ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

# PRODUCTION OF HEAVYWEIGHT CONCRETE FOR RADIATION SHIELDING

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**A Thesis in Construction Technology and Management**

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Addis Ababa

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Production of Heavyweight Concrete for Radiation Shielding**' presented by **SAMSON TESFAYE**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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## UNDERTAKING

I certify that research work titled "Production of Heavyweight Concrete for Radiation Shielding" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Samson Tesfaye

## ABSTRACT

The aim of this research is to produce a heavyweight concrete which could be used to shield photon radiation. Coupled with the production of heavyweight concrete, a case study is also conducted to assess the materials as well as the methodology employed for the construction of radiotherapy rooms of two health institutions in Addis Ababa city. To meet the research objectives two research methodologies are employed; experimental method and a case study.

In the case of the experimental method, the shielding capacity is achieved by incorporating a denser aggregate into the concrete mixture. The concrete is prepared by partially substituting basalt aggregate with hematite ore. Five concrete mixtures with varying content of hematite aggregate per total volume of coarse aggregate (0%, 25%, 50%, 75% and 100%) are produced in the laboratory. After the mixtures are prepared, fresh and hardened concrete properties of the respective mixtures is assessed. For the compressive strength test, concrete cubes of 150 mm sides are molded and samples with 200*200 mm sides and thickness (D) 100mm are prepared for the radiation attenuation tests.

The results of the experiments showed that the slump and density increase with an increase in percentage of hematite in the concrete mix. An average maximum hardened concrete density of 3.29 $gm/cm^3$ is obtained for concrete samples with 100% hematite content. The compressive strength also increased with an increase in the percentage of hematite content up to 50% hematite replacement. It is observed that replacement of hematite with excess of 50% gradually decreases the compressive strength. A maximum compressive strength of 38.28 MPa is achieved at 50% replacement of basalt aggregate with hematite ore.

The photon radiation shielding property of the concrete samples is evaluated using two separate experiments. In the first experiment Cesium-137 was used as a gamma radiation source and radiation survey meter was used to measure the intensity of radiation passing through the shield/absorber. In the second experiment Cobalt-60 is used as a radiation source and a combination of ionization chamber and an electrometer is used to measure the dose. The radiation shielding property of the concrete samples showed an increase with an increase in hematite content. For a Cesium-137 source with a radiation intensity of 0.64

μSv/hr at 1 m in straight line, the linear attenuation coefficient of the samples increased from 0.023 $\frac{1}{cm}$ for normal concrete with no hematite to 0.127 $\frac{1}{cm}$ for concrete with 100% hematite coarse aggregate. For Cobalt-60 with energy 1.25 MeV, the linear attenuation coefficient of the samples increased from 0.135 $\frac{1}{cm}$ for normal concrete with no hematite to 0.196 $\frac{1}{cm}$ for a concrete with 100% hematite coarse aggregate.

The second method employed is case study. According to the case study three major types of construction materials are used for the construction of radiotherapy rooms at the Saint Paul Oncology Excellence. A reinforced concrete with quality C-30 is used for slabs and walls, earth/ embankment at either side of the radiotherapy center is used to reduce the level of radiation energy and boronated-lead is used to construct the radiotherapy doors. On the other hand, Yehuleshet Referral Hospital radiotherapy room is constructed out of normal concrete with varying thickness. The concrete used is a ready mixed concrete with C-40 grade.

Generally, heavyweight concrete which is made of hematite is found to be good for gamma radiation shielding purpose. The radiation shielding property is also achieved without sabotaging other essential concrete properties like slump and compressive strength.

**KEY WORDS:** Heavyweight concrete, hematite ore, basalt aggregate, slump, density, compressive strength, radiotherapy, radiation shielding, linear attenuation coefficient, radiation survey meter, ionization chamber, electrometer, Cesium-127, Cobalt-60, boronated-lead.

## DEDICATION

I dedicated this research to my loving family most of all. Tesfu, Tsehity, Hawi, Leo, Meka, Hansi and Dagi you are a gift from heaven.

This research is also dedicated to the two times Nobel Prize winner Madam Marie Curie who discovered Polonium and Radium, and also explained the process of Radioactivity.

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## LIST OF ABBREVATIONS

AAiT-Addis Ababa Institute of Technology

AAS Method-Atomic Absorption Method

ACI-American Concrete Institute

ACS- American Cancer Society

ASTM-American Society for Testing and Measurement

CNSC-Canadian Nuclear Safety Commission

EPA-Environmental Protection Agency

ERPA-Ethiopian Radiation Protection Agency

$(fcu)_t$-t day Compressive Strength

$(fcu)_{28}$-28th day Compressive Strength

HF Attack-Hydrofluoric Attack

IAEA-International Atomic Energy Agency

LINAC-Linear Accelerator

MoH-Ministry of Health

NCRP-National Council on Radiation Protection

PLC-Private Limited Company

SANRAD-South African Neutron Radiography facility

SPHMMC-Saint Paul Hospital Millennium Medical Center

UNSCEAR-United Nations Scientific Committee on the Effects of Atomic Radiation

# CHAPTER 1 INTRODUCTION

## 1.1. Research Background

Radiation is a transfer of energy from one point to another throughout space. There are different sources of radiation. Sound energy, visible light, radio waves, x-rays and gamma rays are some of the various forms of radiation (Bushong, 2017).

Radiation energy is used in different sectors of industry in modern civilization. The health sector, commercial sector, and defense sectors are some of the major industries that are known to utilize radiation energy. Ionization radiation, the most common form of radiation, is used in health institutions for various purposes. According to Podgorsak, (2010) the primary use of ionization radiation in medicine is for: imaging, treatment of cancer, blood irradiation and sterilization of single use medical devices. There is no argument whether ionization radiations are essential or not in medicine. Ionization radiations are vital part of contemporary medicine. But with the benefits, there comes a price to be paid.

Besides the numerous benefits that come from the application of radiation technology, sometimes accidents occur in the process of attaining and use of radioactive source. The dangerous radiations emanated from radioactive sources can affect the human body, on occasions causing lethal damages (Turner, 2007). Radiation seriously affects health predominantly through the breaking of deoxyribonucleic acid (DNA) molecules (Canadian Nuclear Safety Commission (CNSC), 2012). Hence radiation shielding is a vital area of science applied to prevent the leakage and exposure of harmful radiation to the surrounding environment. The fundamental nature of the shielding is to attenuate or shield the harmful and unwanted rays from exposure to users who work with them or close to their sources.

The purpose of radiation shielding is to reduce the effective equivalent dose from a linear accelerator to a point outside the room to a sufficiently low level (Biggs, 2010). To these end, engineers, physicists, and scientists are engaged in a continuous researches to control and reduce the level of radiation exposure from ionizing radiation sources.

Different kinds of materials are used for radiation shielding in the modern society. The most effective material known so far is lead. Even though lead provides better shielding; it is relatively expensive, needs structural support, and is difficult to work with. Therefore, Engineers usually resort to using concrete for radiation shielding purposes because of its relative cheapness and ease of construction (Kudchadker, 2017).

The objective of this research work is to produce a heavyweight concrete which is able to attenuate/shield Photon radiation. The study is conducted by substituting ordinary basalt aggregate by hematite ore to increase the unit weight of the concrete. After the concrete is prepared various experiments are conducted to assess the engineering properties and shielding capacity.

## 1.2.Statement of the Problem

Currently, cancer has become the major health problem in Ethiopia with steady increase of mortality rate each year. However, the cancer treatment centers are not sufficient in number and equipments to support the growing burden. Ethiopian Ministry of Health (MoH) has started the construction of six specialized healthcare centers for cancer related patients. The six specialized centers are planned to provide specialized healthcare treatment for cancer related patients in Oromia, Amhara, Tigray and SNNP regional states. Almost all of the radiotherapy rooms are constructed using ordinary concrete. The traditionally used ordinary concrete requires considerable thickness in the range of 1.5-3 m to attenuate radiation from high energy radioactive sources.

Globally, a variety of alternative construction materials are being used for shielding radiation energy. Radiotherapy rooms are constructed using lead, steel, ordinary concrete, earth, wood, and polystyrene. All these materials have pros and cons. Lead plates cost more in comparison to other shielding materials, are relatively neutron transparent, and require supporting structure. Normal concretes which occupy larger space are also problems for health institutions with limited space. The walls, especially the primary barriers, take up large portion of the building space. In urban areas where this health institutions are locate a limitation of free space exists (NCRP, 2005).

Heavyweight concrete eliminates most of the above stated shortcomings of radiation shielding materials. Therefore, understanding of the design, construction, and property of heavyweight concretes is vital.

Nevertheless, heavyweight concrete such as hematite concrete are not used widely in the construction industry. The lack of comprehensive scientific studies on to the various types of heavyweight concretes is one of the reasons for the underutilization of the materials. The correction between hematite content and radiation shielding capability of concrete is not clearly understood by designers and construction professionals.

Most of the researches conducted on radiation shielding of heavyweight concrete are not holistic. One of the problems is the partial assessment of concrete properties and the neglect of radiation shielding tests. A study performed by Singh and Ramana (2014) found that it is possible to produce heavyweight concrete using hematite aggregate without affecting much of the compressive strength. However, the researchers replaced only 25% and 50% of the coarse aggregate, leaving a gap about the partial replacement of more than 50% aggregate unanswered. The research was also unable to assess important properties of heavyweight concrete such as: slump and shielding capability. Vidhya and Kumar (2015) also studied high density concrete incorporating hematite. Nevertheless, the research did not explain radiation shielding of the heavyweight concrete. Additionally, Gencel et al., (2010) studied concretes containing hematite for use in radiation shielding. However, the research did not cover the shielding investigations.

The other gap is the lack of knowledge about the properties of Hematite ore in Ethiopia. Iron occurrences are identified in many parts of Ethiopia. However, a detailed investigation on the physical and chemical properties is not conducted. No prior research is conducted locally to assess the utilization of hematite and other heavyweight aggregates in the production of high density concrete.

Considering the above views, two major questions may arise. First, do we know the relationship between the amount of hematite and shielding capacity of concrete? Secondly, do we really understand the correlation between hematite content and the essential properties of concrete? This research is conducted to produce a heavyweight concrete by partial replacement of basalt coarse aggregate with hematite ore and investigate radiation shielding as well as the important concrete properties.

## 1.3.Research Questions

**RQ1:** What are the physical and chemical properties of Sekota/Tsemera hematite ore?

**RQ2:** Is it possible to produce heavyweight concrete out of hematite ore?

**RQ3:** What is the relationship between hematite content and radiation shielding capacity of concrete?

**RQ4:** What is the relationship between hematite content and engineering properties of concrete?

**RQ5:** What is the optimum amount of hematite ore to produce concrete with better radiation shielding capability?

**RQ6:** Which is better shield for photon radiation; normal concrete or heavyweight concrete?

**RQ7:** Does the design and construction of Saint Paul Oncology Excellence Center and Yehulashet Hospital Radiotherapy Centers comply with NCRP 151 (Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities)?

## 1.4.Objective of the Study

### 1.4.1. General Objectives

The general objective of the research is to produce a heavyweight concrete to be used for shielding Photon radiations.

