressive strength. As shown from these test result analysis Water Hyacinth Ash better substitute up to 5-10%. But the optimum ratio to replace cement is 5% in concrete production.

4.6 Water absorption

Table 4. 9 Average water absorption of concrete for the current study

No	Percentage of replacement	Avg water absorption (7) days in (%)	Avg water absorption (28) days in (%)
1	0%	7.48	4.5
2	5%	7.32	3.77
3	10%	7.18	3.62
4	15%	6.75	3.56

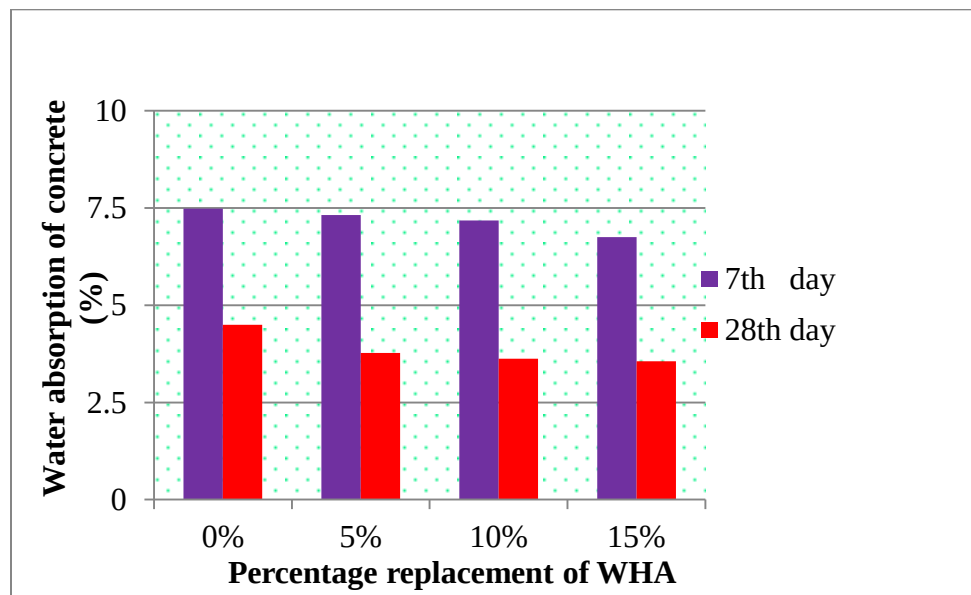


Figure 4. 6 Water absorption of concrete cubes

The water absorption of each concrete mixture was evaluated after 7 and 28 days of curing per ASTM C 642 guidelines. As figure 4.6 shows that, the water absorption of concrete significantly

reduced as the age of concrete increases. On the other hand as the percentage of water hyacinth ash in the replacement of cement increased, the concrete slightly absorbs lower amount of water. It shows that Voids in WHA replacement concrete is less, non Porous when compared to control mix concrete. Water absorption is examined by measuring the increase in mass as a percentage of dry mass. It can be seen that rapid loss of water of hydration at the concrete cover during curing. The surface water absorption of control mix concrete for 7 and 28 days were 7.48% and 4.5% and for 5% replacement the surface water absorption for 7 and 28 days curing were 7.32% and 3.77% respectively. This higher water absorption may be attributed to the higher porosity of the concrete preserved in the surface due to air (Zhang and Zong, 2014). The Amorphous phase of WHA may facilitate the hydration reaction and result in lower un hydrated WHA particles, decreasing water absorption in the concrete samples (Vo, Hwang and Thi, 2020).

4.7 Fourier Transform Infrared Spectroscopy (FTIR)

Figure 4.7 shows that the infrared spectrum of all samples of 7 days with the spectrum ranging from 500 to 4000 cm^{-1} the characteristic wavenumber and the associated functional groups of cement paste.

Figure 4.7 and 4.8 clearly show that the chemical oxides location with respect to wave length. As the percentage of water hyacinth ash increase from 5% to 15%, the graph behaves a smooth curve this indicate no more unreacted particle till 500cm^{-1} , completion of hydration reaction and decomposition of $\text{Ca}(\text{OH})_2$ and CaCO_3 leads to release of water and for mation of strong bond between the paste particles. As a result, the compressive strength of concrete is improved.

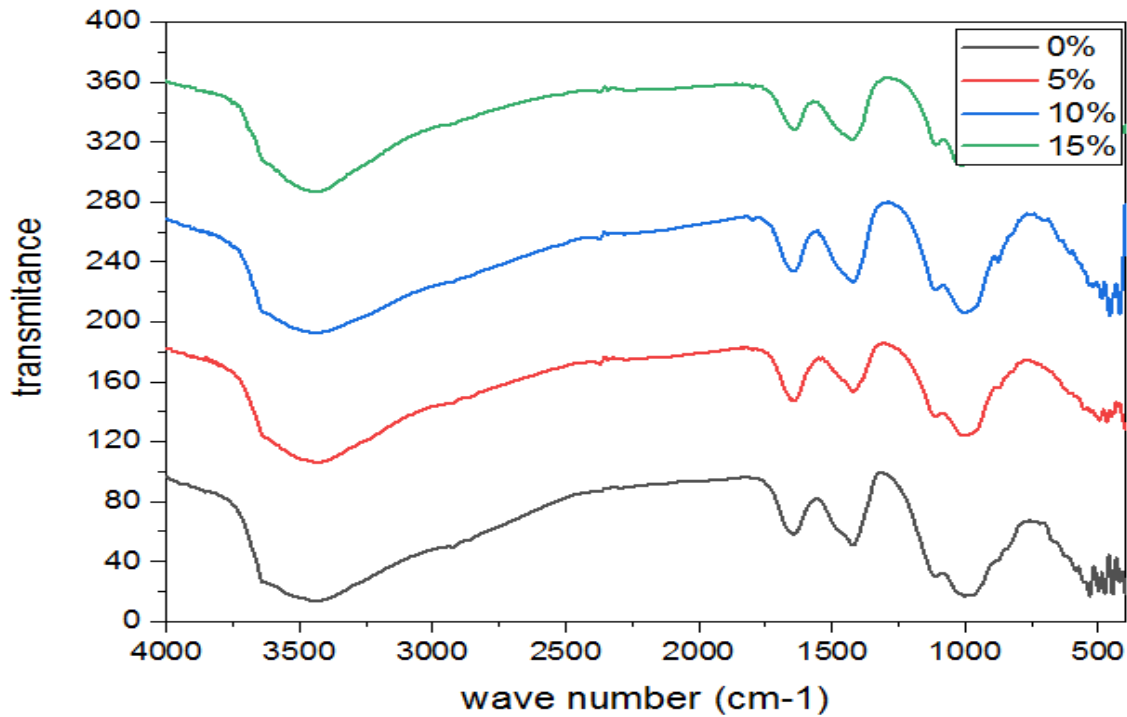


Figure 4. 7 Infrared spectra of concrete cement paste with water hyacinth ash for 7th day

Fig. 4.7 represents the FTIR spectra of the WHA sample. From the result of the FTIR spectrum analysis of WHA, The major peaks were as follows: 3650, 3720, 2350, 2290, 1500, 920 889, 680 cm^{-1} . Due to the presence of calcium content in the sample of low wavenumber band is observed at 684 cm^{-1} . H-O-H band vibrations are found at the peak value of 1500 cm^{-1} (Solaiyan, 2020).

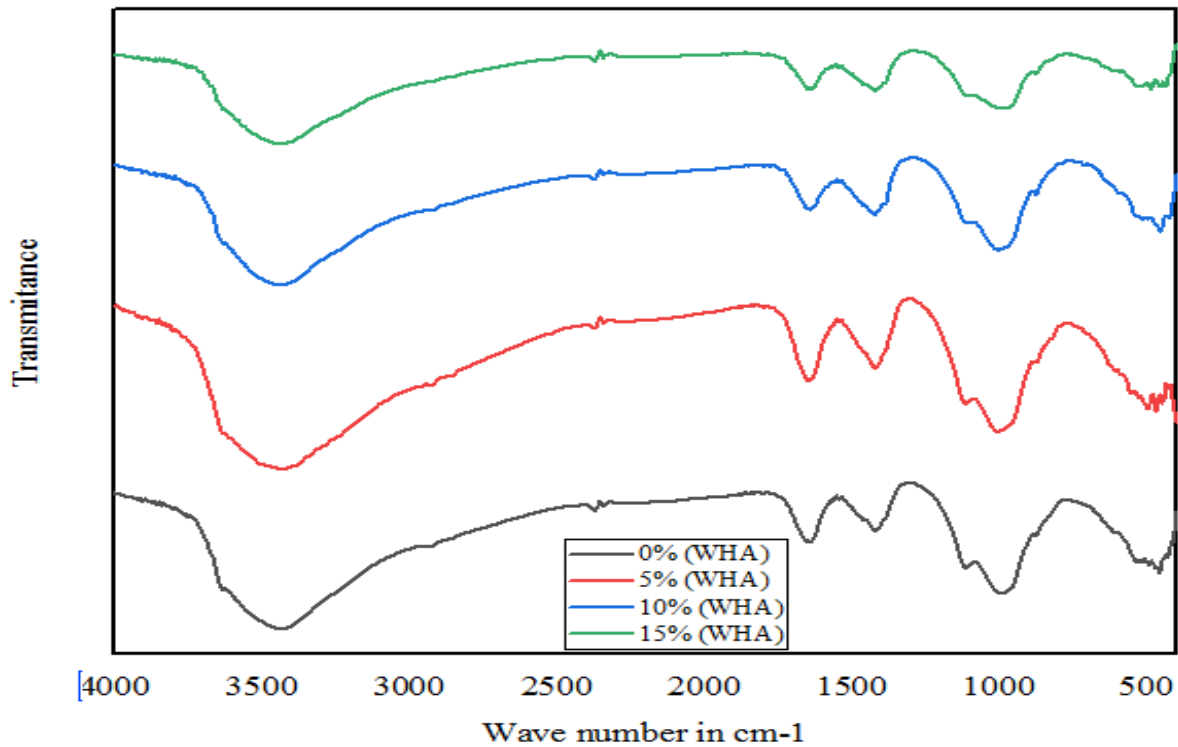


Figure 4. 8 infrared spectroscopy of concrete cement paste with water hyacinth ash for 28th day

The FTIR spectra for the water hyacinth ash samples after 7 and 28 days of curing at room temperature and at different concentrations of alkalis **is** in the range of 4000 to 400 cm^{-1} . The FTIR patterns of WHA paste hydrated for different ages are shown in Figure, 4.8 The results showed that the wavenumbers and curves of 28-day pastes were essentially the same, indicating that the hydration products did not change with the development of the hydration process.