### 1.4.2. Specific Objectives

- Assess the physical and chemical properties of hematite ore obtained from Sekota/Tsemera hematite ore.
- Identify the correlation between content of hematite aggregate and important properties of concrete.
- Identify the correlation between content of hematite aggregate and radiation shielding property of concrete.
- Find the optimum amount of hematite ore aggregate to be used as a substitute of basalt aggregate to produce the best quality radiation shielding concrete.
- Evaluate the compliance of the design and construction of Saint Paul Oncology Excellence Center and Yehulashet Hospital Radiotherapy Centers according to NCRP 151 recommendations.

### 1.5.Significance of the Study

On a theoretical level, the intended importance of the study is to advance knowledge in the field of radiation shielding. The results of the study helps to extend what has been known about the use of hematite ore as a replacement of basalt aggregate to produce radiation shielding heavyweight concrete. As a result, the study conducted by this research can provide a detailed contribution in the area of Radiation Shielding. The study also serves as a stepping stone for further research and studies in the future. The research can be used by researchers from Medical Physics, Civil Engineering, Physics, geology, and Nuclear energy fields.

On a practical level, the research helps to solve the problem of radiation shielding by producing an innovative concrete technology. The research results can be used by construction practitioners such as Architects, and Engineers for designing and construction of radiotherapy rooms. The radiotherapy room walls which are constructed out of this technology are thinner in width. For this reason an additional space which otherwise could be occupied by the walls of normal concrete could be saved. This makes it easy to use the space for other purposes. The benefit of the research goes beyond providing safe working environment for health institution employees. Industries which are known to use X-rays and gamma radiation in manufacturing can also use hematite ore concrete to shield employees from exposure.

A third intended outcome of the study is to clarify research techniques employed for investigating radiation shielding capability of concrete. Specifically, the research clearly refines gamma radiation shielding investigative techniques.

### 1.6.Limitation of the Study

The study is concerned with producing a radiation shielding concrete by using hematite mineral ore. Apparently Ethiopia is endowed with the mineral ore of hematite. Most of the iron deposits in Ethiopia are relatively unexplored. Sekota/Tsemera which is located in Northern Amhara region has a huge potential for hematite and other mineral ores, however, the deposits are not investigated thoroughly. The quantity and the engineering properties of the hematite are not studied. Additionally, the mining operation of the deposit is not underway so the hematite samples obtained are acquired by excavating about 50 cm below the ground level. Deep excavation which would procure better hematite ore is not possible due to budget and time constrains.

On the other hand, Ethiopian research institutions are in their infant stage and there is very limited expert and prior studies conducted about the research topic. Therefore, the research literatures reviewed for this study are from researches conducted in foreign nations.

The research is also limited to shielding gamma radiation; X-rays and neutron radiations which are also other types of photon radiation are out of the scope of this research.

## 1.7.Scope of the Study

For the research to be as detailed as possible and to be finalized timely, it is highly required to limit the areas it covers. The research covers the following areas:

- Experimental investigation on the major physical and chemical properties of hematite aggregate.
- Production of heavyweight concrete samples using hematite aggregate as a partial substitute of basalt aggregate.
- Experimental investigation on the shielding capability of the heavyweight concrete and normal concrete. The radiation shielding experiment is conducted only for gamma radiation.
- Experimental investigation on the fresh and hardened concrete properties. The slump, density and compressive strength of the heavyweight concrete and normal concrete are assessed.
- A case study to investigate the design and construction of Saint Paul Oncology Excellence Center and Yehulashet Hospital Radiotherapy Centers.
- Assessment of the compliance level of design and construction of Saint Paul Oncology Excellence Center and Yehulashet Hospital Radiotherapy Centers with NCRP 151.

## 1.8.Brief Overview of the Research Methodology and Flowchart of Research Methodology

### 1.8.1. Research Methodology for the Case Study

The following methodology is chosen to conduct the case study for the evaluation of the design and construction of two radiotherapy centers in Addis Ababa.

#### *1.8.1.1.Study of Contractual Documents*

Contract documents such as drawings and technical specifications for the radiotherapy facilities are obtained from the contractors and consultants. The designs and specifications are studied in detail to get a detailed understanding of the design of the facilities. The dimensions of the primary and secondary barrier, materials used for construction and the location of treatment rooms relative to other rooms are studied.

#### *1.8.1.2.Onsite Observation of the Facilities*

Critical onsite observations are conducted to assess the overall construction methodology employed for the radiotherapy facilities. Special attention is given to critically examine the arrangements and dimensions of primary and secondary barriers on the radiotherapy rooms in the facilities.

#### *1.8.1.3.Comparison of the Design and Construction Process with NCRP Report No. 151*

The overall information obtained through study of design documents, onsite observation and interview is used to assess the degree of compliance with NCRP 151. NCRP Report No. 151 is an internationally accepted guide line for the structural shielding design and evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities.

### 1.8.2. Research Methodology for the Experimental Study

In order to answer the research questions and accomplish the research objectives, the following methodology is systematically implemented.

#### *1.8.2.1.Initial Activities*

Various literatures on three major topics are thoroughly reviewed. Books, journals, reports and other types of academic papers on radiation and radiotherapy, radiation shielding, and heavyweight concrete are surveyed. Then, about 300 kg of hematite ore sample is obtained from Amhara Regional State, Wag-Himra Special Zone, Sekota Woreda, Tsemera Kebele. Based on the mix design five concrete mixtures are prepared.

#### *1.8.2.2.Concrete Mix Development*

Five types of concrete mixtures are developed using different proportions of hematite and basalt aggregate. The cement and water contents are fixed for all concrete mixtures. After that, different test are conducted in order to determine the physical and chemical properties of the aggregates.

#### *1.8.2.3.Testing Concrete*

Then, four types of tests are carried out on the concrete samples produced, in order to assess whether the concrete mixtures satisfy the design requirements or not.

### 1.8.3. Flow Chart of the Research Methodology

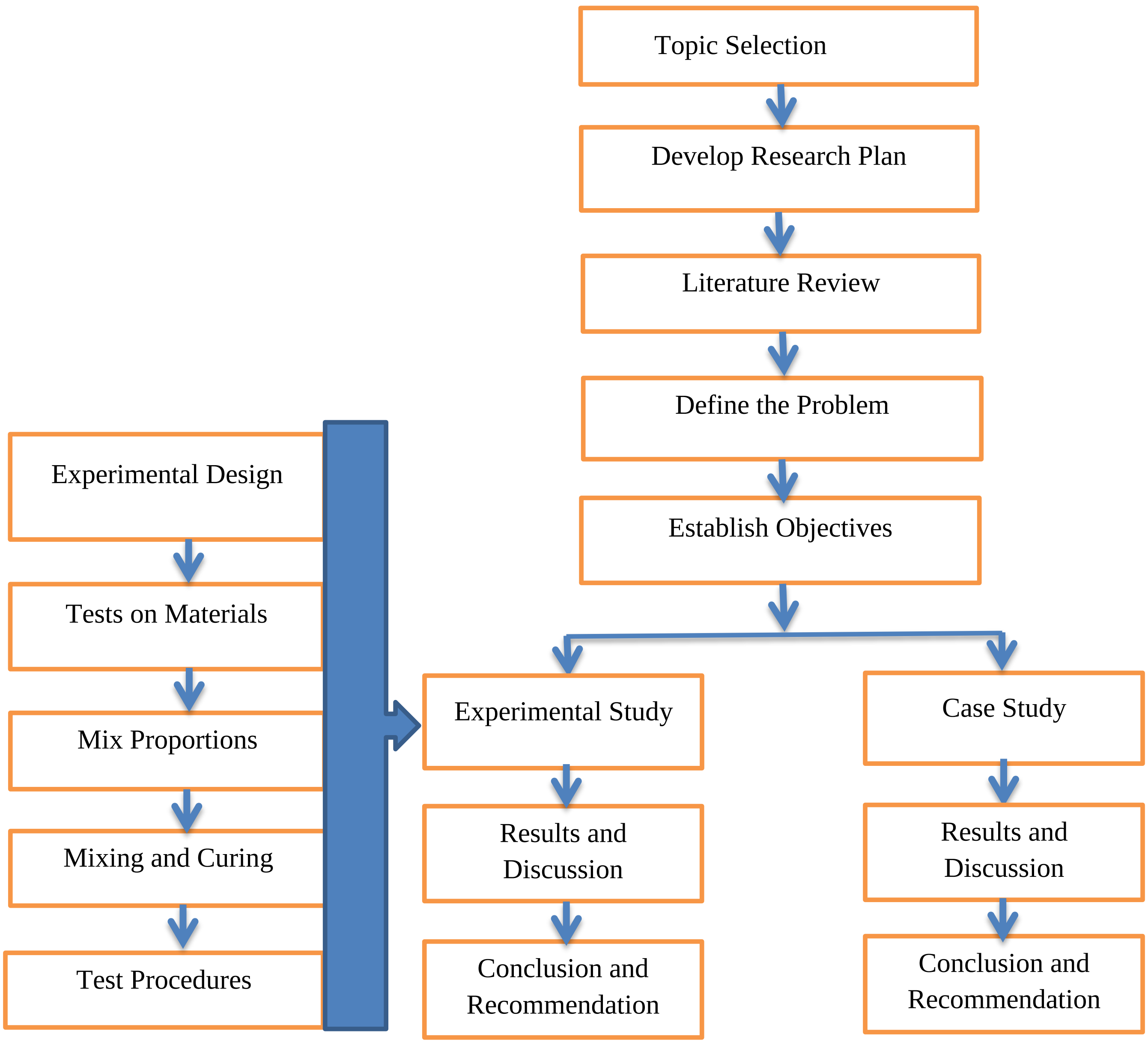



Figure 1.8.3: Flow Chart of the research methodology

### 1.9.Thesis Structure

The research paper is organized into eight chapters and dedicated sections for the reference and appendix. Chapter 1 is an introduction which gives general overview about the research, research background, purpose of the research, significance of the study, limitation of the study, scope of the study, methodology and the thesis layout. Chapter 2 presents the numerous works of researchers in the field of therapeutic radiation and radiation shielding. The chapter illuminates what it is meant by radiation, purpose and type of radiotherapy, and photon radiation shielding. Chapter 3 is dedicated to review about concrete technology, particularly heavyweight concrete. The chapter gives overview of concrete, classification of concrete, concrete making materials, mix design, concreter quality tests, and heavyweight concrete.

Chapter 4 presents the research design. It comprises of introduction, research design and approach, research design, data collection methods, analysis and presentation of data, testing of hypothesis, and generalizations. Chapter 5 is dedicated to case study for the evaluation of design and construction of two radiotherapy centers in Addis Ababa. It includes introduction, overview of radiotherapy centers, evaluation of Saint Paul hospital, evaluation of Yehuleshet Referral hospital, and compliance assessment of the two radiotherapy centers.

Chapter 6 presents the materials used for producing the heavy weight concrete mixture, physical properties of the aggregates and the blended aggregates, heavyweight concrete mixture, casting and curing process, and design of research experiments: slump, density, compressive strength test of cubic concrete specimens and gamma ray shielding test. Chapter 7 presents the outcomes of the experimental investigations and the case study. Results of the consistency, density, compressive strength, and gamma radiation attenuation tests are clearly put forward. Additionally, results from the case study are also presented systematically.

Finally**,** chapter 8 is devoted to drawing conclusions and contribution to knowledge from the experimental investigations and case study. Based on the drawn conclusions, appropriate recommendations are established.

Reference which includes the listing of references used in preparing the study and appendix which includes photos, raw data from the experimental study, sample interview question for the case study and other relevant documents are also included.

# CHAPTER 2 THEORETICAL REVIEW OF THERAPEUTIC RADIATION AND SHIELDING CONCEPTS

## 2.1.Introduction

The previous chapter presents background of the research, problem that lead to the research study, and the objective of the study. Radiations are known to provide enormous benefits to modern human civilization. However, if the radiation energy is not handled properly and appropriate shielding precautions are not implemented, radiations can cause serious harm to individuals.

The main objective of the study is producing a heavyweight concrete to be used for building radiation shielding walls in radiotherapy facilities. In order to design and develop such type of concrete, a detailed knowledge of ionization radiation and shielding concepts is paramount important.

In this chapter, therefore, radiation energy and its application in modern medicine is investigated. The chapter gives a detailed clarification of radiation and radiotherapy. Coupled with the explanation, radiation shielding design is illuminated methodically. To do this, an in-depth inquiry on the works of various researchers and authors is conducted.

Structurally, the chapter includes four sections. The first section is an introductory part. The second part includes: definition of radiation, types and sources of radiation, benefits of radiation in medicine and the biological effects of radiation. The third part briefly explains about the purpose of radiation therapy, and the types of radiotherapy. Finally, the fourth section, presents photon radiation shielding. The purpose of Radiation shielding, radiation transmission formula and the most important calculations involved in the determination of shielding capacity of concrete specimens are assessed thoroughly.

## 2.2.Definition of Radiation

EPA (2012) defines radiation as energy. It is the discharge and transference of energy throughout space. Therefore, radiation can be defined as an energy traveling throughout space. The roaming energy is originated from different sources and the source determines the inherent characteristic of the radiation. According to EPA the radiation energy can originate from two sources: naturally from unstable atoms which have an unbalanced number of neutrons and protons and artificially formed using special machines like diagnostic X-ray machines, nuclear-weapons and nuclear power production. Another very close definition comes from CNSC (2012) which describes radiation as energy in the form of waves or streams of particles. CNSC however, identifies only one source for the radiation energy. It argues that radiation energy is discharged when atoms decay giving off energy. Then, the energy moves from one point to another in the form of wave.

### 2.2.1. Classification of Radiation Energy

According to Podgorsak (2010) and EPA (2012) radiation can be classified into two major categories based on their ability to ionize matter. Consequently radiations are classified as Ionizing and non-ionizing depending on the ability to hit electrons out of their orbits and giving the atom a positive charge.

Ahmed (2007), on the other hand, categorizes radiation in three different ways: ionizing and non-ionizing, particles and waves, hazardous and non-hazardous. According to him none of the three categorizations draw a solid boundary between properties of individual particles comprising the radiation, rather they show the bulk behavior of particle beams. Based on the above literatures it is more appropriate to classify radiation energy as ionizing and non-ionizing.

#### *2.2.1.1. Ionizing Radiation*

UNSCEAR (2008) and Canadian Nuclear Safety Commission (2012) define ionizing radiation as radiations which are capable of knocking electrons out of their orbits around atoms and giving the atom a positive charge. Hence, ionizing radiation is able to ionize matter because its quantum energy exceeds the ionization potential of atoms and molecules of the absorber. On the other hand, Ahmed (2007) points out a weak-link in the definition of ionization by arguing that it is not correct to declare that an electron always ionize an atom with which it interacts. He concluded that great number of electrons interacts with a large number of atoms; the principal mode of interaction will lead to the ionization of atoms.

Bushong (2017) further classified ionizing radiation into two categories: particulate radiation and electromagnetic radiation. Based on Bushong there are two main types of particulate radiation: alpha particles, and beta particles. According to Ahmed (2007) particulate radiation originate from decaying of unstable atoms and are emitted from the nucleus of heavy elements. The alpha particle contains two protons and two neutrons whereas, beta particles are negatively charged particles that are physically identical to electrons and can penetrate more deeply than alpha particles. EPA (2012) states that alpha particles come from the decay of the heaviest radioactive elements, such as uranium, radium and polonium and Beta particles are small, fast-moving particles with a negative electrical charge that are emitted from an atom's nucleus during radioactive decay. Beta particles are more penetrating than alpha particles but are less damaging to living tissue and DNA because the ionizations they produce are more widely spaced.

Bushong (2017) categorized electromagnetic ionizing radiation into two major parts: X-rays and gamma rays. X-rays and gamma rays are often called photons. According to Bushong electromagnetic radiations are alternatively referred as Photons. Photon radiations have no mass and no charge and travel at the speed of light ($c = 3 \times 10^8$ m/s).

EPA (2012) agrees with the above definition and describes Gamma rays (γ) as weightless packets of energy called photons and X-rays are similar to gamma rays in that they are photons of pure energy. According to EPA the only difference between x-rays and gamma rays is their origin. Gamma rays are emitted from the nucleus of a radioisotope and are usually associated with alpha or beta emission. X-rays are produced outside the nucleus in the electron shells.

#### *2.2.1.2. Non-ionizing Radiation*

CNSC (2012) defines non-ionizing radiation as the category of radiations with energy lower than the ionization potential of atoms and therefore cannot ionize matter. That means the radiations are not able to knock electrons from an atom and disrupt the balance. Generally, non-ionizing radiations are not hazardous to the human body Examples of non-ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight. These radiations are characterize by low-frequency waves and are not considered to pose a health risk.

### 2.2.2. Biological Aspects of Radiation Protection

Since 1942 the biological effects of ionizing radiation to humans has been studied extensively. The abundant studies conducted both in the laboratory and among human population have shine a light on the numerous biological effects that are associated with the exposure of living organism to ionizing radiation (Merril Eisenbund and Thomas Gesell, 1997) and (CNSC, 2012).

According to University of Pittsburgh Radiation Safety Office (2008), biological effects of ionizing radiation can be classified into two broad categories: Acute effects and Delayed effects.

#### *2.2.2.1. Acute Effects*

Acute effects are caused when a huge dose of whole-body radiation is received rapidly or when the exposure is received largely in the first few days (Merril Eisenbund and Thomas Gesell, 1997). The symptoms of acute radiation injury can be seen as early as a few hours after exposure. The effects are dependent on the dose and what area of the body is exposed over what time (Turner, 2007).

Depending on the level of dose received and the condition of exposure subsequent effects can be seen on humans. Relatively minor effects such as nausea would occur at doses less than 1 Gray (Gy). Nausea occurs in increasing frequency above 1 Gy and will be seen in almost all exposures above about 3 Gy. For a dose range of 4 to 5 Gy about 50% of the exposed individuals are expected to die. When the whole-body dose approaches 10 Gy, the fatalities would reach 100%. At whole-body doses in excess of 10 Gy, the predominant symptoms may be due to injury to the gastrointestinal tract and central nervous system (Turner, 2007) and (Ahmed, 2007).

#### *2.2.2.2. Delayed Effects*

The delayed effects of radiation may not manifest for several years after the exposure. The effects can result either from enormous doses or from relatively small exposures repeated over an extended period of time (Merril Eisenbund and Thomas Gesell, 1997). Delayed radiation effects may result from previous acute, high-dose exposure or from chronic low-level exposures over a period of years (University of Pittsburgh Radiation Safety Office, 2008). Such a long development period of the disease makes it difficult to determine safe levels of dose for workers and general population (Ahmed, 2007).

The delayed effects can manifest in the exposed individual or in the offspring of the exposed individual. The effects that grow in the exposed individual are called somatic effects and the ones which appear in the offspring of the exposed person are genetic effects (Merril Eisenbund and Thomas Gesell, 1997).

Genetic effects pass on from generation to generation due to mutation of genetic material (Ahmed, 2007). Surprisingly, Ahmed states that four percent of humans inherit characteristics that result from recessive mutations due to natural factors in the environment. Many of these characteristics are minor, such as variation in eye or hair color. Other mutations can result in catastrophic effects like serious deformity, crippling disease, and premature death (Merril Eisenbund and Thomas Gesell, 1997).

The somatic effects are the ones that appear in the particular person that is exposed to radiation. The effect can become obvious immediately after the exposure or can take a long time to cause noticeable changes. Cancer, Cataract, development of abnormalities in fetus and Growth retardation are some of the common semantic effects in humans (Ahmed, 2007).

#### 2.2.3. Benefits of Photon Radiation in Medicine

American Cancer Society (2011) stated that the phenomenon of radioactivity and radiation were discovered more than 100 years ago. Since then developments in technology and superior understanding of its effects on the body have made radiotherapy an important part of cancer treatment. The document further states that, at that time, more than half of all people with cancer will get radiation at least as a part of their cancer treatment. CTRad (2012) supports the argument on the invaluable contribution of radiotherapy in cancer treatment. According to CTRad radiotherapy can cure cancer. It is provided for about half of cancer patients and is an important part of curative treatment for about 40% of patients. In modern medicine radiation energy is used for diagnosis as well as treatments of diseases.

The most common benefit of ionizing radiation is for imaging purpose. According to Lawrence et al. (2012), x-ray imaging allows physicians to identify tumors with respect to the normal anatomical structure of the patient. Because x-rays travel in straight lines until they are absorbed or scattered, they can produce images which authentically represent spatial relationships within the body. Hall and Brenner (2008) identified variety of imaging techniques such as Basic X-ray Machine, computed tomography (CT) scan, fluoroscopy, and mammography, dental X-ray, Lithotripsy Machine, and Bone Densitometry (DEXA) Machine for the diagnosis of diseases.

Shrimpton (2001) stated that in diagnostic nuclear medicine, radiopharmaceuticals are given to patients where it is administered either by injection, inhalation or ingestion. These radiopharmaceuticals emit $\gamma$ rays which are detected by Gamma camera and give a picture about the examined organ.

Rose and Williams (2012) gave a similar explanation of nuclear medicine. According to them in nuclear medicine radionuclide is attached, or labeled, to a pharmaceutical, forming a radiopharmaceutical. This is introduced into the body by intravenous injection but also by ingestion and inhalation. Then, Gamma cameras are used to detect and record the distribution of a radiopharmaceutical within the body.

The other important benefit of ionizing radiations is in radiotherapy. Radiotherapy is a medical procedure which uses different types of radiations to cure patients from cancer. According to Lawrence et al. (2008), radiotherapy uses high energy ionizing radiation to shrink tumors and kill cancer cells. For that purpose x-ray, gamma ray, and charged particles are used for cancer treatment.

Mills et al. (2012) congruently declares that variety of ionizing radiation beams are applied in radiotherapy. According to him ionizing radiation beams used range from low energy x-rays to megavoltage x-ray beams. The most notable source still being used for a gamma ray beam is cobalt-60. Peter (2012) reinforced the above reasoning by stating that the goal of treatment planning of external beam radiotherapy is to produce a dose distribution within the patient that will destroy the tumor while sparing as much healthy tissue as possible.