Figure, 4.8 clearly shows that the IR spectra of concrete matrix cured at ambient environment at the age of 28 days. Due to the presence of activated alkali, the material becomes sharper at the peak of 960.80 cm^{-1} , this shift represents the gel component of WHA material reacted with alkali activators. Because of this reaction, a new product is formed like alumino-silicate hydrate gel. The **extended** vibrations related to O-H twisting vibrations and H-O- H extending vibrations ($3600 \text{ to } 1600 \text{ cm}^{-1}$) represents the free water and gave proof of a soluble base initiation response in concrete (Solaiyan, 2020) **revealing** that the expansion of H-O-H extending vibrations was seen at 3500 cm^{-1} . during the hydration reaction $1030 \text{ to } 1170 \text{ cm}^{-1}$ which is attributed to the Ca-modified silica gel (C-S-H). The band area detail of $4000\text{-}3500 \text{ cm}^{-1}$ indicates the loss of

Ca(OH)₂, 3500-1600 cm⁻¹ indicates the stretching of the (-OH) bond and bending of the (H-O-H) vibrations, 1000-800 cm⁻¹ indicates the loss of the CaCO₃ gel (Fauzi et al, 2016).

Table 4.10 clearly shows that positions of infrared bands and functional groups in attenuated total reflection Fourier transform infrared spectroscopy (FTIR) spectra of OPC paste in concrete with the addition of water hyacinth ash.

Table 4. 10 wavenumbers concerning functional groups for cement chemistry

Wavenumber (cm ⁻¹)	Functional group	Reference
968-970	Si-O-Si (Si-O-Al)	(Run-Sheng Lin, Clay, 2019)
1400-1500	CO(CaCO ₃ ⁻²)	
1640-1650	H ₂ O	
3390-3408	Ca(OH) ₂	
3500-1170	C-S-H	(Fauzi et al., 2016).
1000-800	loss of the CaCO ₃ gel	

4.9 Statistical analysis

This part of the study gives attention to determine the laboratory test result by using statistical analysis. A statistical software package SPSS® was used to perform a Two-Way Factorial Analysis of Variance (ANOVA) based on independent variables (WHA percentage replacement and age of concrete) and the dependent variable (compressive strength). If there is a correlation between compressive strength, WHA percentage replacement and age of concrete, statistical method is used to determine their relationship. These programs were used to determine if there was a significant difference between the treatments, and the effect of WHA on the compressive strength (Mae et al., 2015).

4.9.1 Factorial ANOVA

Factorial analysis of variance (ANOVA) is a statistical process that permits to explore the influence of two or more independent variables (factors) on a single dependent variable. Many experimental designs use factorial ANOVAs to explore differences between treatment groups while considering individual characteristics. factorial ANOVAs allow exploring how multiple independent variables affect change in the dependent variable. This effect is measured with

individual main effects for each factor, along with the interaction effect with all factors (Mike Allen,2017).

4.9.2 Hypothesis Testing in Factorial ANOVA

The intent of hypothesis testing is formally examined two opposing assumptions (hypotheses. there are two types of hypothesis), the null hypothesis, H_0 , and alternative hypothesis, H_A

The null hypothesis, H_0 : row means are the same, i.e., $\mu_{01} = \mu_{02} = \mu_{03}$.

The alternative hypothesis, H_A : at least one row mean is different. In this study $H_{A1} \neq H_{A2}$
In a Factorial ANOVA, because of the presence of more than two variables, there will be multiple null and alternative hypotheses based on the number of levels. The effects of those multiple independent variables can be categorized as major effects and correlated effects. The central effect is the impact of a single independent variable on a dependent variable; whereas, an interaction effect is the simultaneous impacts of multiple independent variables on a dependent variable (Husk and Replacement, 2015).

Null Hypothesis (H_0): μ_{01} = Age of concrete doesn't affect the compressive strength of concrete
 μ_{02} = WHA replacement doesn't affect the compressive strength of concrete
 μ_{03} = Both Age of concrete and WHA replacement doesn't affect the compressive strength of concrete.

4.9.3 Major Factors Affecting the Compressive Strength of Concrete

Two-Way Factorial ANOVA with a level of Confidence of 95% and a Significant Level, alpha, is the probability of making the wrong decision when the null hypothesis is true of $\alpha = 0.05$ was used to analyze the factors affecting compressive strength of concrete. The significance level for a given hypothesis test is a value for which a P-value less than or equal to it is considered statistically significant. Typical values for $\alpha = 0.05$. If the P-value is less than (or equal to) α , then the null hypothesis is rejected in favor of the alternative hypothesis. And, if the P-value is greater than α , then the null hypothesis is not rejected.

After conducting the F-test for major effects, Post – hoc test was done to analyze the interaction effect of the variables. The interaction effects consist of five labels for the ages, 3, 7, 28, 56 and 91 days and three labels of WHA replacement, with control mixes for 0% and 5%, 10% and 15%

replacement level of concretes. The profile plot of the different WHA replacements for estimated marginal means of strength at different testing days is illustrated in figure, 4.9.

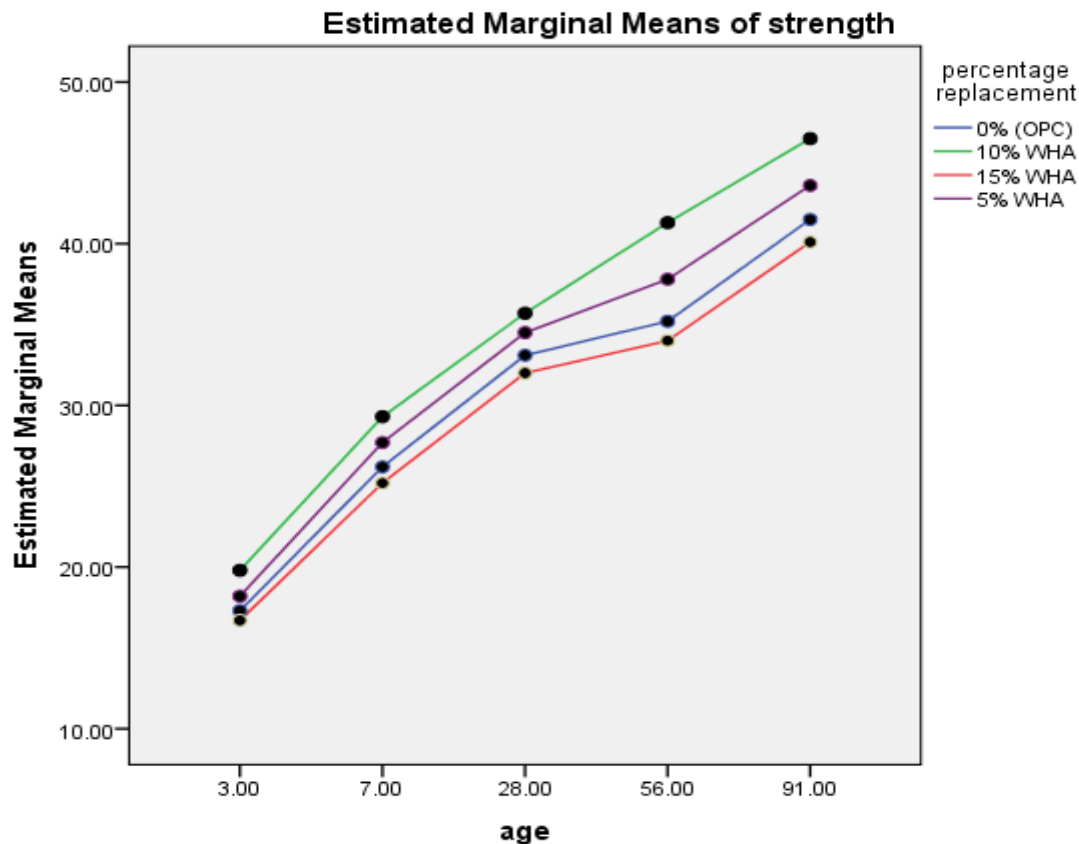


Figure 4. 9 Profile plot for various percentage replacement level of WHA

As we can see from Figure 4.9, the estimated marginal means at the 56th day show a larger difference compared with the other curing ages. 5% WHA has a better marginal means up to 28th day and is more significant than the others. while between 56th and 91st day, 10% WHA shows an increase in marginal mean. However, concretes made with WHA replacement continues its strength development up to 91st days which confirms with the previous studies described in the literature review. The WHA replacement levels between 5% to 10% show a better marginal means for more than 28th-day strength. It tells that pozzolanic materials continue their strength development at later days.

4.9.4 Post hoc test

Post hoc tests are considered for conditions in which the scholars have already obtained a significant P-value with a factor that consists of three or more means and further investigation of

the differences from those means are significantly different within each level. Tukey HSD test was used; as it is one of the most important post hoc test methods. The post hoc test result of WHA replacement is demonstrated in Table, 4.11.

Table 4. 11 Post hoc test result in SPSS

Multiple Comparisons							
	(I) WHA	(J) WHA	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	0% (OPC)	10%WHA	-4.1200	0.57	0.035	-24.6295	16.3895
		15%WHA	1.0000	0.57	0.092	-19.5095	21.5095
		5%WHA	-1.9200*	0.57	0.021	-22.4295	18.5895
	10% WHA	0%(OPC)	4.1200	0.57	0.023	-16.3895	24.6295
		15%WHA	5.1200	0.57	0.056	-15.3895	25.6295
		5% WHA	2.2000	0.57	0.025	-15.3895	22.7095
	15% WHA	0% (OPC)	-1.0000	0.57	0.142	-21.5095	19.5095
		10%WHA	-5.1200*	0.57	0.450	-25.6295	15.3895
		5%WHA	-2.9200	0.57	0.015	-23.4295	17.5895
	5% WHA	0%(OPC)	1.9200	0.57	0.026	-18.5895	22.4295
		10%WHA	-2.2000*	0.57	0.042	-22.7095	18.3095
		15%WHA	2.9200	0.57	0.016	-17.5895	23.4295
LSD	0% (OPC)	10%WHA	-4.1200*	0.57	0.024	-19.3168	11.0768
		15%WHA	1.0000	0.57	0.013	-14.1968	16.1968
		5%WHA	-1.9200	0.57	0.028	-17.1168	13.2768
	10% WHA	0%(OPC)	4.1200	0.57	0.039	-11.0768	19.3168
		15%WHA	5.1200	0.57	0.063	-10.0768	20.3168
		5% WHA	2.2000	0.57	0.026	-12.9968	17.3968
	15% WHA	0% (OPC)	-1.0000	0.57	0.057	-16.1968	14.1968
		10%WHA	-5.1200*	0.57	0.006	-20.3168	10.0768
		5%WHA	-2.9200	0.57	0.014	-18.1168	12.2768
	5% WHA	0%(OPC)	1.9200	0.57	0.009	-13.2768	17.1168
		10%WHA	-2.2000*	0.57	0.007	-17.3968	12.9968

		15%WHA	2.9200	0.57	0.006	-12.2768	18.1168
The mean difference is significant at 0.05 level.							