## 2.3.Radiotherapy/Radiation Therapy

### 2.3.1. Purpose of Radiation Therapy

According to Kildea (2010), the sole purpose of radiation therapy is to deliver a prescribed dose of radiation to tumors (malignant cells). Cancer cells are known for their capacity to divide quickly and grow out of control.

After the patient is diagnosed with a tumor, a radiation oncologist may prescribe a dose of radiation to destroy the malignancy and a suitable treatment schedule. The prescribed dose is based on medical precedence, the oncologist’s experience and the patient's condition.

Radiation, delivered through radiotherapy procedures, damages the genes (DNA). Radiation damages the genes of a cancer cell so that it cannot grow and divide any more. This means radiation can be used to kill cancer cells and shrink tumors. Radiation therapy kills cancer cells that are dividing (American Cancer Society, 2011).

### 2.3.2. Types of Radiotherapy

Kildea (2010) classified radiotherapy into three major categories based on the location of the source of radiation employed. These are: external beam radiation therapy, brachytherapy and unsealed source radiotherapy. Whereas, Taylor and Maughan (2008) classified radiotherapy into two: External Beam Radiotherapy (Traditional) and New Radiotherapy Techniques.

The first type of radiotherapy is brachytherapy. Taylor and Maughan (2008) stated that brachytherapy is the delivery of radiotherapy from a radioactive source that is put in or near the cancer. The source is a small piece of metal that when it breaks down it emits radiotherapy. There is no machine involved. Kildea (2010) correspondingly stated that in brachytherapy the source of radiation is a temporary or permanently sealed radioactive source placed directly into the region of the patient's body to be treated.

In the Unsealed source radiotherapy procedure, which is the second type of radiotherapy, the source of radiation is administered systemically by injection or ingestion (Kildea, 2010). Taylor and Maughan (2008) explained the working mechanism of unsealed radiotherapy as follows. Cancer cells take up different molecules to help them grow or develop. Molecular radiotherapy takes advantage of this by creating either a look-alike molecule that looks like the one the cancer needs or by making the actual molecule the cancer needs but radioactive.

These molecules are then injected into the patient and the cancer cells take them up. The molecules that have been taken into the cancer cells then produce radiotherapy and cause the cancer cells to die.

External beam radiotherapy is a traditional method of giving radiotherapy and still the best treatment in many cases. The patient lies on a radiotherapy bed in the same position every day for a radiotherapy treatment session. In each session, between 2-4 radiotherapy beams are given. A radiotherapy beam is switched on to deliver the beam. Then, the radiotherapy machine moves into a different position before giving the next beam from a different angle. The machine that gives the radiotherapy is called a linear accelerator or LINAC (Taylor and Maughan, 2008) and (Kildea, 2010).

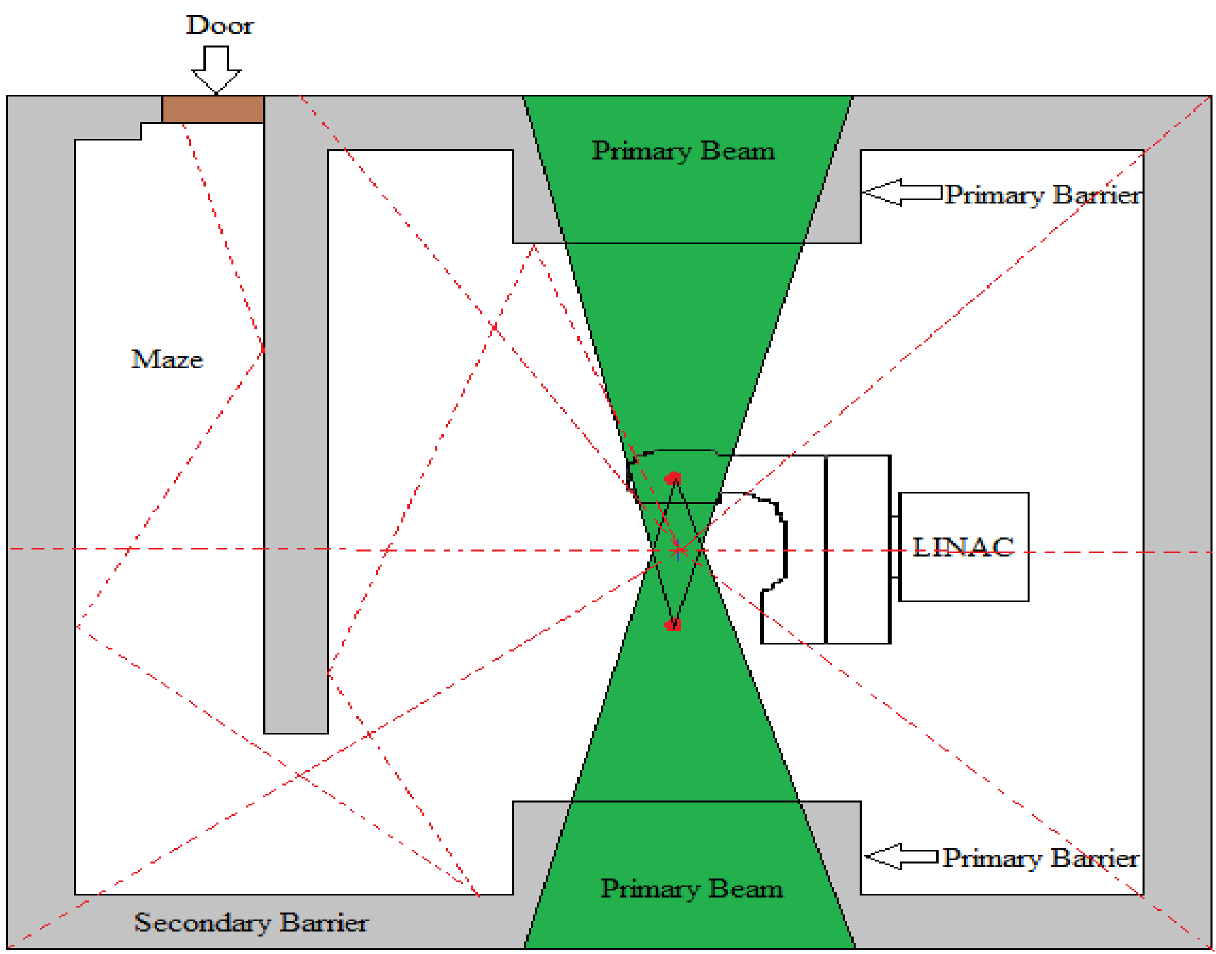



Figure 2.3.2: A Plan view showing the directions of primary beam and secondary beam, primary and secondary barrier, maze, and door (Kildea, 2010)

According to NCRP (2005) the applicable energy range for radiotherapy treatment varies from 1.25 MV to 24 MV. In radiotherapy facilities LINACs or cobalt-60 therapy units are employed and the radiation source is usually incorporated into a support that rotates in a single plane around the patient. The horizontal axis rotation is referred to as the isocenter axis. The isocenter is the volume defined by the intersection of the isocenter axis and the axes of rotation of both the patient couch and the collimator of the radiation unit, and is typically close to the center of the treatment room.

### 2.4. Photon Radiation Shielding

Gur et al. (2016) defined radiation shield as a physical barrier placed between a radiation source and the object to be protected so as to reduce the radiation level at the position of the object. Radiation shielding calculations are usually done by hand or performed by using computers.

#### 2.4.1. Purpose of Radiation Shielding

According to NCRP (2005) the purpose of radiation shielding design in medical radiotherapy installations is to limit radiation exposures to members of the public and employees to an acceptable level. Similarly, Martin (2008) state that the goal of radiation shielding design is to make sure all the exposure levels to the public and healthcare staffs are maintained below the regulatory limits.

Biggs (2014) indicated that the objective of radiation shielding is to reduce the effective equivalent dose from a linear accelerator to a point outside the room to a level that is determined by individual states. Congruently, Kudchadker (2012) identified the two goals of shielding:

(1) To limit radiation exposure of staff, patients, visitors and the public to acceptable levels

(2) To optimize protection of patients, staff and the public.

#### 2.4.2. Radiation Transmission

Demir et al. (2009) state that photons with incident intensity $I_0$, penetrating a layer of material with mass thickness x with intensity I given by the exponential attenuation law. Similarly, Martin (2013) coined that attenuation of photon radiation by different absorbing materials under narrow beam condition satisfies the Beer Lambert equation:

$$I(x) = I_0 e^{-\mu x} \qquad \text{Eqn. (2.4.2)}$$

Where Io is the initial photon intensity, I(x) is the photon intensity after passing through an absorber of thickness x in narrow-beam geometry, and μ ($cm^{-1}$) is the total attenuation coefficient.

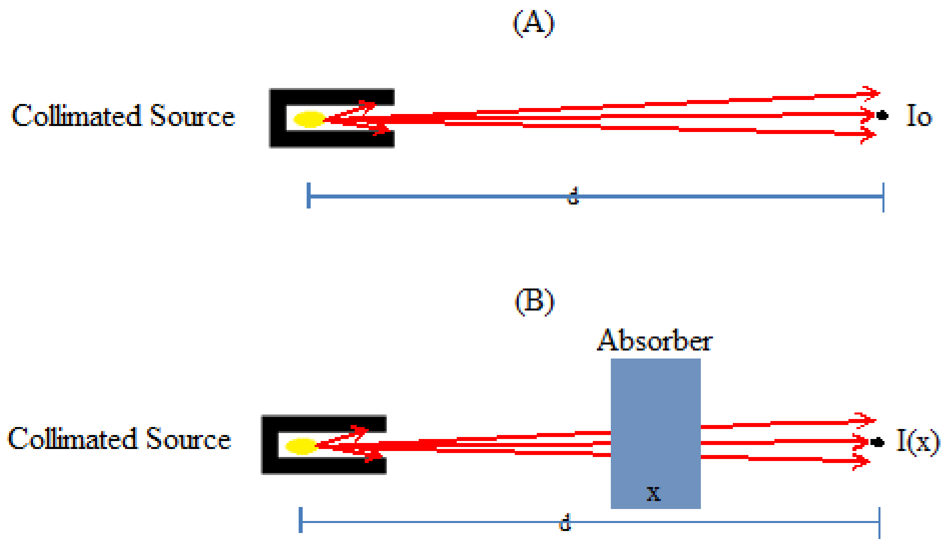



Figure 2.4.2: Diagram depicting (A) initial photon intensity and (B) photon intensity passing through an absorber (Melissa, 2008)

### 2.4.3. Photon Attenuation Coefficient

According to RSSC (2004), linear attenuation coefficient is the sum of the probabilities of interaction per unit path length by each of the three scattering and absorption processes: photoelectric effect, Compton Effect, and pair production. Linear attenuation coefficient has dimensions of inverse length (1/cm).

The values of μ is obtained with collimated narrow beams of monoenergetic photons incident on the different absorbers with a detector placed behind each absorber such that scattered photons are not detectable (Martin, 2013).