From the Tukey HSD test, we can conclude that there is a statistically significant difference between control mix concrete with 5% and 10% WHA which has an α value of 0.021 and 0.035 respectively, which both are less than 0.05. However, WHA 15% has an α value of 0.092 and this number is greater than 0.05. Thus, there is no statistically significant difference between control mix 0% (OPC) and 15% WHA.

Table 4. 12 Pairwise comparison using SPSS

Dependent Variable: strength

(I) percentage replacement	(J) percentage replacement	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
					Lower Bound	Upper Bound
0% (OPC)	10% WHA	-4.120	.576	.097	-9.087	.847
	15% WHA	1.000	.576	.674	-3.967	5.967
	5% WHA	-1.920	.576	.423	-6.887	3.047
10% WHA	0% (OPC)	4.120	.576	.097	-.847	9.087
	15% WHA	5.120*	.576	.044	.153	10.087
	5% WHA	2.200	.576	.360	-2.767	7.167
15% WHA	0% (OPC)	-1.000	.576	.674	-5.967	3.967
	10% WHA	-5.120*	.576	.044	-10.087	-.153
	5% WHA	-2.920	.576	.229	-7.887	2.047
5% WHA	0% (OPC)	1.920	.576	.423	-3.047	6.887
	10% WHA	-2.200	.576	.360	-7.167	2.767
	15% WHA	2.920	.576	.229	-2.047	7.887

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4.10 Cost Analysis

The other main advantage of using water hyacinth ash in the production of concrete is its economic benefit. Even if it has no material purchasing cost and difficult to quantify its size reducing and burning cost of producing water hyacinth ash, targeting labour cost from its harvesting to its final product for 1m³ concrete sample (Table 4.13) illustrate that cost of ordinary Portland cement saves more than 5% in replacing 5% to 15% WHA.

The main concern in this study is substituting cement with biological waste material. So the cost of cement was taken from Dangote cement, Derba cement, Habesha cement, East cement, and Mosobo cement on average. But the other ingredients' cost taken as a constant factor depends on local suppliers.

Table 4. 13 Cost Analysis of 1m³ of concrete with different ratio of WHA

		Cement	Fine Aggregate	Coarse aggregate	Water	WHA
OPC	Quantity (kg/m ³)	360	818.58	1098.43	197	-
	Unit cost (birr)	5.5	0.4	0.5	0.003	-
	Cost/m ³	1980	327.43	549.21	0.591	-
	Totl cost/m ³	1980.00+327.43+549.15+0.59=2,857.17				
5%WHA	Quantity (kg/m ³)	342	818.58	1098.43	197	18
	Unit cost (birr)	5.5	0.4	0.5	0.003	2.5
	Cost/m ³	1881	327.43	549.21	0.591	45
	Totl cost/m ³	1881.00+327.43+549.21+0.591+45.00=2,803.23				
10%WHA	Quantity (kg/m ³)	324	818.58	1098.43	197	36
	Unit cost (birr)	5.5	0.4	0.5	0.003	2.5
	Cost/m ³	1782	327.43	549.21	0.591	90
	Totl cost/m ³	1782+327.43+549.21+0.59+90=2,749.23				
15%WHA	Quantity (kg/m ³)	306	818.58	1098.43	197	54
	Unit cost (birr)	5.5	0.4	0.5	0.003	2.5
	Cost/m ³	1683	327.43	549.21	0.591	135
	Totl cost/m ³	1683+327.43+549.21+0.591+135=2,695.23				

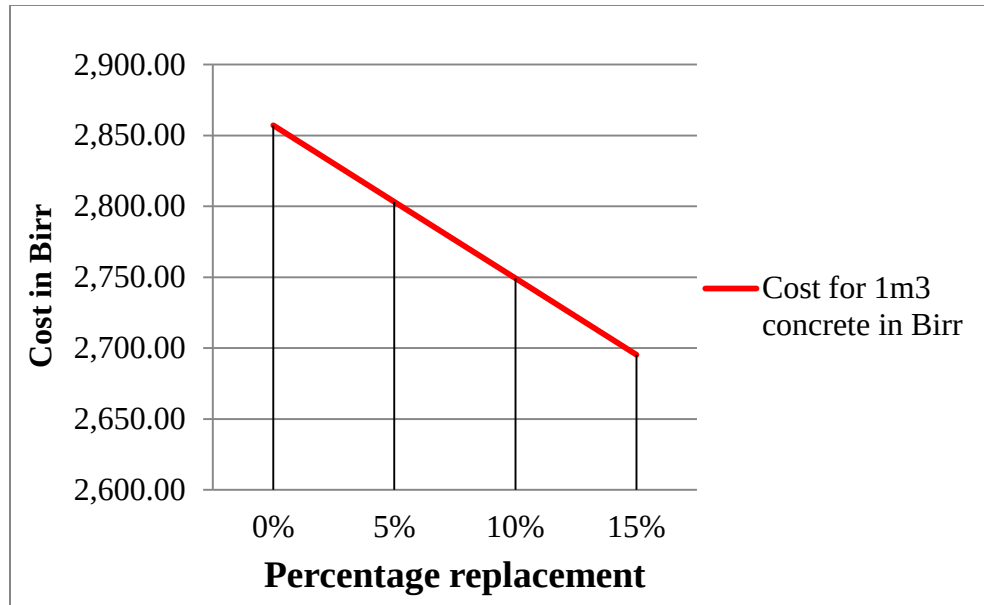


Figure 4. 10 Cost Analysis of *different* WHA Replacement rati

Summary of the chapter

Water hyacinth (Emboch) is a worthless biological weed which was a pandemic for water bodies. In this experimental investigation, it was clearly seen that water hyacinth (Emboch) ash can be cement substitute material in the production of concrete. Using Water hyacinth (Emboch) ash substitute 5-10% in improving the concrete properties. It has multidimensional benefit when we use its ash in concrete production. it can reduces cost of concrete up to 5% for one meter cube of concrete. On the other hand it helps us to make the environment clean and safe.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The aim of this study was to investigate the fresh properties, mechanical properties, durability test, and microstructure performance of concrete with the partial replacement of ordinary Portland cement by water hyacinth ash. In pursuit of the objective, various forms of literature were reviewed regarding this additives (Water Hyacinth Ash), experimental work was performed and the test results were discussed. This chapter was set out to conclude.

- Burning water hyacinth ash at 800° c for 6 hours yields a good pozzolanic property for use as supplementary cementitious material in concrete.
- The slump values of concrete are highly dependent on the proportion of WHA. High levels of WHA increase the slump results. The results are due to specific surface area and the smooth shape of WHA. As the percentage replacement of WHA increases, the workability of the concrete mix increases.
- Replacing WHA between 5% to 10% improves the compressive strength of concrete. However, further, increase water hyacinth ash replacement results in decrease the compressive strength of concrete.
- Water hyacinth ash in concrete gives the higher compressive strength as compared to the control mix concrete. As the percentage of water hyacinth ash increases the compressive strength of concrete tends to increase up to certain percentage and then start's decreasing with the increase of ash content. Hence optimal results were found at the 10% replacement of cement with water hyacinth ash.
- The compressive strength decreased when cured in 5% Na₂SO₄ comparatively when cured in normal water. Compressive strength is increased for 3, 7, 28, 56, and 91 days when cured in normal water while curing the concrete sample in 5% Na₂SO₄ slightly reduced the compressive strength due to sulfate attack.
- The concrete specimens exhibited a reduction of water absorption with curing time. At 7 and 28 days of curing. The concrete mixture with higher percentage of water hyacinth ash

exhibited the best durability of the concrete specimens. As the age of concrete increases the water absorption reduced. This is due to the minim void and pore of the concrete sample.

- The microstructure analysis shows that the structure of C-S-H gels changes in samples with the addition of the water hyacinth ash which contributes to increased compressive strength. The decomposition of Ca(OH)_2 and formation of CaO and release of H_2O lead to reduction of porosity of concrete.
- Using Water Hyacinth(Emboch) ash as a cement substitution can save up to 5% for one meter cube in concrete.

5.2 RECOMMENDATION

Based on the current study the following recommendations are forwarded.

1. Water hyacinth is one of the worthless biological wastes in lakes and seas, but this material which is regarded as waste. can be used for value-added purposes by incorporating it in concrete as partial replacement of cement.
2. Removal of WH from the lake is not enough. Instead using as a cement replacement improves properties of concrete.
3. Utilization of Water Hyacinth Ash as a cementitious material best reduce cement demand.
4. Using biological waste like Water Hyacinth Ash as binding material keeps the environment clean and safe
5. Utilization of local biological materials like WHA as a supplementary cementitious material should be encouraged in concrete production to ensure the freedom of the sea and lake.

Suggestion for future study

6. A further intensive study should be carried out by academic institutions to investigate the long term properties and effects of concrete produced by partially replacing cement with WHA.
7. To investigate the effect of different burning temperature on the chemical properties of the WHA and on properties of concrete.
8. To investigate the use of WHA in concrete as a replacement of admixtures and fine aggregate.
9. To investigate the use of Water Hyacinth Ash in concrete with regards to its modulus of elasticity, flexure, drying shrinkage ,split tensile test.

References

1. Abirami, U., Kayalvizhi, K., And Pavithra, K. (2018) 'Experimental Study on Behaviour of Concrete Replaced with Water Hyacinth Ash', 6(14), pp. 14–16.
2. Access, O. (2007) 'We are intech open , the world ' s leading publisher of Open Access books Built by scientists, for scientists'.
3. Aquatic Invasive Species Quick Guide Water Hyacinth (*Eichhornia crassipes*)' (1884), p. 15.
4. Asmare, E. (2017) 'Journal of Biodiversity & Endangered Current Trend of Water Hyacinth Expansion and Its Consequence on the Fisheries around North-Eastern Part of Lake Tana, Ethiopia', 5(2), pp. 2–5. Doi: 10.4172/2332-2543.1000189.
5. Chen, Q. (2003) 'Accelerated carbonated cement-heavy', (November).
6. Clay, C. H. (2019) 'Calcined Hwangtoh Clay'. Doi: 10.3390/ma12030458.
7. Committee, A. C. I. *Et al.* (2005) 'Building code requirements for structural concrete and commentary (ACI 318M-05)', 2003.
8. 'Concrete Technology, 2nd Edition Neville.' (1997).
9. 'Construction Materials - Laboratory Manual By Abebe Dinku.pdf' (2005).
10. Debouch, W. *Et al.* (2017) 'Hydration development of mineral additives blended cement using thermogravimetric analysis (TGA): Methodology of calculating the degree of hydration', *Construction and Building Materials*. Elsevier Ltd, 146, pp. 687–701. Doi: 10.1016/j.conbuildmat.2017.04.132.
11. Deterioration, F. *Et al.* (2006) 'Types and Causes of Concrete Deterioration',.
12. 'Determination of water/cement ratio of concrete' (2018).
13. Dinesh, S. And Murugesh, V. (2017) 'Experimental Behaviour of Water Hyacinth Ash as the Partial Replacement of Cement In Concrete', (3), 244–248.