### 2.4.4. Half-Value and Tenth-Value Layers

Akkurt (2012) state that thickness of any given material, where 50% of the incident energy has been attenuated, is known as the half-value layer (HVL). In other term, HVL is the thickness of absorber required to decrease the intensity of a beam of photons to one-half its initial value. The HVL is expressed in units of distance. Like the attenuation coefficient, it is photon energy dependent. Increase of the penetrating energy of a stream of photons will result in an increase in a material's HVL. It can be calculated by setting I = ½ $I_0$ and solving the attenuation equation for x:

$$\text{HVL} = x_{1/2} = \frac{ln2}{\mu} = \frac{0.693}{\mu} \qquad \text{Eqn. (2.4.4a)}$$

According to Martin (2013) the TVL is the thickness of absorber required to decrease the intensity of a beam of photons to one-tenth of its initial value. RSSC (2011) congruently defined half value layer (TVL) as the thickness of a shielding material required to reduce the intensity of radiation at a point to one tenth of its original intensity. The tenth-value layer (TVL) is calculated by the formula:

$$\text{TVL} = x_{1/10} = \frac{ln10}{\mu} = \frac{2.3026}{\mu} \qquad \text{Eqn. (2.4.4b)}$$

# CHAPTER 3 CONCRETE TECHNOLOGY IN RADIATION SHIELDING

## 3.1.Overview of Concrete

Penttala (1997) and Li (2011) stated that concrete is one of the most versatile and widely produced construction materials in the world. Concrete is a manmade building material that exhibits similar properties with stone. Besides providing structural strength, concrete can also be used to deliver a good radiation shielding structures. Kosmatka et al. (2003) also defined Concrete as a solid material made up of two major components: aggregates and paste. The paste is the sticky substance that binds the aggregates together forming a rock like solid mass when it hardens. Aggregates are the inert filler materials which contribute about 60-75% by volume of the concrete.

## 3.2.Classification of Concretes used for Radiation Shielding

Different authors have tried to classify concrete in various categories. Since the research is about radiation shielding concrete, classification of concrete based on the NCRP Repot 151 is paramount important. According to NCRP Report No 151 (2005) there are two major types of radiation shielding concrete: Ordinary concrete and Heavyweight concrete.

According to NCRP 151 (2005) Ordinary concrete is usually considered to have a density of 2.35 $gcm^{-3}$. Ordinary concretes are commonly used in the construction of structural components in buildings and infrastructures. The cost of production for ordinary concrete is relatively less for three major factors: (1) The ingredients used to produce ordinary concrete are usually readily found, (2) In concrete construction, the cost of formwork is more than half the total cost so it is often cheaper to use more concrete than to construct elaborated forms.

Heavyweight concrete is used in the construction of radiation shielding walls in nuclear reactors, hospitals and laboratories. It is also used in bridge deck construction. According to NCRP 151 (2005) Heavyweight has a density of >2.35 $gcm^{-3}$. The higher densities for heavyweight concrete are attained by incorporating high density aggregates. Iron ores, barium minerals or ferrous materials can be used as aggregates to produce a high density concrete. The major advantage of heavyweight concrete is the higher capability of shielding photon radiation. Because of the shielding ability thinner shielding walls can be constructed out of heavyweight concrete which is a great advantage in places where space is at a premium. The disadvantages of heavyweight concrete are cost and handling difficulties. The handling difficulties include: contractors unfamiliarity with the concrete type, concrete pumps are not designed to transport heavyweight concretes and there is a problem of settling out of the heavyweight aggregates.

### 3.3.Concrete Making Materials

As a composite material, concrete is made of different graded aggregates or fillers embedded in a hardened matrix of cementitious material. Before the concrete production process commences, the properties of major constituents of concrete mixtures, such as aggregates, cementitious materials, admixtures, and water, should be understood first to better learn the properties and performance of concrete (Kosmatka et al., 2003).

#### 3.3.1. Aggregates

Neville and Brooks (1990) stated that aggregates make up the skeleton of concrete. Approximately three fourth of the volume of traditional concrete is occupied by aggregate. Because of the presence of aggregates in such large percentage of the mass, aggregates govern the properties to both the fresh and hardened concrete. Kosmatka et al. (2003) agreed with Neville and Brooks by implying that fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy.

Neville (1997) classifies aggregates into two size groups based on their tendency to pass through a sieve of 5mm opening. Sand is the main division with particles not larger than 5mm; whereas, coarse aggregate comprises of materials at least 5 mm in size. Neville also classified aggregates into natural and artificial based on their origin/formation. Accordingly, natural aggregates are formed from natural processes; however, artificial aggregates are man-made aggregates with either light weight or high-density composite materials.

Additionally, Li (2011) classify aggregates into four based on their unit weight. Ultra-lightweight aggregate have a unit weight of less than 500 $kg/m^3$. Lightweight aggregate on the other hand have a unit weight between 500 and 1120 $kg/m^3$. Normal-weight aggregate which are the most used types have a density between 1520–1680 Kg/m$^3$. The last one, heavy-weight aggregates have a unit weight in excess of 2100 kg/m$^3$.

### 3.3.2. Cement

The selection of the type and amount of cement considerably affects both the fresh and hardened concrete property. According, Kosmatka et al. (2003) Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates. When hydraulic cements react with water it set and form a hardened solid matter.

Illstone and Domone (2001) stated that the crucial ingredients of Portland cement are calcium oxide (CaO) and silicon dioxide or silica ($SiO_2$). Both of these occur in large quantities, the former in various forms of calcareous calcium carbonate ($CaCO_3$), e.g. chalk and limestone, and the latter in a variety of mineral forms in argillaceous clay or shale.

### 3.3.3. Water

Any water at all, to be used for concrete work, should be subjected to test and must be within the range of water required for concrete, before used. Mostly, all consumable water is adequate for concrete work but testing and specifying the chemical content especially chloride content of water is mandatory (Yunusa, 2011) and (Neville and Brooks, 2010).

## 3.4.Concrete Mix Design

Illstone and Domone (2001) defined mix design as the process of selecting the proportions of cement, water, fine and coarse aggregates and sometimes cement replacement materials and admixtures to produce an economic concrete mix with the required concrete properties. Correspondingly, Neville and Brooks (2010) stated that mix design is the processes of selecting suitable ingredients and determining their relative quantities, with the purpose of producing an economical concrete that has certain minimum properties. The essential concrete properties which are sought after are workability, strength, and durability.

Kosmatka (2003) described mix design as the process of determining the required and measurable characteristics of a concrete mixture. The characteristics include: (1) fresh concrete properties; (2) required mechanical properties of hardened concrete such as strength and durability requirements; and (3) the inclusion, exclusion, or limits on specific ingredients. On the other hand Kett (2000) stated that concrete mix design can be proportioned from existing statistical data using the same materials, proportions, and concreting conditions. When there are no existing records or they are insufficient, the concrete mixture must be determined by trial mixtures.

### 3.4.1. Principal Requirements for Concrete

Kosmatka (2003) states that a properly proportioned concrete mix should possess: (1) Acceptable workability of the freshly mixed concrete; (2) Durability, strength, and uniform appearance of the hardened concrete and (3) Economy. Compatibly, Li (2011) in his book "Advanced Concrete Technology" mentioned that the requirements for a good concrete mixture are: (1) Quality (strength and durability); (2) Workability; (3) Economy.

### 3.4.2. Mix Design Systems

There are many different methods for designing a concrete mix. The two most common approaches for concrete mix design are; the weight method and the absolute volume method (Li, 2011).

#### *3.4.2.1. Weight Method*

In the weight method, the unit weight of fresh concrete is known from previous experience for the commonly used raw materials and is used to calculate the weight of the last unknown component of concrete, usually the sand. If the unit weight of fresh concrete (wet concrete) is known, we have

$$W_{\text{wet concrete}} = W_{\text{cement}} + W_{\text{water}} + W_{\text{aggregate}} + W_{\text{sand}} + W_{\text{admixtures}} \qquad \text{Eqn. (3.4.2.1)}$$

If the weights of cement, water, coarse aggregate, and admixtures have been determined, then the weight of sand can be obtained from above equation. The unit weight of wet concrete usually ranges from 2300 to 2400 kg/m$^3$.

#### *3.4.2.2.Absolute Volume Method*

In the absolute volume method, the total volume (1m$^3$) is equal to the sum of volume of each ingredient (i.e., water, air, cement, and coarse aggregate). Thus, we have

$$\frac{\text{Wcement}}{\rho\text{cement}} + \frac{\text{Wcement}}{\rho\text{cement}} + \frac{\text{Wcement}}{\rho\text{cement}} + \frac{\text{Wcement}}{\rho\text{cement}} + \frac{\text{Wcement}}{\rho\text{cement}} + \text{Volume \%( Air)} = 1 \qquad \text{Eqn. (3.4.2.2)}$$

Again, when the weights of cement, water, coarse aggregate, and admixture have been determined, their corresponding volumes can be calculated, using their predetermined densities. With the volume of air determined during concrete mix design, the volume of sand can be calculated using the above equation.

### 3.4.3. Procedures for Concrete Mix Design

According to Li (2011) before starting concrete mix design, basic information on raw materials and background data should be collected, including; (A) Sieve analysis results and fineness modulus of fine and coarse aggregate (B) Dry-rodded density (unit weight) of coarse aggregate (C) Bulk specific gravity of each raw material (D) Absorption capacity or moisture content of the aggregates (E) Variation of the approximate mixing water requirement with slump, air content, and grading of the available aggregates (F) Relationships between strength and water/cement ratio for available combinations of cement and aggregate (G) Job specifications, if any, (normally, 28-day compressive strength is specified).

ACI 211.1-91 (2002) identified the following steps which are followed in order to compute the relative proportions of ingredients in concrete mixture development: (1) Choice of slump (2) Choice of maximum size of aggregate (3) Estimation of mixing water and the air content (4) Selection of water/cement ratio (5) Calculation of cement content (6) Estimation of coarse aggregate content (7) Estimation of fine aggregate content (8) Adjustment of amount of free water (9) Trial mixes (10) Mix proportion adjustments.

## 3.5.Concrete Quality Testing

Neville and Brooks (2010) mention that the main purpose of determining the quality of a concrete specimen is to ensure that the quality of concrete produced is satisfactory to be used for the actual structure. Accordingly, Kosmatka (2003) state that satisfactory concrete construction and performance requires concrete with specific properties. To assure that these properties are obtained, quality control and acceptance testing are indispensable parts of the construction process. Test results provide important feedback used to base decisions regarding mix adjustments.

### 3.5.1. Fresh Concrete Tests

#### *3.5.1.1. Consistency*

According to Kosmatka (2003) slump test illustrated in ASTM C 143 is most generally accepted and widely used method to assess the consistency of a particular fresh concrete. The test equipment consists of a slump cone 300 mm high, with a 200 mm diameter base and 100 mm diameter top and a steel rod 16 mm in diameter and 600 mm long with a hemispherical shaped tip.

#### *3.5.1.2. Density/ Unit Weight*

The density (unit weight) of freshly mixed concrete is determined in accordance with ASTM C 138. The test also gives indications of the air content provided the relative densities of the ingredients are known. A balance or scale sensitive to 0.3% of the anticipated mass of the sample and container is required. The size of the container used to determine density and yield varies with the size of aggregate (Neville and Brooks, 2010).

### 3.5.2. Hardened Concrete Test

#### *3.5.2.1. Density of Concrete*

Kosmatka (2003) states that the density and relative density (specific gravity) of hardened concrete can be determined in accordance with ASTM C 642 procedures. The density can be obtained by multiplying the relative density (specific gravity) by the density of water (1000 $kg/m^3$).