14. Durdzi, T. (2016) ‘Hydration of multi-component cement containing cement clinker, slag, calcareous fly ash and limestone’, 6834.
15. Edition, F., Member, H. And Society, C. (2015) *Properties of concrete*.
16. Edition, S. (2013) ‘Durability of Concrete’, (September).
17. Emeritus, T. (1997) ‘Cement chemistry’.
18. Faculty, C. E. (2012) ‘Environmental impacts of cement production ©’, 296–302.
19. Frqvwlwxxwhv, R. *Et al.* (2018) ‘, QJUHGLHQWV LQ & RQFUHWH’, 37(176 2).
20. Hegazy, A. A. And Khalil, A. A. (2019) ‘Egyptian Journal of Chemistry’, 62(6), pp. 1145–1155. Doi: 10.21608/chem.2019.6563.1579.
21. Husk, E. R., And Replacement, P. (2015) ‘Masters thesis Solomon Melaku Belay Study of the Potential of Ethiopian Rice Husk as a Partial Replacement of Cement Bahir Dar University Bahir Dar Institute of Technology (bit) Faculty of Civil and Water Resource Engineering Supervised by Dr. Asrege’.
22. Insulation, T. And Board, P. (2019) ‘Thermal Insulation Particle Board Manufacture’. Doi: 10.3390/ma12040560.
23. Juanzon, J. B. (2017) ‘Performance evaluation of water hyacinth fiber reinforced self-compacting concrete using varied rice hull ash as admixture’.
24. Manoj, A. (2019) ‘Experimental Investigation on Water Hyacinth Ash as a Supplementary Cementing Material’, 5(3), 683–685.
25. Mehta, B. Y. P. K. (2001) ‘Reducing the Environmental Impact of Concrete’, (October), pp. 61–66.
26. Mohammadi, B. (2013) ‘Development of Concrete Water Absorption Testing for Quality Control School of Graduate Studies’, (December).
27. Muruges, V., Balasundaram, N. And Vadivel, T. S. (2018) ‘Experimental Studies on

- Durability Studies of Concrete with Partial Replacement of Cement by Water Hyacinth Ash', 7, 22–24.
28. Naik, B. T. R., And Moriconi, G. (2005) 'Utilization construction', (May).
 29. Neville, A. (2004) 'The confused world of sulfate attack on concrete', 34, pp. 1275–1296.
Doi: 10.1016/j.cemconres.2004.04.004.
 30. Okwadha, G. D. O. And Makomele, D. M. (2018) 'Evaluation of water hyacinth extract as an admixture in concrete production Evaluation of water hyacinth extract as an admixture in concrete production', *Journal of Building Engineering*. Elsevier Ltd, 16(January), pp. 129–133. Doi: 10.1016/j.job.2018.01.002.
 31. Pandey, S. And Mire, A. (2019) 'Compressive Strength of Concrete by Partial Replacement of Cement with Dolomite Powder', 7(Vii), pp. 625–628.
 32. Pickel, D. (2014) 'Recycled concrete aggregate : influence of aggregate pre-saturation and curing conditions on the by'.
 33. Popovics, S. (1998) 'Concrete materials'.
 34. Production, C., Control, Q. And Building, I. N. (2005) 'School of graduate studies', (November).
 35. 'Quality of Water for Making Concrete : A Review of' (2015), 5(1), pp. 1–10.
 36. Sancak, E. And Özkan, F. (2015) 'Sodium Sulphate Effect on Cement Produced with Building Stone Waste', 2015.
 37. Solaiyan, E. (2020) 'Study on engineering and microstructural properties of ambient cured GP concrete produce of GGBS and m-sand', 7(7), pp. 499–506.
 38. Tome, S. *Et al.* (2018) 'Characterization and Leachability Behaviour of Geopolymer Cement Synthesised from Municipal Solid Waste Incinerator Fly Ash and Volcanic Ash Blends'.
Doi: 10.3390/recycling3040050.

39. Torrens-martín, D., Fernandez-carrasco, L. J. And Martinez-ramirez, S. (2009) ‘C-S-H gels in blended cements : Study by infrared spectroscopy’.
40. Tran, K. A. (2007) ‘The durability of concrete’.
41. Vidya, B. And Rao, K. S. (2019) ‘Thermogravimetric analysis of concrete’, (May). Doi: 10.21884/IJMTER.2018.5120.JRKJ2.
42. Vo, D. *Et al.* (2021) ‘The influence of MgO addition on the performance of alkali-activated materials with slag À rice husk ash blending’, *Journal of Building Engineering*. Elsevier Ltd, 33(January 2020), p. 101605. Doi: 10.1016/j.jobbe.2020.101605.
43. Vo, D., Hwang, C., And Thi, K. T. (2020) ‘Effect of Fly Ash and Reactive MgO on the Engineering Properties and Durability of High-Performance Concrete Produced with Alkali-Activated Slag and Recycled Aggregate’, 2020(11), pp. 1–11. Doi: 10.1061/(ASCE)MT.1943-5533.0003420.
44. Yahaya, B. S. *Et al.* (2014) ‘Comparison of the Compressive Strength of Concrete Made with Different Brands of Ordinary Portland cement’, 4(3), pp. 36–39.
45. Zeyad, A. M., Khan, A. H. And Tayeh, B. A. (2020) ‘Durability and strength characteristics of high-strength concrete incorporated with volcanic pumice powder and polypropylene fibers’, *Journal of Materials Research and Technology*. Korea Institute of Oriental Medicine, 9(1), pp. 806–813. Doi: 10.1016/j.jmrt.2019.11.021.
46. Zhang, S. P. And Zong, L. (2014) ‘Evaluation of the relationship between water absorption and durability of concrete materials’, *Advances in Materials Science and Engineering*, 2014. Doi: 10.1155/2014/650373.

APPENDICES

APPENDIX.A: PHYSICAL PROPERTIES TEST FOR FINE AND COARSE AGGREGATE

Test for fine aggregate

Depend on ASTM C 33 fine aggregate is an aggregate that has a size smaller than 4.75mm.

Silt content of sand

Objective: the objective of the test is to determine the silt (finer than sieve 200) content in sand.

Apparatus

Graduated cylinder or nay jar

The dish for taking sample of sand

Small size spoon

Sample sand

Funnel

Clean water (tap water)

Balance digital balance

Oven machine

Procedures of test

1. Take graduated cylinder or jar having a capacity of greater than 100mm
2. Pour 30ml of sand into the cylinder
3. Fill $\frac{3}{4}$ of the cylinder with water
4. Shake the cylinder for about a minute
5. Leave the cylinder for about our hour to allow the silt to settle on the layer
6. Measure the amount of fineness forming a separate layer on the top of

Calculation

$$\text{Silt content(\%)} = \frac{A * 100}{B}$$

Where A=Amount of silt deposited above the sand

B= amount of clean sand

According to Ethiopian standard, 6% is recommended

Results : Silt content(%) = $\frac{A}{B} * 100 = \frac{2}{47} * 100 = 4.25\%$

If the silt content is above 6%, its better to remove the sand and substitute by another.in this test the silt content is 4.25%.so, the sand used through out the experiment comply with the Ethiopian standar.

Moisture content

Moisture content is the total amount of water present in the aggregate. i.e. both internally inside the pores and externally at the surface.

Objective

The objective of this test is to determine the moisture content of fine aggregate

Apparatus:

- ✓ Balance of suitable capacity, readable and accurate
- ✓ Containers, airtight, non-corrodible
- ✓ Well ventilated oven
- ✓ Means of reducing the laboratory sample

Procedure

1. Weigh 100kg of fine aggregate
2. Oven dry the sample with oven for about 24hrs with a temperature of 105⁰c-110⁰c
3. Remove the sample from the oven and place them on the discator for about an hour in order to cool with out absorbing water from the atmosphere
4. Weigh the aggregate separately (oven dry)
5. Calculate the moisture content of fine aggregate

Calculation

$$W(\%) = \frac{(A-B)}{B} * 100$$

Where W=moisture content (%)

A= Weight of orginal sample (g)

B= Weight of oven dry sample (g)

$$\text{Result : } W(\%) = \frac{(A-B)}{B} * 100 = \frac{(500-491)}{491} * 100 = 1.83\%$$

Fineness modulus and gradation of fine aggregate

Objective

The objective of this test is to determine the particle size distribution of fine aggregate

Theory

Sieve analysis is a procedure for the determination of particle size distribution of aggregate using a series of square or round openings starting with the largest also used to determine the grading and the fineness modulus.

Apparatus

- ✓ Digital balance
- ✓ ASTM C 33 sieves 9.5, 4.75, 2.36, 0.06, 0.03, 0.015
- ✓ Trowel

Observation and calculation

Procedure for grading fine aggregate

1. Weigh 1000gm sample of fine aggregate
2. Quarter the sample using a riffle box
3. From the quartered sample take 250gm
4. Weigh the empty sieves and record the data
5. Place the pan to the bottom of the sieve shaker and put the other sieves into the pan with increasing opening size of the sieves
6. Place 250gm of sample on the top sieve (the larger size of sieve)
7. Shake the sample for about 2minute in a sieve shaker
8. Weigh each sieve together with the aggregate retained on it
9. Calculate the weight retained on each sieve
10. Fill in the gradation chart and compute the fineness modulus

The initial sample of fine aggregate 1000gm or 1kg

Calculation of fineness modulus of fine aggregate

$$FM = \frac{\sum \text{Cumulative coarser}(\%)}{100}$$

Where:

F.M=fineness modulus of fine aggregate

Table A.1. Fine modulus of fine aggregate

Sieve size (mm)	Weight of Sieve	Weight of Sieve and weight of the sample	Weight retained Sample (gm)	Percentage Retained sample (%)	Cumulative Retained coarser (%)	Cumulative pass (%)	ASTM limits	
							Min	Max
9.5	702.4	702.4	0	0.00	0.00	100	100.00	100
4.75	738.3	772.4	33.8	3.38	3.38	96.62	95.00	100.00
2.36	736.2	793.2	57.0	5.70	9.08	90.92	80.00	100.00
1.18	611.6	771.2	159.6	15.96	25.04	74.96	50.00	85.00
0.6	607.2	878.9	271.7	27.17	52.21	47.79	25.00	60.00
0.3	582.5	910.5	328.0	32.80	85.01	14.99	10.00	30.00
0.15	572.7	659.2	86.5	8.65	93.66	6.34	2.00	10.00
0.075	540.4	589.9	49.5	4.95	98.61	1.39	00	5.00
Pan	413.5	427.5	14	1.4	100	0.00		
			1000		268.38			
					100			
					F.M=2.68			

$$FM = \frac{\Sigma \text{Cumulative coarser}(\%)}{100} = 268.38 = \mathbf{2.68}$$

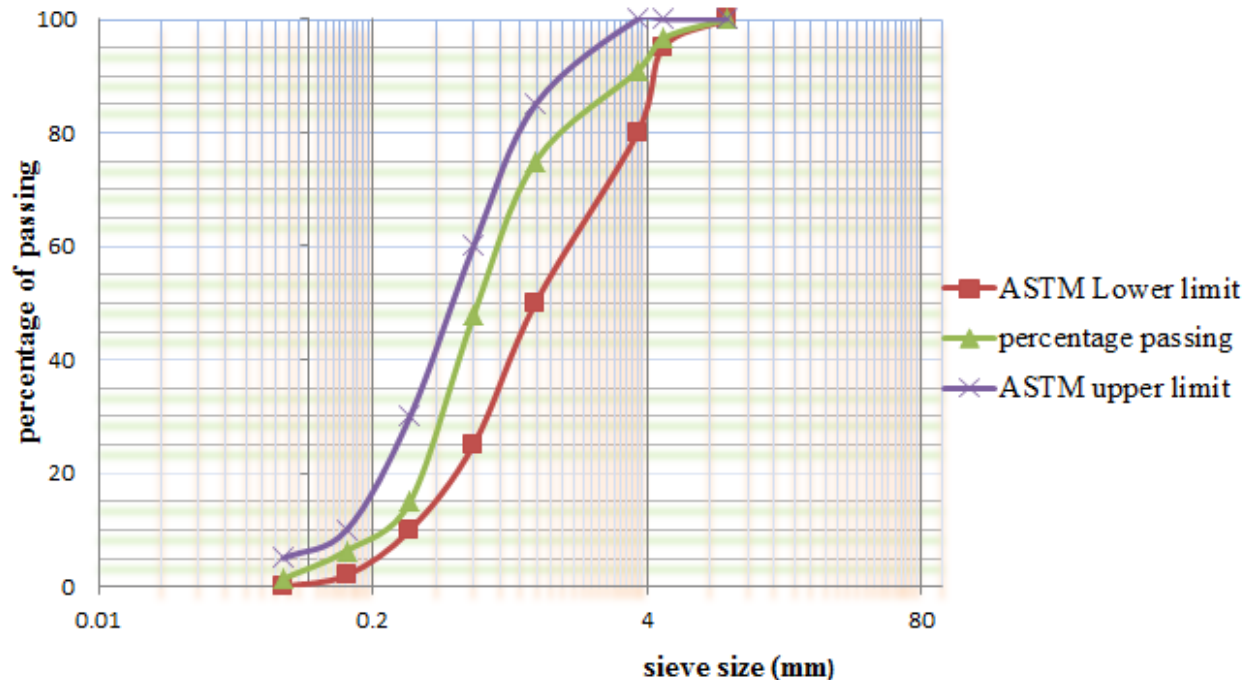


Figure A:1. Gradation curve of fine aggregate (sand)

Specific gravity and absorption capacity of fine aggregate

Objective:

To determine the bulk specific gravity and absorption capacity of fine aggregate

Theory:

Apparatus:

- **Balance** – a balance or scale capacity weighing 1kg
- **Pycnometer**- a flask or other suitable container into which the fine aggregate test sample can readily be introduced.
- **Mold** - a metal device weighing 340 ± 15 g and having a flat circular tamping face 25 ± 3 mm in diameter
- **Water tank** – a container to immerse the sample in the water for a specific period

Sample preparation

Take 1000gm of fine aggregate from the sample by using quartering. dry it in a suitable pan or vessel to constant weight at a temperature of 110°C . and cool it at suitable temperature. then cover with water for 15hrs and spread the sample on a flat surface exposed to gently moving warm air. Until it is uniformly dried. then insert the partially dried fine aggregate loosely into the mold and tamp 25 times. lastly reject the mold in perpendicular manner. this tells us the fine aggregate

sample has reached on a surface dry condition.

Procedure :

1. Immediately introduce into the pycnometer 500gm of fine aggregate sample prepared and fill with water to approximately 90% capacity.
2. Shake or roll the pycnometer to eliminate all air bubbles at a temperature of 23⁰c and adjust the water to its calibrated capacity
3. Measure the weight of pycnometer, water, and sample fine aggregate together

Result of test :

$$\text{Bulk specific gravity (SSD)} = \frac{A}{A+B-C} = \frac{490}{490+1817.8-2127} = 2.71$$

Where A=weight of the oven-dry sample in air (g)

B=weight of pycnometer filled with water (g)

C= weight of the dry sample and weight of pycnometer filled with water (g)

Conclusion and recommendation

According to ASTM standard the value of specific gravity for fine aggregate should between 2.6 and 2.8 therefore the sample having a bulk specific gravity of 2.71 is best for the concrete mix

Absorption capacity

Objective:

- To determine the absorption capacity of fine aggregate

Absorption is the void to permit water flow in the sample. To quantify the water used in the mix of concrete it is must to know the absorption capacity of fine aggregate.

Apparatus:

- Balance
- Oven
- Container

Sample preparation

From the sample of fine aggregate take apart by using quartering or sample more split. The sample was immersed in water. By using a flat metal pan the sample was dried at a temperature of 105⁰c within an oven. Then measure the sample after drying.

Procedure:

1. By using sample more split take sample of fine aggregate and immerses with water

2. Measure the sample at SSD condition
3. Place the SSD sample in an oven at a temperature of 105⁰c for 24hrs
4. Take out the sample from the oven and cooled at room temperature until it was safe to measure the weight

Calculation

$$\text{Absorption capacity(\%)} = \frac{(A-B)}{B} * 100 == \frac{(505-488)}{488} * 100 = 3.48\%$$

Where A= Weight of SSD sample in water (g)

B= weight of the oven-dry sample (g)

Test of coarse aggregate

Gradation

Objective:

The objective of the test is to determine the particle size distribution of coarse aggregate

Theory:

As specified in ASTM standard an aggregate has sieve more than 4.75 mm. the aggregate used for the current study was locally available crushed stone which was inert and free from any dirt.

Apparatus

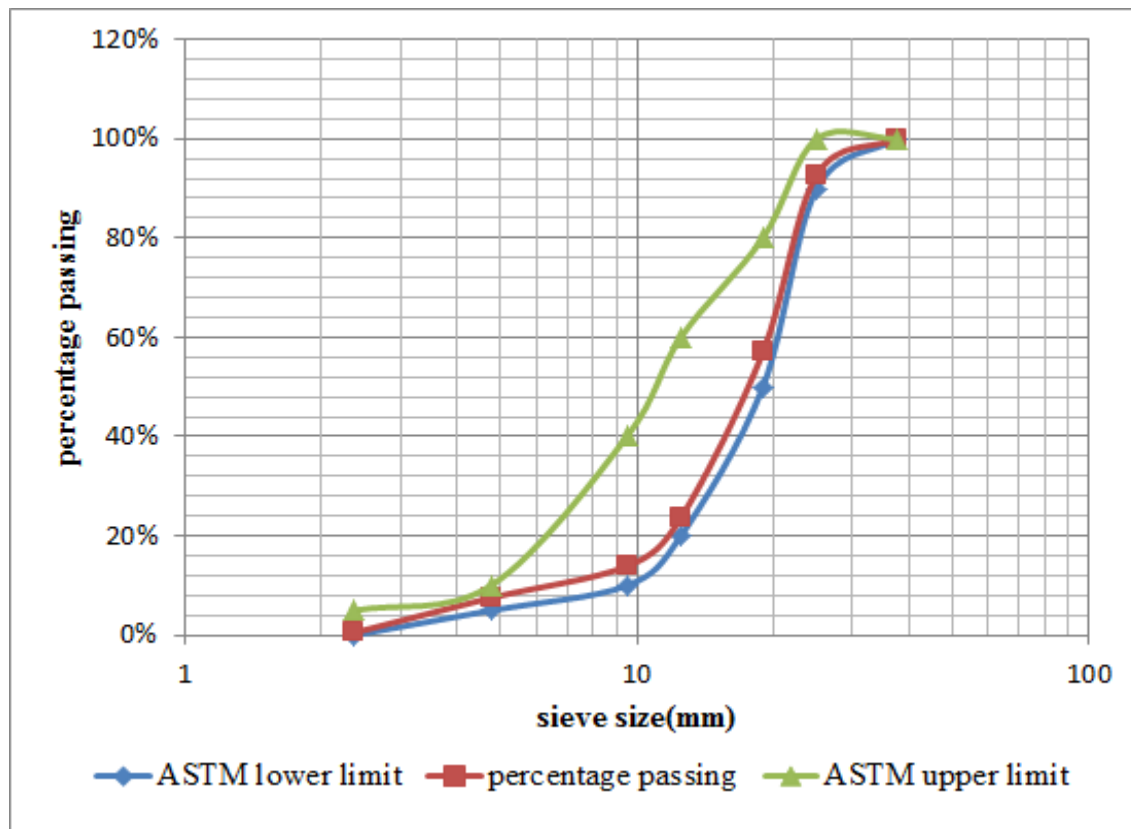
- Balance
- Series of sieves(37.5 ,25, 19, 12.5, 9.5, 4.75,2.36)mm and pan
- Shovel
- Sieve brush

Procedure for grading of coarse aggregate

- ✓ Weigh 2000gm of a sample of coarse aggregate
- ✓ Shake the measured sample coarse aggregate with a shaker machine for a minute
- ✓ Measure the weight of sample retained coarse aggregate in consecutive sieves

Table A:2. Particle size distribution of coarse aggregate

Sieve size	Weight of Sieve	Weight of sieve & sample weight	Weight retained (gm)	%weight retained (%)	Commulative % retained (gm)	Commulative % pass	ASTM limits	
							min	max
37.5	712.00	712.00	0	0	0	100%	100%	100%
25	701.00	846.00	145.00	7.25	7.25	92.75%	90%	100%
19	724.00	1584.00	860.00	43.00	50.25	57.00%	50%	80%
12.5	682.50	1204.50	522.00	26.10	76.35	23.66%	20%	60%
9.5	702.46	897.46	195.00	9.75	86.10	13.91%	10%	40%
4.75	737.70	865.20	127.50	6.37	92.47	7.54%	5%	10%
2.36	736.20	877.20	141.00	7.05	99.52	0.49%	0%	5%
pan	412.00	422.00	10.00	0.5	100	0.00%	0%	0%

**Figure A:2. Particle size distribution of coarse aggregate**

BULK DENSITY (UNIT WEIGHT)

Bulk density is the weight of the aggregate required to fill a container of a specified unit volume. Volume is occupied by both the aggregates and the voids between the aggregate particles.