#### *3.5.2.2. Compressive Strength of Concrete*

According to BS EN 12390-1 (2000), the compressive strength of concrete is done using 150 × 150 mm cylinders and 150 mm cubes. A smaller sized sample can also be used depending on the apparent maximum size of aggregates. Cubic test specimens can be cast in steel, plastic or any other material which is sufficiently water tight. A thin layer of mineral oil is applied on the inner surface of the molds to insure the ease of de-molding. After application of the mold oil, the concrete is casted and is compacted.

The concrete is casted in about 50 mm layers. Compaction is achieved by at least 35 strokes/blows of 25 mm diameter square steel punner. Alternatively vibration can be used. The most common age for testing is 28 days but additional tests can be made at 3 and 7 days, and less commonly, at 1, 2, and 14 days, 13 and 26 weeks and 1 year. During testing, the cubes shall be tested at right angles to the position of casting. The load is applied at a constant rate of stress within the range of 0.2 to 0.1 MPa/sec and the crushing strength is reported to the nearest 0.5 MPa.

## 3.6.Heavyweight Concretes

### 3.6.1. Overview of Heavyweight Concretes

According to TS EN 206-1 (2002) concrete with specific gravity/density of 2600 kg/m$^3$ or above are termed as heavyweight concrete. On the other hand, NCRP 151 (2005) defined heavyweight concretes as concretes having a density in excess of 2350 Kgm$^{-3}$The alternative nomenclature for heavyweight is high density concrete. The concrete obtains this kind of density due to the incorporation of heavyweight aggregates with specific gravities higher than 2100 kg/m3 in the concrete mix (Li, 2011).

Natural minerals and ores like that of hematite, magnetite, limonite, barite and artificial aggregates such as steel punching and iron shot are used in the production of heavyweight concrete. Other minerals like bauxite, hydrous iron ore or serpentine, which are to relatively heavier than normal weight aggregates, can be used in case high fixed water content is required (ASTM C 637, 1998) and (ASTM C 638, 1997).

El-Sayed (2002) states that the heavyweight aggregates that are introduced into the concrete mixture help to improve the radiation shielding capability of the concrete. Heavyweight concrete is used to protect employees and the public from harmful exposures in radiation exposed work environments, such as nuclear power plant, radiotherapy rooms and industrial irradiation.

Biological shielding used for nuclear power plants, medical units, and atomic research and test facilities requires massive walls to contain radiation. Concrete is an excellent radiation shielding material. For biological shields, the mass of the concrete can be increased with the use of heavyweight aggregates. The aggregates can be either natural or manufactured. Natural heavyweight aggregates include barite, magnetite, hematite, geothite, illmenite, and ferrophosphorus. The specific gravity of these aggregates ranges from 3.4 to 6.5. Steel, with a specific gravity of 7.8, can be used as aggregate for heavyweight concrete. However, the specific gravity of the aggregates makes workability and segregation of heavyweight concrete problematical. Using a higher proportion of sand improves the workability. (Michael S. Mamlouk and John P. Zaniewski, 2011).

### 3.6.2. Previous Studies on Heavyweight Concretes

Various types of heavyweight concrete are produced in different parts of the world. The concretes are manufactured using diverse types of aggregates. The aggregates used, which include hematite, magnetite, steel punching, galena and others, have one common denominator: they are all heavyweights. This sub-section reviews some of the core studies conducted on heavyweight concrete. The studies outlined in this sub-section are used to extract information and data about heavyweight aggregates and as a model to design the experimental investigation of this research. The following paragraphs summarize some of the researches conducted in various parts of the world.

#### *3.6.2.1. Hematite Concrete*

Suresh and Abraham (2015) conducted a study on heavyweight concrete using hematite and laterite as coarse aggregate. The concrete mixes were prepared by replacing conventional aggregates with hematite and laterite. Physical and mechanical properties of all the mixes were determined and then compared with the standard mix. Accordingly, concrete with a density up to 3004 $kg/m^3$ was obtained for hematite concrete and density up to 2663 $kg/m^3$ was obtained for laterite concrete.

The report of this study shows that five basic properties of the concrete are affected by the gradual increase in the content of the heavy aggregates. The slump values show a decreasing tendency with increasing the percentage of heavy weight aggregate. According to the researchers the differences in the slump value is due to the differences in the rate of water absorption of aggregates. The result also shows that increasing the content of hematite or laterite increases the density of concrete. The maximum compressive strength (47.26 $N/mm^2$) is obtained at 25% replacement of coarse aggregate with hematite stone and that for laterite concrete is 42.03 $N/mm^2$ for 25% replacement of coarse aggregate with laterite stone. Beyond 25% replacement compressive strength value shows a decreasing tendency for both hematite and laterite concrete.

Based on the results obtained in this study, it may be seen that hematite and laterite could be used for making heavy weight concrete, without affecting much of the compressive strength, tensile strength and flexural strength of concrete. The research also deduced that 25% replacement of coarse aggregate with hematite or laterite aggregate gives the optimum results for the physical and mechanical properties of a heavyweight concrete.

Vidhya and Kumar (2015) performed an experimental investigation on strength characteristic of High density concrete incorporating Hematite. The concrete was studied using Hematite (iron ore) having a density varies from 3400-3600 Kg/$m^3$. Several properties of concretes including the compressive strength were studied for experimental concrete with design mix of M30 grade. The high density concrete was also compared with normal weight concrete of the same strength grade with respect to the above parameters. Based on the experimental investigations carried, the high density Concrete was found to have more Compressive strength, Split tensile strength, flexural strength values than the conventional concrete. By replacing the hematite aggregates instead of granite aggregates, density of concrete about 3467 kg/$m^3$ was achieved.

The study conducted by the researchers has clearly indicated the prospect of producing a heavyweight concrete from medium quality hematite stone. Using the medium quality hematite stone the researchers were able a produce a heavyweight concrete with a density of 3467 kg/$m^3$. Nevertheless, without due investigation and experimental study the research concluded that the high density Concrete is effective in shielding the Gamma rays by about 40% more when compared to the conventional concrete. It is very difficult to take the conclusion as an experimental result and the claim that the concrete is able to shield 40 % of gamma rays is not experimentally supported.

Ramushu (2014) conducted an experimental study on high density shielding concrete for neutron radiography. The objective of the research was to investigate, design, and test high density shielding concrete to be used for the construction of a newly upgraded South African Neutron Radiography (SANRAD) facility. The final mixture was composed of CEM I 52.5 N, silica fume, water, hematite sand, hematite stone, steel shot, colemanite and chemical admixtures. The final developed mixture met all the requirements specified for shielding purposes. A density of 4231 kg/m$^3$ was achieved with the final mixture and the mixture had the desired consistency. A 29.9 MPa of 28-day cube strength was achieved which surpasses the specified 25 MPa. And also the shielding capabilities of the hardened concrete were impressive with the desired dose rate being achieved at the first 250 to 300 mm thickness.

This research indicated a concise way of making a heavy way concrete that can be used to shield neutron radiography. Based on the report, the study objectives are clearly accomplished. However, the researcher had a lot of difficulty when mixing the various concrete mixtures. Most of the mixtures had zero slumps and the fresh concrete was flocculated. And also the setting time of the concrete was retarded. The recommended concrete mixture took three days to fully set. The introduction of colemanite into the mixtures was responsible for the zero slumps and delay in the setting time of the concrete.

Gencel et al. (2010) in their study of heavyweight concretes for use as shielding barriers produced heavyweight concrete using hematite ore. The research studied effects of different concentrations of hematite (10 to 50 volume % at 10% intervals) on physical and mechanical properties of concrete. A unique water-to-cement ratio of 0.42 kg/m$^3$ and 400 kg/m$^3$ cement content was selected. The result of the investigation showed the addition of hematite increases the unit weight so that a smaller thickness of concrete is required to provide radiation shielding. Besides, after 30 freeze-thaw cycles the plain concrete loses 21.3 % of its compressive strength while the composite containing 10 % hematite loses only 7.8 % of the strength. Hematite concrete was also found to have lower drying shrinkage than plain concrete, thus lowering stresses resulting from the shrinkage. They concluded that, despite the reasonable increase in density, resistance to drying shrinkage and freeze-thaw effects, most of the mechanical properties of concrete with hematite do not differ from those of plain concrete. Using plain concrete as the reference, compressive strength increased by 4.33 % – 0.48 % by replacement with hematite. At the 40 % – 50 % replaced, weak points are increasing due to oxidation in mortar-aggregate interface. With respect to the plain concrete, the slump value changes by 1.37 % – 6.85 % as a consequence of replacement with hematite. Unitweight of concrete for shielding increases with replacement ratio of hematite to concrete.

#### *3.6.2.2. Magnetite Concrete*

Sawy (2017) in a study to investigate the use of heavyweight concrete in nuclear power reactor shielding, produced two types of concretes for radiation shielding: steel-magnetite concrete and magnetite-basalt concrete. The research indicated that flux and dose rate values for both neutron and gamma rays decreases with an increase in layer thickness. The other important finding is that steel-magnetite concrete was found to be better attenuator of neutron as well as gamma rays than magnetite-basalt concrete.

Rodado (2007) obtained a patent by producing a heavy mass for manufacturing products with a high radio-protection capacity. The heavy mass proposed by the invention allows obtaining poured concrete, concrete foe forming bricks, slabs or dry mortar. In a specified embodiment for poured concrete the following mixture has been made: Kg cement type 42.5 or 52.5, 1.150 Kg water, 12 kg Magnetite with 8 mm grain size, 12 Kg Magnetite with 30 mm grain size and 2% of additives. According to the report this formulation is found to provide concrete with density on order of 4.06 Kg/dm$^3$. Additionally, by increasing the amount of magnetite with a 30 mm grain size by up to 35% more, a concrete with a density of 4.1 Kg/dm$^3$ was obtained.

#### *3.6.2.3. Galena Concrete*

Mortazavi et al. (2007) made a quest to produce a high-density concrete for shielding megavoltage radiotherapy rooms and nuclear reactors. The researchers used Galena (PbS) mineral as an aggregate. Galena mineral used in the study had a density of 7400 kg/m$^3$. The concrete made of galena reached a density of 4800 kg/m$^3$. To measure the gamma radiation attenuation of Galena concrete samples, the samples were exposed to a narrow beam of gamma rays emitted from a cobalt-60 therapy unit. The measured half value layer thickness of the Galena concrete samples for cobalt-60 gamma rays was much less than that of ordinary concrete (2.6 cm compared to 6.0 cm). Furthermore, the galena concrete samples had significantly higher compressive strength (500 kg/cm$^2$ compared to 300 kg/cm$^2$). Finally the study concluded that the Galena concrete samples show good shielding properties in comparison with all samples made by using high-density materials other than depleted uranium. Based on the preliminary results, Galena concrete may be a suitable option where high-density concrete is required in megavoltage radiotherapy rooms as well as nuclear reactors.

Based on the report from this study it can be said that researchers have made an impressive result in producing a heavyweight concrete using Galena. The concrete produced had a density of 4800 kg/m$^3$ and was able to efficiently shield the gamma rays emitted from the Cobalt-60. However, it is evident that the galena concrete is not economical. The researchers used a pure galena mineral with a lead content of 86.59 % and Sulfur content of 13.40 % and a density of 7400 kg/m$^3$. Such type of mineral ore is not readily available and it costs more relative to other minerals. The other shortcoming of the mix is the possibility of segregation. The galena concrete produced is highly prone to segregation.

Moreover, Egwuonwu et al. (2012) conducted an experimental investigation on the use of Galena Concrete in electro-magnetic radiation shielding. The concretes were moulded into cylindrical tablets of various densities and blue visible light and gamma-ray sourced from cobolt-60, were transmitted through the concretes and detected with the aid of Op-Amp and digital Geiger-Muller Counter respectively. The results obtained show that a typical Ishiagu galena concrete of about 2.80 g/cm$^3$ has the capacity of shielding visible blue light with about 2.51 mm TVL and 0.81 mm HVL. It also shows that the concrete of similar density can optimally shield gamma radiation with about 5.06 cm TVL and 1.53 cm HVL. The researchers finally concluded that the shielding effect of galena concrete wall based on the investigation is sufficient for providing useful barriers to electromagnetic radiations which are capable of causing harm to living organisms, even of high penetrating power.

According to the report from this study, the researcher was able to produce a concrete using a Galena mineral compound. The researcher has made an investigation on the Gamma ray and X-ray attenuation of the concrete and has gained positive results. However, the recommendation of the mixture for shielding nuclear reactor is of a great flaw. Galena, which is composed of lead and sulfur, is effective in shielding gamma rays but poor in shielding nuclear radiation. In order to effectively shield a neutron radiation from a nuclear reactor, a shield made of a considerable amount of hydrogen should be used.

#### *3.6.2.4. Recycled Lead Shot Concrete*

Najjar (2015) conducted a study to improve X-Ray radiation resistance of concrete. According to the research, when the lead-to-cement ratio is increased from 0% to 80%, concrete compressive strength and x-ray shielding properties are improved with maximum of 80%. After that, when the lead to cement ratio is increased from 80% to 140%, the x-ray shielding properties of concrete is increased but its compressive strength is decreased. This suggests that the optimum percentage of recycled lead shot (RLS) is about 80% of the cement weight. Also, the results have demonstrated that the density of concrete increases as the percentage of recycled lead shots increases, and the workability of concrete decreases while recycled lead shots ratio increases. In addition, linear attenuation coefficient (LAC) was found to decrease and half value layer (HVL) increases as photon energy increases.

### 3.6.3. Aggregates for Producing Heavyweight Concrete

According to ASTM C 638 (1997) aggregates used for the production of heavyweight concrete are classified into two major groups. The first group is minerals, rocks and synthetic materials that have high specific gravity (heavy aggregates) and the second group consists of minerals and synthetic glasses that contain considerable amount of boron.

#### *3.6.3.1. Heavyweight Aggregates*

ASTM C 638 (1997) categorizes heavyweight aggregates in to two groups: iron mineral ores and barium minerals. The most common iron ore mineral exploited for the production of iron all over the world is hematite. Hematite has a chemical formula of $Fe_2O_3$ and is a non-magnetic iron mineral. The second iron ore mineral used in the production of heavyweight concrete is Magnetite ($FeFe_2O_4$). Magnetite is a magnetic mineral which occurs in association with hematite and ilmenite. The other naturally occurring iron mineral ore is Ilmenite ($FeTiO_3$). The ores of Ilmenite are usually found with either magnetite or hematite.

Barite ($BaSO_4$) is the most common barium mineral and the major barium ore. Ferrophosphorus ($Fe_2P$, $FeP_2$ and FeP) is a material produced in the production of phosphorus. The compound consists of a mixture of iron phosphides, and has been used as coarse and fine aggregate in radiation shielding concrete.

#### *3.6.3.2. Minerals and Synthetic Glasses that Contain Considerable Amount of Boron*

The second category is boron minerals and Boron-Frit Glasses. The commercially important sources of boron are principally sodium, calcium, and magnesium borate precipitates. Boron is most frequently incorporated in the concrete as borate minerals or synthetic boron frits. Both methods of incorporating boron cause some retardation of time of setting of the concrete, which can be counteracted by the use of a suitable accelerator. Whereas Boron-Frit glasses are clear, colorless, synthetic glasses produced by fusion and quenching used in making ceramic glazes (ASTM C 638, 1997).

### 3.6.4. Mix Design for Heavyweight Concrete

According to ACI 211 (2002) there are two ways for proportioning heavyweight concrete mix; the conventionally placed and the pre-placed heavyweight concrete. In the conventionally placed Heavyweight concrete the concrete shall be designed in order to deliver the aspired compressive strength, density, and workability. In the conventional method the aggregates and the paste are mixed readily in the concrete mixer before being casted into the desired formwork. The coarse aggregate for the pre-placed heavyweight concrete may be heavyweight mineral aggregate, a blend mineral aggregates and steel particles. In the pre-placed heavyweight concrete production, the aggregates are first placed in the prepared formwork then a special concrete gun introduces the paste to the aggregates with a high pressure. The proportioning of heavyweight concrete for radiation shielding is described in the Appendix 4. The appendix uses the absolute volume method, which is generally accepted and is more convenient for heavyweight concrete.

# CHAPTER 4 RESEARCH DESIGN

## 4.1.Introduction

In chapter 3 a detailed explanation of concrete for radiation shielding is given. Concrete, is a composite material made up of various ingredients, which exhibit the property of stone upon hardening. There are different ways to categorize concrete. According to its compressive strength, concrete can be classified into four categories. Low-strength concrete (< 20 MPa), moderate-strength concrete (20-50 MPa), high-strength concretes (50-150 MPa) and ultra-high-strength concretes (> 150 MPa). According to the materials other than cement, aggregate and water that are added into concrete mixtures as additives, concretes can be classified into different categories. Fiber-reinforced concrete (FRC) is a type of concrete with fibers incorporated. Macro-defect-free (MDF) is a cement based composite that incorporates a large amount of water-soluble polymer, produced in a twin-roll mixing process. Concrete that has been densified with small particles (DSP) has incorporated a large amount of silica fume, a mineral admixture with very small particles. Based on the unit weight, concrete is classified as ordinary concrete and heavyweight concrete. Ordinary concrete is usually considered to have a density of 2.35 $gcm^{-3}$, whereas, heavyweight concrete is a concrete with a density of more than 2.35 $gcm^{-3}$.

This chapter explains the research design used for the research study. The research design includes the framework for the collection of data, analysis of data, interpretation, and presentation. It gives a clear description of the data collection method, analysis of data, hypothesis testing and interpretation techniques used for the experimental investigation and survey study employed for the research study.

Anatomically, this chapter is composed of seven sections. In section one a brief introduction about the chapter is given. The second section gives explanation of the research type and the research approach implemented for the research study. Section three explains the two research design methods used for the study. Research design in the case of Case study and research design in case of hypothesis-testing research are explained in detail. The fourth section gives an overview of the method of data collection employed for the research. The fifth section explains the techniques used for processing, presenting, and analyzing the collected data. Section six covers the methodology for testing the formulated hypothesis. The last section, section seven, covers the means of generalization and interpretation based on the results of hypothesis testing.

## 4.2.Research Type and Approach

### 4.2.1. Type of Research

C.R. Kothari (2004) classifies researches into two broad categories: applied research and fundamental (basic or pure) research. Applied research aims at finding a solution for an immediate problem facing a society or an industrial/business organization, whereas fundamental research is mainly concerned with generalizations and with the formulation of a theory.

Gathering knowledge for knowledge's sake is termed pure or basic research. Research concerning some natural phenomenon or relating to pure mathematics are examples of fundamental research. Thus, the central aim of applied research is to discover a solution for some pressing practical problem, whereas basic research is directed towards finding information that has a broad base of applications and thus, adds to the already existing organized body of scientific knowledge.

Based on the type of the research problem and the aim of the research, this research can be classified as fundamental/basic research. The objective of the research is to produce a heavyweight concrete to be used for shielding photon radiations and investigate the correlation between hematite content and essential concrete properties.

### 4.2.2. Research Approach

Based on the type of the research, two types of approaches are followed: quantitative research approach for the experimental study and a qualitative approach for the case study.

Quantitative approach involves the collection of data in quantitative form which is subjected to quantitative analysis in a formal way. In the Experimental study the effect of hematite aggregate on radiation shielding property and other essential heavy weight concrete properties is studied by manipulated the percentage of hematite in the concrete samples.

Quantitative data is collected from the experiment and further analyzed to identify correlation between the dependent and independent variables.

Qualitative approach focuses on the individual investigation of behavior of a study unit. This approach usually produces results either in a non-quantitative form or in a form which is not subjected to quantitative analysis and interpretation. For the case study two radiotherapy centers which are being built in Addis Ababa are studied to determine the design and construction methods, materials used, challenges faced and, compare the overall status of the projects execution with NCRP 151. NCRP is an internationally acclaimed document for design and construction of radiotherapy facilities. The data is collected in a non-quantitative fashion and it is not quantitatively analyzed further.

### 4.3.Research Design

C. R. Kothari (2004) defined research design as the conceptual structure within which research is conducted; it constitutes the blueprint for the collection, measurement and analysis of data. Therefore, the design incorporates a plan of what the researcher intends to do from formulating the hypothesis to the final analysis and presentation of the data.

Based on the objective of the research and the nature of the problem to be studied; two methods of research designs are employed. Thus, the research is a composite of Case study and Experimental Study. A case study is used for conducting an in-depth study of Saint Paul Oncology Excellence Center and Yehuleshet Referral Hospital**.** The design and construction of the two Radiotherapy centers is explored in detail. The second method used is an experimental investigation conducted to assess the effect of hematite ore on the major properties of concrete. The correlation between hematite content, and consistency, density, compressive strength and radiation shielding properties is examined using an experimental approach.

#### 4.3.1. Research Design in case of Case Study

According to C. R. Kothari (2004) a case study method is a very popular form of qualitative analysis and involves a careful and complete observation of a social unit, an institution, a cultural group or even the entire community. It is a method of study in depth rather than breadth. The case study places more emphasis on the full analysis of a limited number of events or conditions and their interrelations. The case study deals with the processes that take place and their interrelationship.

#### 4.3.2. Research Design in Case of Hypothesis-Testing Research (Experimental Research)

The research design in case of hypothesis-testing research studies is employed in this experimental study. Hypothesis-testing research studies (experimental studies) are those where the researcher tests the correlation of fundamental relationships between variables.

A phenomenon which can take on different quantitative values is called a variable. If one variable depends upon or is a consequence of the other variable, it is termed as a dependent variable. The variable that is originator of the dependent variable is termed as an independent variable. In this research experiment, the independent variable is the amount of hematite aggregate in the concrete. The dependent variables are the desired properties of concrete. The dependent variables include: slump, density, compressive strength and gamma radiation shielding of concrete.

Independent variables that are not related to the purpose of the study, but may affect the dependent variable are termed as extraneous variables. The maximum cement content, aggregate quality, curing temperature, and water to cement ratio are the extraneous variable in the research study. One important characteristic of a good research design is to minimize the effect of extraneous variables. In order to control the effect of independent extraneous variables on the dependent variables a control is employed. As a control mechanism the maximum cement content, aggregate quality, and water to cement ratio are made to be equally proportioned for all the concrete mixture groups.