Specific gravity

OBJECTIVE

The objective of this test is to determine the bulk specific capacity of coarse aggregate

Theory

Specific gravity is the ratio of the density of the aggregate to the density of water at a stated temperature.

Absorption capacity

Objective

The objective of this test is to determine the absorption capacity of coarse aggregate

According to ASTM C 128 Absorption capacity is the increase in the mass of aggregate due to water penetrating the pores of the particles, during a prescribed period but not including water adhering to the outside surface of the particles, expressed as percentage of the dry mass.

Apparatus

- ✓ Balance
- ✓ Oven
- ✓ Container to handle the sample

Sample

Take a certain gram of coarse aggregate and immerses in water then by removing the water and oven-dried the sample for 24hrs at 105⁰c the cool down the sample

Calculation and result conclusion

Where A = Weight of saturated -surface dry sample in the air [g]

B = Weight of oven-dry sample in air [g]

$$\text{Absorption capacity(\%)} = \frac{(A-B)}{B} * 100 = \frac{(1004-990)}{990} * 100 = 1.41\%$$

Specific gravity test

Bulk specific gravity: is defined as the ratio of the weight in air of a given volume of a permeable material (including both its permeable and impermeable voids) to the weight in air of an equal volume of water.

$$\text{Bulk specific gravity} = \frac{(A)}{B-C}$$

Bulk specific gravity (SSD basis): is defined as the ratio of the weight in air of a permeable material in a saturated surface dry condition to the weight in air of an equal volume of water.

$$\text{Bulk specific gravity (SSD)} = \frac{(A)}{B-C} = \frac{(990)}{1004-644} = 2.75$$

Where A = weight of the oven-dry sample in air.

B = weight of SSD sample in air

C = weight of saturated sample in water.

Moisture content

Objective

The objective of this test is to determine the quantity of moisture available on the coarse aggregate.

Theory

Moisture is the surplus water available on the aggregate which supplied to the concrete during mixing

Apparatus

- Balance
- Rectangular box to Handel the sample
- Oven machine

Procedure

1. Measure the weight of a certain amount of coarse aggregate in a digital balance
2. Oven dry the sample measured in no 1 in a temperature of 105⁰c

Result and calculation

$$\text{Moisture content (\%)} = \frac{(\text{natural weight of sample} - \text{weight of oven dry sample})}{\text{Weight of oven dry sample}} * 100$$

Where $W1$ = weight of natural aggregate

$W2$ = weight of oven-dry sample

M = Moisture content

$$M = \frac{(W1-W2)}{W2} * 100 = \frac{(1000-990)}{990} * 100 = 1.01\%$$

APPENDIX B: MIX DESIGN FOR ONE METER CUBE CONCRETE

Table B:1. Physical properties of fine aggregate

No	Physical properties	Result
1	Unit weight	1838.5kg/m ³
2	Specific gravity	2.71
3	Moisture concrete	1.8%
4	Absorption capacity	3.48
5	Fineness modulus	2.63

Table B:2. Physical properties of coarse aggregate

No	Physical properties	Result
1	Unit weight	1594.567kg/m ³
2	Fineness modulus	4.63
3	Specific gravity	2.75
4	Moisture content	1.01%
5	Absorption capacity	1.41%
6	Nominal aggregate size	25mm

Step 1: choice of Slump

For the current study 25-50mm slump was used as a minimum possible requirement

Step 2: Choice of the maximum size of aggregate.

The nominal maximum aggregate size was 25mm for the current study

For the proposed 25 MPa compressive strength concrete, a margin of 8.5 MPa shall be added to the specified compressive strength to get the target mean strength. Because there is no test data available, therefor

$$f_m = f_{c_k} + 1.65 s$$
$$25 + 1.65 * 5 = 33.25 \text{MPa}$$

Step 3: Estimation of mixing water and air content

According to ACI 211.1, the quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum coarse aggregate size, the shape and grading of both CA and FA, as well as the amount of entrained air.

Table B:3. Mixing Water Quantity in kg/m³ for the listed nominal maximum aggregate size

Slump(mm)	Mixing Water Quantity in kg/m ³ for the listed nominal maximum aggregate size							
	9.5mm	12.5mm	19mm	25mm	37.5mm	50mm	75mm	100mm
25 - 50	207	199	190	179	166	154	130	113
75 - 100	228	216	205	193	181	169	145	124
150 - 175	243	228	216	202	190	178	160	-
Air content	3	2.5	2	1.5	1	0.5	0.3	0.2

For the nominal maximum aggregate of 25mm for the slump 25mm-50mm the weight of water from the above table 179kg/m³

Entrapped air content = **1.5%**

Volume of air = $1.5/100 = 0.015\text{m}^3$

water content = **179kg/m³**

Volume of water = weight of water /unit weight of water = $179\text{kg}/1000\text{kg/m}^3 = 0.179\text{m}^3$

Step 4. Selection of water/cement ratio

The required water/cement ratio is determined by strength, durability and finish ability

Table B:4. Water-cement ratio by weight

28 days compressive strength in Mpa	Water-cement ratio by weight	
	Non-Air Entrained	Air-Entrained
41.4	0.41	-
34.5	0.48	0.40
27.6	0.57	0.48
20.7	0.68	0.59
13.8	0.82	0.74

To calculate water /cement ratio interpolation is used

$X = \text{water/cement ratio}$

$$34.5 = 0.48 \frac{(34.5-33.25)}{233.25-27.6} \frac{0.48-X}{X-0.57} = \underline{x = 0.49}$$

$$\frac{33.25}{27.6} = x = 0.57$$

Step 5. Calculation of cement content.

The amount of cement is fixed by the determinations made in Steps 3 and 4 above

$$\text{Weight of cement} = \frac{\text{weight of water}}{\text{Water/cement}} = \frac{179\text{kg}}{0.496} = 360.66\text{kg} \approx \underline{\underline{360\text{kg}}}$$

$$\text{Volume of cement} = \text{weight of cement} / \text{specific gravity of cement} * 1000\text{kg/m}^3$$

$$V_c = 360\text{kg} / 3.15 * 1000\text{kg/m}^3 = \underline{\underline{0.11428\text{m}^3}}$$

Step 6. Estimation of coarse aggregate content

Table B:5. Fine Aggregate Fineness Modulus

Nominal Maximum Aggregate Size	Fine Aggregate Fineness Modulus				
	2.4	2.6	2.68	2.8	3.0
9.5mm	0.50	0.48		0.46	0.44
12.5mm	0.59	0.57		0.55	0.53
19mm	0.66	0.64		0.62	0.60
25mm	0.71	0.69	0.682	0.67	0.65
37.5mm	0.75	0.73		0.71	0.69
50mm	0.78	0.76		0.74	0.72

Fineness modulus of fine aggregate is 2.63 by using interpolation for nominal maximum aggregate size 25mm hence dry rodded volume is 0.682.

$$\text{Weight of coarse aggregate} = 1594.5 \text{ kg} * 0.682 = \underline{\underline{1087.449\text{kg}}}$$

$$\text{Volume of coarse aggregate} = \text{weight of coarse aggregate} / \text{S.G} * 1000\text{kg/m}^3$$

$$V = 1087.449 / 2.75 * 1000\text{kg/m}^3 = \underline{\underline{0.395\text{m}^3}}$$

Step 7 estimation of fine aggregate

To estimate the fine aggregate let's take a unit volume of concrete 1m^3 and subtract the sum of from 1m^3 .

$$\text{Volume of fine aggregate} = 1 - (0.015 + 0.179 + 0.11428 + 0.395) = 1 - 0.70628 = \underline{\underline{0.2967\text{m}^3}}$$

$$\text{Weight of coarse aggregate} = \text{volume of fine aggregate} * \text{SG} * 1000\text{kg/m}^3$$

$$W_t = 0.2967\text{m}^3 * 2.71 * 1000\text{kg/m}^3 = \underline{\underline{804.11\text{kg}}}$$

Step 8 adjustment of the the mix ratio

There is moisture from both coarse and fine aggregate the mix should be adjusted

$$wt\ of\ CA\ (wet) = 1087.449\ kg * 1.0101 = \underline{1098.43kg}$$

$$wt\ of\ sand\ (wet) = 804.11kg * 1.018 = \underline{818.585kg}$$

again there are absorption on the aggregate so, it is mandatory to adjust water supplied to the concrete

$$water\ from\ CA = 1087.449\ kg * (0.0101 - 0.0141) = -4.349kg$$

$$water\ from\ sand = 804.11kg * (0.018 - 0.0348) = -13.51kg$$

$$Therefore\ the\ weight\ of\ water = 179kg + 4.349kg + 13.51kg = \underline{196.98kg}$$

The final batch weight for 1m³ c-25 concrete:

Table B:6. The final batch weight for 1m³ c-25 concrete

No	Mix ingredients	Weight (kg)
1	Water	197.00
2	Cement	360.00
3	Coarse aggregate	1098.43
4	Fine aggregate	818.58

Appendix.C: Compressive Strength Result For Both Control Mix And Sulfate Attack

Table C:1. Compressive Strength Result For Both Control Mix And Sulfate Attack

3rd-day experiment result										
Percentage of replacement	Sample 1			Sample 2			Sample 3			Avg C strength (Mpa)
	Weight (kg)	C.load (KN)	stress (Mpa)	Weight (kg)	C .load (KN)	stress (Mpa)	Weight (kg)	C. load (KN)	Stress (Mpa)	
Con mix	8.71	394.65	17.54	8.78	391.95	17.42	8.73	383.4	17.04	17.3
5% WHA	8.84	383.62	17.05	8.98	432.00	19.2	8.98	418.95	18.62	18.29
10% WHA	8.13	453.60	20.16	8.93	454.95	20.22	8.87	433.12	19.25	19.87
15% WHA	8.76	370.37	16.45	8.79	360.2	16.01	8.85	364.5	16.20	16.2
Compressive strength in 5% Na₂SO₄ Solution										
Con mix in sulfate so/n	8.86	427.05	18.98	8.88	404.10	17.96	8.89	426.37	18.95	16.1
5% in Sulfate so/n	8.75	398.30	17.7	8.75	407.20	18.1	8.79	409.35	18.2	18.0
10% in Sulfate so/n	8.82	390.15	17.34	8.82	395.55	17.58	8.78	373.50	16.60	17.1
15% WHA in Sulfate	8.81	346.50	15.40	8.84	340.15	15.12	8.82	335.3	14.90	15.18
7th-day experiment result										
Percentage of replacement	Sample 1			Sample 2			Sample 3			Average C strength (Mpa)
	Weight (kg)	C. load KN	stress (Mpa)	Weight (kg)	C. load KN	Stress (Mpa)	Weight (kg)	C.load KN	Stress (Mpa)	
Con mix	8.56	606.15	26.94	8.24	579.15	25.74	8.95	582.53	25.89	26.2
5% WHA	9.26	620.10	27.56	8.62	635.17	28.23	8.86	618.30	27.48	27.76
10% WHA	8.68	670.50	29.80	9.21	647.10	28.76	9.02	655.5	29.58	29.38
15% WHA	9.15	572.6	25.43	8.46	593.55	26.38	8.26	544.0	24.2	25.2
Compressive strength in 5% Na₂SO₄ Solution										
Con mix in	8.75	562.45	25.02	9.02	569.70	25.32	8.45	580.45	25.84	25.6

sulfate so/n										
5% in sulfate so/n	9.13	610.0	27.07	8.52	588.15	26.14	8.56	566.63	25.19	27.30
10% in sulfate so/n	8.64	594.00	26.40	8.74	572.17	25.43	8.72	603.45	26.82	26.23
15% in Sulfate so/n	9.24	551.30	24.51	90.6	563.17	25.03	9.04	540.37	24.02	24.50
28th-day experimental result										
Percentage of replacement	Sample 1			Sample 2			Sample 3			Average C strength (Mpa)
	Weight (kg)	C load KN	Stress (Mpa)	Weight (kg)	C load KN	Stress (Mpa)	Weight (kg)	C load KN	Stress (Mpa)	
Con mix	8.81	746.7	33.19	8.94	735.70	32.70	8.87	752.60	33.54	33.1
5% WHA	9.00	747.6	33.23	8.64	799.8	35.94	8.65	769.3	34.19	34.5
10% WHA	8.79	815.62	36.25	8.83	798.74	35.50	8.82	798.26	35.48	35.74
15% WHA	9.09	755.54	33.58	8.99	742.20	32.99	8.91	757.00	33.64	32.0
Compressive strength in 5% Na₂SO₄ Solution										
Con mix in sulfate so/n	9.08	738.90	32.84	8.91	715.30	31.79	8.98	682.20	30.32	31.6
5% in Sulfate so/n	9.12	756.90	33.64	8.71	786.60	34.96	8.78	735.30	32.86	33.80
10% in sulfate so/n	8.96	740.20	32.91	8.84	751.51	33.40	8.97	732.59	32.56	32.90
15% in sulfate so/n	8.79	698.5	31.04	8.87	677.7	30.12	8.85	684.5	30.42	30.50
56th-day experimental result										
Percentage of replacement	Sample 1			Sample 2			Sample 3			Avg strength (Mpa)
	Weight (kg)	C load KN	stress (Mpa)	Weight (kg)	C load KN	Stress (Mpa)	Weight (kg)	C load KN	stress (Mpa)	

Con mix	8.75	801	35.6	8.80	783	34.8	8.89	794.2	35.3	35.2
5%WHA	8.80	848.2	37.7	8.40	843.5	37.5	8.86	859.5	38.2	37.8
10% WHA	8.85	931.5	41.4	8.96	964	42.8	8.89	893.4	39.7	41.3
15% WHA	8.87	778.5	34.6	8.82	725	32.5	8.68	787.5	35.0	34.0
Compressive strength in 5% Na₂SO₄ Solution										
Con mix in sulfate so/n	8.77	756	33.6	9.04	767.2	34.1	8.91	787.5	35.0	34.2
5% in Sulfate so/n	8.74	830.2	36.9	8.56	846.0	37.6	8.36	803.2	35.7	36.7
10% in sulfate so/n	8.89	819.0	36.4	8.87	792.0	35.2	8.79	776.2	34.5	35.4
15% in sulfate so/n	8.69	750	33.3	8.89	830	36.9	8.89	666	29.6	33.2
91st day experimental result										
Percentage of replacement	Sample 1			Sample 2			Sample 3			Average C strength
	Weight (kg)	C load KN	Stres (Mpa)	Weight (kg)	C load KN	Stress (Mpa)	Weight (kg)	C load KN	stress	
Con mix	8.79	963.1	42.8	8.68	965.2	42.9	8.25	928.3	41.7	42.5
5% WHA	9.64	1012.5	45.0	9.97	1032.7	45.9	9.72	1003.5	44.6	45.2
10% WHA	9.86	1075.5	47.8	9.87	1071.0	47.6	8.98	1077.7	46.9	47.5
15% WHA	8.57	945.0	42.0	8.63	931.5	41.4	8.64	904.5	40.2	41.2
Compressive strength in 5% Na₂SO₄ Solution										
Con mix in sulfate so/n	8.35	931.5	41.4	8.62	956.2	42.5	8.19	904.5	40.2	41.4
5% in Sulfate so/n	9.74	1001.2	44.5	9.86	1019.2	45.3	8.72	972	43.2	44.3
10% in sulfate so/n	8.57	979.0	43.5	8.54	967.5	43.0	9.23	1003.5	44.6	43.7
15% in sulfate so/n	8.79	897.8	39.9	8.86	895.5	39.8	8.95	915.8	40.7	40.1

Appendix D: Water Absorption Test Result

Water absorption test of concrete

$W1$ = Oven dry weight

$W2$ = saturated weight

WA = Water absorption

$$WA(\%) = \frac{W2 - W1}{W1} \times 100$$

Table D:1. Water absorption of concrete with respect to curing days

Days	Ratio	W1 (gm)	W2 (gm)	Absorption in %	Average WA (%)
7 th	0% Cot mix	8265	8909	7.79	7.48
		8259	8916	7.95	
		8270	8825	6.71	
	5%WHA + 95%C	8245	8812	6.88	7.32
		8179	8862	8.35	
		8275	8832	6.73	
	10%WHA +90%C	8149	8735	7.19	7.18
		8162	8732	6.98	
		8126	8714	7.38	
	15%WHA +85%C	8172	8728	6.80	6.75
		8156	8716	6.86	
		8168	8708	6.61	
	28 th day				
28 th	0% Cot mix	8382	8750	4.39	4.50
		8437	8820	4.54	
		8562	8954	4.57	
	5%WHA + 95%C	8523	8827	3.56	3.77
		8633	8953	3.71	
		8627	8972	3.99	
	10%WHA +90%C	8357	8663	3.66	3.62
		8574	8838	3.08	
		8380	8726	4.13	
	15%WHA +85%C	8398	8703	3.63	3.56
		8477	8789	3.68	
		8327	8608	3.37	

APPENDIX E: Microstructural Test With (FTIR) Fourier Infrared Spectroscopy

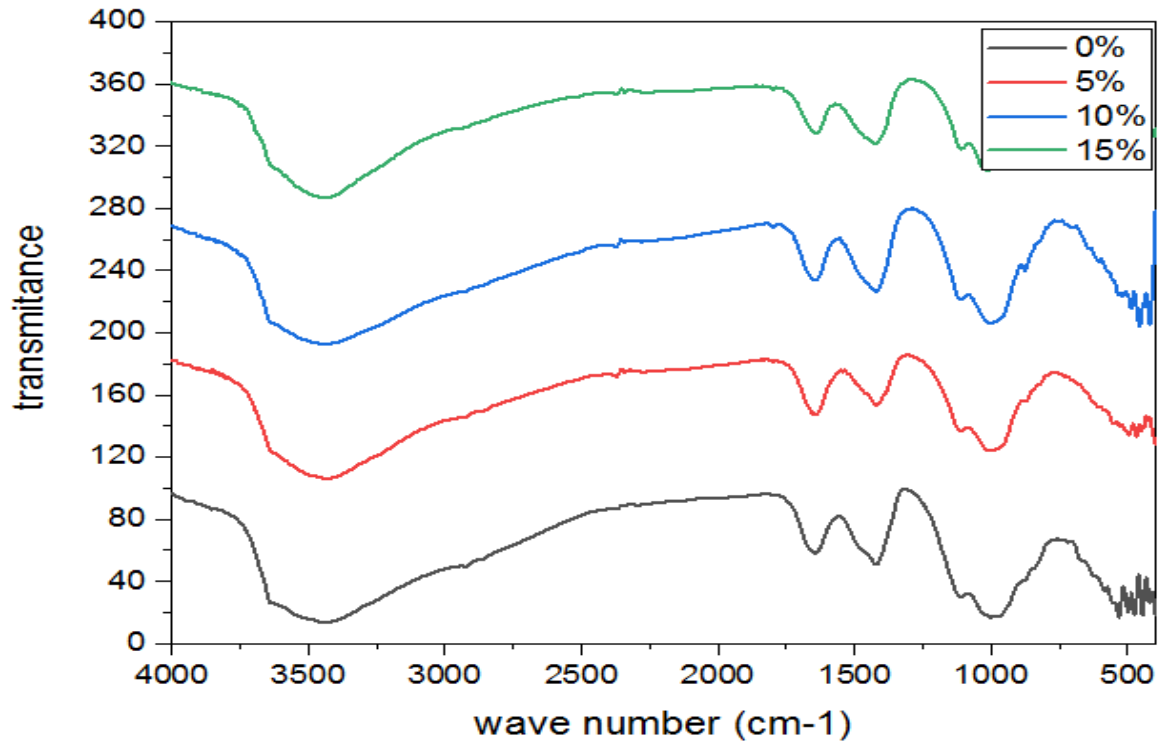


Figure E:1. Infrared spectroscopy of concrete cement paste with water hyacinth ash for 7th day

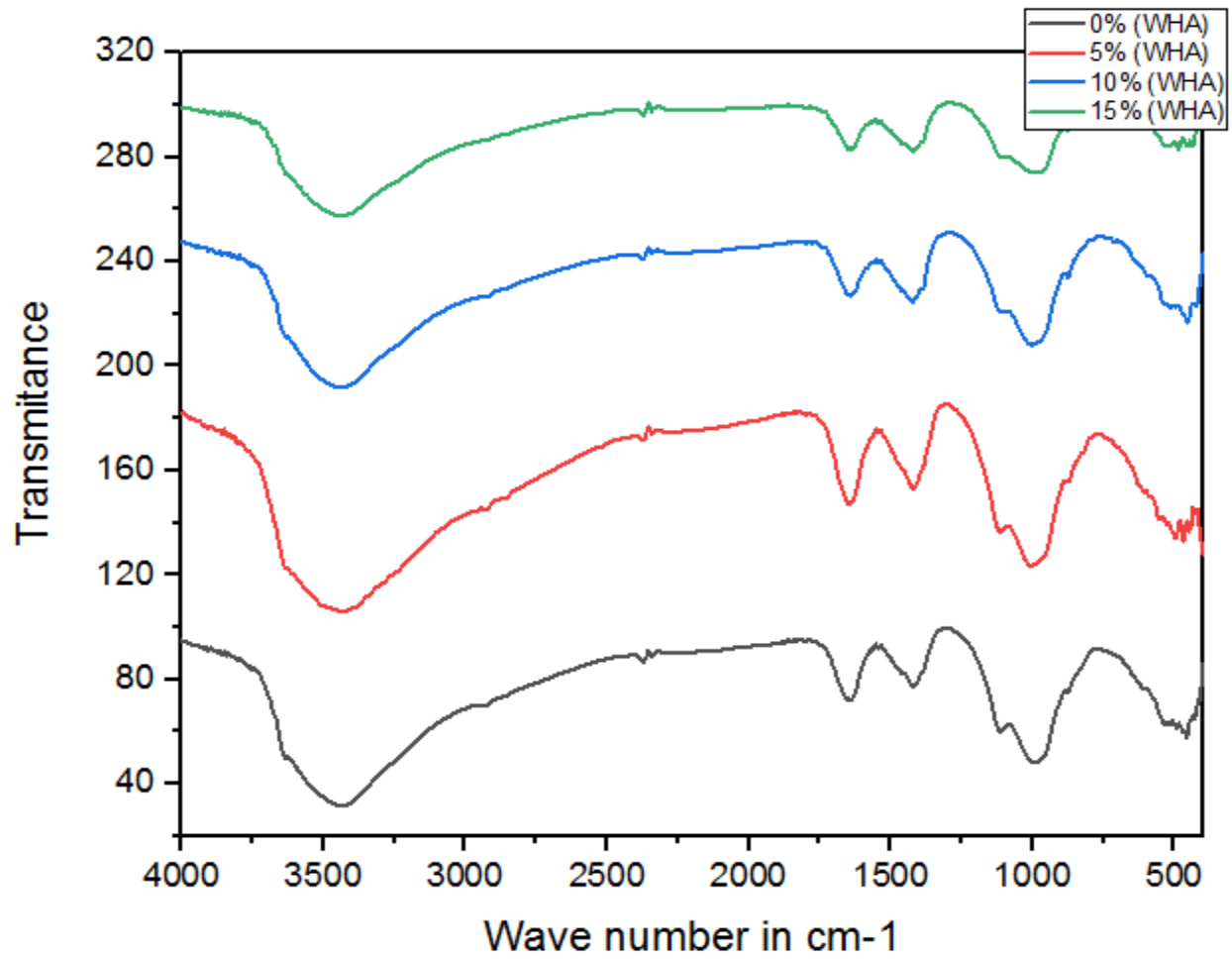


Figure E:2. Infrared spectroscopy of concrete cement paste with water hyacinth ash for 28th day

Appendix F: Statistical Analysis With SpSS

Univariate Analysis of Variance

Table F:1 Statistical Analysis With SpSS

		N
WHA	0%(OPC)	12
	10% WHA	12
	15% WHA	12
	5% WHA	12
Age	3	15
	7	15
	28	15
	56	15

Table F:2. Estimating the mean and standard divation

strength * percentage replacement

strength

percentage replacement	Mean	Std. Deviation	Minimum	Maximum
0%WHA	28.4750	7.59007	18.80	35.20
5%WHA	29.7500	8.06329	19.40	37.80
10%WHA	31.2750	9.32036	19.80	41.30
15%WHA	28.6000	7.22265	18.70	34.50
Total	29.5250	7.32698	18.70	41.30

Lower bound and upper bound

Descriptives

Table F:3.Lower and upper bound of dependant variables

strength

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
3.00	4	18.0000	1.34907	.67454	15.8533	20.1467	16.70	19.80
7.00	4	27.1000	1.79072	.89536	24.2506	29.9494	25.20	29.30
28.00	4	33.8250	1.61529	.80765	31.2547	36.3953	32.00	35.70
56.00	4	37.0750	3.23252	1.61626	31.9313	42.2187	34.00	41.30

Table F:4. Frequency distribution of percentage replacement

percentage replacement					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0% (OPC)	4	25.0	25.0	25.0
	10% WHA	4	25.0	25.0	50.0
	15% WHA	4	25.0	25.0	75.0
	5% WHA	4	25.0	25.0	100.0
	Total	16	100.0	100.0	

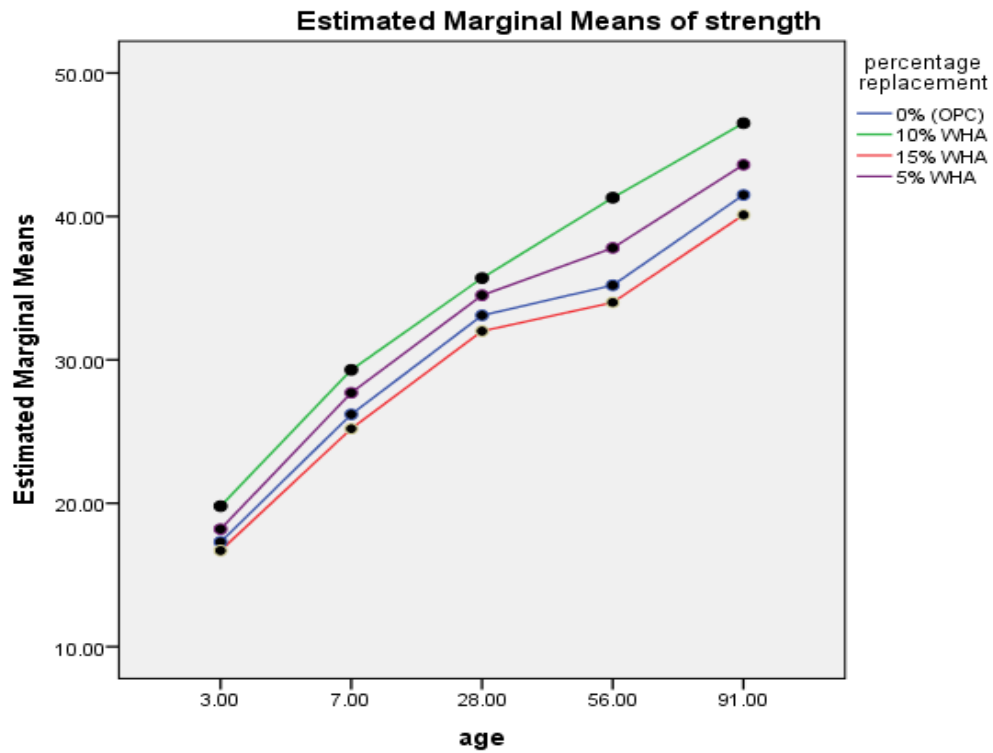


Figure F:1 Estimated mariginal means of strength

Table F:5.Tests between subject effects

Tests of Between-Subjects Effects

Dependent Variable: strength

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	770.947 ^a	4	192.737	61.769	.000	.957
Intercept	4885.586	1	4885.586	1565.756	.000	.993
PR	.722	1	.722	.231	.640	.021
age	770.225	3	256.742	82.282	.000	.957
Error	34.323	11	3.120			
Total	14752.880	16				
Corrected Total	805.270	15				

a. R Squared = .957 (Adjusted R Squared = .942)

Table F:6. Post hoc test

Post hoc test

Multiple Comparisons							
	(I) WHA	(J) WHA	Mean Differenc e (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	0% (OPC)	10%WHA	-4.1200	0.57	0.035	-24.6295	16.3895
		15%WHA	1.0000	0.57	0.892	-19.5095	21.5095
		5%WHA	-1.9200*	0.57	0.021	-22.4295	18.5895
	10% WHA	0%(OPC)	4.1200	0.57	0.023	-16.3895	24.6295
		15%WHA	5.1200	0.57	0.056	-15.3895	25.6295
		5% WHA	2.2000	0.57	0.025	-15.3895	22.7095
	15% WHA	0% (OPC)	-1.0000	0.57	0.142	-21.5095	19.5095
		10%WHA	-5.1200*	0.57	0.450	-25.6295	15.3895
		5%WHA	-2.9200	0.57	0.015	-23.4295	17.5895
	5% WHA	0%(OPC)	1.9200	0.57	0.026	-18.5895	22.4295
		10%WHA	-2.2000*	0.57	0.042	-22.7095	18.3095
		15%WHA	2.9200	0.57	0.016	-17.5895	23.4295
LSD	0% (OPC)	10%WHA	-4.1200*	0.57	0.024	-19.3168	11.0768
		15%WHA	1.0000	0.57	0.013	-14.1968	16.1968
		5%WHA	-1.9200	0.57	0.028	-17.1168	13.2768
	10% WHA	0%(OPC)	4.1200	0.57	0.039	-11.0768	19.3168
		15%WHA	5.1200	0.57	0.063	-10.0768	20.3168
		5% WHA	2.2000	0.57	0.426	-12.9968	17.3968
	15% WHA	0% (OPC)	-1.0000	0.57	0.057	-16.1968	14.1968
		10%WHA	-5.1200*	0.57	0.006	-20.3168	10.0768
		5%WHA	-2.9200	0.57	0.014	-18.1168	12.2768
	5% WHA	0%(OPC)	1.9200	0.57	0.009	-13.2768	17.1168
		10%WHA	-2.2000*	0.57	0.089	-17.3968	12.9968
		15%WHA	2.9200	0.57	0.006	-12.2768	18.1168

Table F:7 Confidence intervals for grand mean

Grand Mean

Dependent Variable: strength

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
32.860 ^a	.824	31.104	34.616

- a. Covariates appearing in the model are evaluated at the following values: age =37.0000.

Table F:8 Univariate test**Univariate Tests**

Dependent Variable: strength

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Content. Parameter	Observed Power
Contrast	76.552	3	25.517	1.879	.176	.273	5.638	.389
Error	203.674	15	13.578					

The F tests the effect of percentage replacement. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

- a. Computed using alpha = .05

Pairwise Comparisons**Table F:9 Pairwise comparisons for dependant variable**

Dependent Variable: strength

(I) percentage replacement	(J) percentage replacement	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
					Lower Bound	Upper Bound
0% (OPC)	10% WHA	-4.120	.576	.097	-9.087	.847
	15% WHA	1.000	.576	.674	-3.967	5.967
	5% WHA	-1.920	.576	.423	-6.887	3.047
10% WHA	0% (OPC)	4.120	.576	.097	-.847	9.087
	15% WHA	5.120 [*]	.576	.044	.153	10.087
	5% WHA	2.200	.576	.360	-2.767	7.167
15% WHA	0% (OPC)	-1.000	.576	.674	-5.967	3.967
	10% WHA	-5.120 [*]	.576	.044	-10.087	-.153
	5% WHA	-2.920	.576	.229	-7.887	2.047
5% WHA	0% (OPC)	1.920	.576	.423	-3.047	6.887

10% WHA	-2.200	.576	.360	-7.167	2.767
15% WHA	2.920	.576	.229	-2.047	7.887

Based on estimated marginal means

*, The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Appendix. G: Selected Photos









Samsung Dual Camera
Shot with my Galaxy M20



Samsung Dual Camera
Shot with my Galaxy M20



Samsung Dual Camera
Shot with my Galaxy M20



Figure G:1 Selected photos