According to C. R. Kothari (2004) there are several types of experimental designs. The type of Experimental design employed for the research study is an After-only with control design. In this design two groups (test group and control group) are selected and the treatment is introduced into the test group only. The dependent variable is then measured in both the groups. Treatment impact is assessed by subtracting the value of the dependent variable in the control group from its value in the test group. In view of that, two groups (experimental and control group) are designated to study the effect of hematite aggregate on the consistency, density, compressive strength, and shielding capacity of concrete.

In an experimental hypothesis-testing research when a group is exposed to a usual condition, it is termed a control group, but when the group is exposed to some a special condition, it is termed an experimental group. Two different treatment modalities are used for the experimental group and control group. The experimental group is prepared by substituting basalt coarse aggregate with varying percentage of hematite ore aggregate. Concrete with 25%, 50%, 75%, and 100% of hematite ore contents per total volume of coarse aggregate are produced. The control group is an ordinary concrete with 0% hematite content. The water to cement ratio, maximum cement contents and other factors are same for both groups.

## 4.4.Data Collection Method

### 4.4.1. Data Collection for Case Study

The primary data are collected afresh and for the first time, and thus happen to be original in character. Primary data for the case study is collected using observations of the radiotherapy facilities and by direct communication with respondents through personal interviews.

In the first method, the construction of Saint Paul Oncology Excellence Center and Yehuleshet Referral Hospital is assessed using visual means. The observation is planned prior and the results are recorded systematically. Secondly, a structured personal interview is conducted to gather primary data. The interviewer asks questions through a face-to-face contact with the Engineers and Architects involved in the construction process. The interview involves a set of predetermined questions and the questions are asked in a prescribed order.

The secondary data is collected by examining contract documents. The designs/ drawings of the facilities is examined and studied in detail to collect valuable secondary data.

### 4.4.2. Data Collection for Experimental Study

The primary data for the experimental study is collected during the course of doing experiments. The primary data on the slump, density, compressive strength and radiation shielding properties of the concrete specimens is read and recorded from the respective experimental investigations.

### 4.5.Processing, Analysis, and Presentation of Data

After the data have been collected, the next task is analyzing the data. The analysis of data requires a number of closely related operations such as establishment of categories, tabulation and then drawing statistical inferences.

Three important tasks are conducted in orderly manner for processing the data. First, the bulk data collected from the experiment is condensed into a few manageable groups and tables for further analysis. Thus, the raw data is classified into purposeful and usable categories. Second, the categorized data is tabulated in a systematic way. In the tabulation process, the classified data are put in the form of tables. Third, the tabulated data is analyzed by applying well defined statistical formula known as Arithmetic Mean/Mean. The mean is used to condense the set of numerical data into single numerical values which are representative of the entire distribution.

$$\mu=\frac{X1+X2+X3....+Xn}{n}=\frac{\sum_{i=1}^{n} Xi}{n} \qquad \text{Eqn. (4.5a)}$$

The processed data is presented either in bar or line charts. In bar charts, the height of the bars represents the class frequencies and the bars are not connected to each other. Line chart is also used to show the increase or decrease of the dependent variables under consideration. The different values in the chart are connected to one another by lines. Both graphical representation methods are used to present the quantitative data.

In the process of analysis, a combination of shewhart chart and t-test is applied to check the confidence limits for the assessed properties of the test group. In other words, the degree of increase in the dependent variables due the addition of hematite is investigated. A t-test is used to check whether such a difference is a real one or is the result of random fluctuations. t-test is based on t-distribution and is considered an appropriate test for judging the significance of a sample mean or for judging the significance of difference between the means of two samples in case of small sample(s) when population variance is not known.

$$\text{Confidence limits} = (Y_{m1} - Y_{m2}) \pm t\, \alpha_{/2} \sqrt{S_w^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)} \qquad \text{Eqn. (4.5b)}$$

## 4.6.Testing of Hypothesis

After analyzing the data as stated above, the next step is testing the hypotheses which have been formulated. The research hypothesis is a predictive statement that relates an independent variable to a dependent variable. It is a predictive statement, capable of being tested by scientific methods, that relates an independent variable to some dependent variable.

C. R. Kothari (2004) stated that null hypothesis is symbolized as $H_0$ and the alternative hypothesis as $H_a$. If the sample results do not support the null hypothesis, it is concluded that the alternative hypothesis is true. In other words, if $H_0$ is accepted as true, then Ha is rejected and if $H_0$ is rejected, then $H_a$ is accepted. Based on the problem of the research study, the following hypotheses are devised.

### 4.6.1. Effect of Hematite Content by Volume on the Consistency/ Workability of Concrete

**$H_o$:** Increase in the content of hematite by volume has no effect on the consistency of concrete.

**$H_a$:** Increase in the content of hematite by volume improves the consistency of concrete.

### 4.6.2. Effect of Hematite Content by Volume on the Density of Concrete

**$H_o$:** Increase in the content of hematite by volume has no effect on the density of concrete.

**$H_a$:** Increase in the content of hematite by volume improves the density of concrete.

### 4.6.3. Effect of Hematite Content by Volume on the Compressive Strength of Concrete

**$H_o$:** Increase in the content of hematite by volume has no effect on the compressive strength of concrete.

**$H_a$:** Increase in the content of hematite by volume improves the compressive strength of concrete.

### 4.6.4. Effect of Hematite Content by Volume on the Gamma Radiation Shielding of Concrete

**$H_o$:** Increase in the content of hematite by volume has no effect on the gamma radiation shielding capacity of concrete.

**$H_a$:** Increase in the content of hematite by volume improves the gamma radiation shielding capacity of concrete**.**

## 4.7.Generalizations and Interpretation

After collecting, processing, and analyzing the data, inferences/ implications are drawn and put forward. Interpretation is a task of drawing inferences from collected data after analytical assessments are conducted. The interpretation includes linking the results of the study with other similar studies and the establishment of concepts or theories. Therefore, generalizing the relationship between collected data and comparing the outcomes with results of other researches/ theory is conducted. Additionally, in the final phase, the real significances of the research findings are put forward.

For the experimental results, after the hypothesis testing is concluded, generalizations are made about the effect of hematite on radiation shielding, slump, density and compressive strength of concrete. The generalizations are made based on the experimental results. In the case of the case study, since there are no hypotheses to start with, the findings are explained on the basis of design recommendations from NCRP 151. Interpretation of the case study results is conducted by comparing the outcomes with NCRP 151.

# CHAPTER 5 CASE STUDY: EVALUATION OF DESIGN AND CONSTRUCTION OF TWO RADIOTHERAPY CENTERS IN ADDIS ABABA

## 5.1.Introduction

In the previous chapter a comprehensive explanation of the research design is conducted. In order to meet the research objectives two research designs are formulated: Case study and experimental/ hypothesis testing research designs.

In this chapter, a case study is conducted to assess the overall status of two radiotherapy centers in Addis Ababa. The construction materials used, and the method of construction employed are assessed methodically. Finally, a comparative analysis between the constructions methodologies employed for the two radiotherapy centers with Recommendations of the NCRP Report No. 151 is conducted to assess the conformity of the design and construction process to international standards.

Organizationally, the chapter includes three sections. The first part includes: introductory paragraphs for the chapter. The second section presents the general overview of radiotherapy centers in Ethiopia. Section three and four are dedicated to a case study conducted for the investigation of construction practice of two radiotherapy centers being constructed in Addis Ababa at the time of the research study. Finally, the last section of this chapter deals with the comparison between the methodologies used for the construction of the Radiotherapy centers with the NCRP Report No. 151.

## 5.2. General Overview of Radiotherapy Centers in Ethiopia

Tigeneh W. et al., (2015) stated that cancer is one of the main causes of mortality in Ethiopia. A survey conducted at Addis Ababa cancer registry indicates that 64,000 new cases of cancer occur annually among which cervical and breast cancer constitute the significant majority. Mortality from cervical cancer alone was estimated to be 3,235 annually in Ethiopia. Hence, cancer has become the major health problem in Ethiopia with steady increase of mortality rate each year. However, the cancer treatment centers are not sufficient in number and equipments to support the growing burden.

According to Werissaw Haileselassie (2019) prior to 2018, Ethiopia relied on a single healthcare institution for every cancer related case. Black Lion Referral hospital, located in the capital Addis Ababa, was the sole healthcare institution providing cancer treatment for the rapidly increasing population. The hospital is a teaching institution linked with the College of Health Sciences of Addis Ababa University.

Currently, the Ethiopian Ministry of Health (MoH) has started the construction of six specialized healthcare centers for cancer related patients. The six specialized centers are planned to provide specialized healthcare treatment for cancer related patients in Oromia, Amhara, Tigray and SNNP regional states. Currently the five centers are under construction in Hawassa, Gondor, Mekelle, Jimma and Haramaya. The construction and installation of equipment for the five centers was planned to be finalized in 2018-2019 fiscal year, however, due to design improvements and complications that came with it, the Hawassa, Mekelle and Jimma Oncology centers are still pending. The construction of the Gondor and Haramaya Oncology centers is currently finalized.

## 5.3.Saint Paul Oncology Excellence Center

### 5.3.1. Project Description

In 2018, St. Paul's Hospital Millennium Medical College (SPHMMC) opened its Oncology department. It is the second hospital offering cancer treatment in the country. Saint Paul Hospital is currently building a 2B+G+8 Cardiac center, B+G+8 GI (Gastrointestinal) center, ENT center and a B+G+8 Oncology Excellence Center. The initial contract cost of the construction was about 986-million-birr, however due to design change and additions the contract cost is raised to 1.6-billion-birr.

The Oncology Excellence Center is a nine-story building and the first Oncology excellence center for the county. The cancer excellence center is a 300 million birr project which is expected to be completed within 3 years. The complex is planned to have five radiation machines and 250 beds.

The consultant that designed the Healthcare Centers is an Ethiopian firm by the name AT-CON Engineering and Architectural Consulting PLC. Following an open competitive bid Asmelash and Sons Construction PLC won the bid and started construction on February 02, 2016. The project was planned to be finalized within 3 years, however due to delay of site handover and design changes the project time has been extended by more than 1 year.

### 5.3.2. Summary of Project Description

- Project: Saint Paul Oncology Excellence Center
- Location: Paulos-Enkulal-Fabrika, Addis Ababa, Ethiopia
- Owner/Employer: Saint Paul Hospital, Ministry of Health
- Consultant: AT-CON Engineering and Architectural Consulting PLC
- Contractor: Asmelash and Sons Construction PLC
- Contract price: The initial contract price is 300-million-birr, however due to design change and additions the contract cost is raised.
- Contract price of the Oncology Excellence Center: 300 million birr
- Project start date: February 02, 2016
- Project completion time: The project was planned to be finalized within 3 years, however due to delay of site handover and design changes the project time has been extended by more than 1 year.
- Percentage Completion: the percentage completion of the project is not determined by the contractor at the time of interview by the researcher.

### 5.3.3. Design of the Facility

A Grade 1 local consulting firm by the name AT-CON Engineering and Architectural Consulting PLC designed the Saint Paul Oncology Excellence Center. After the designs are completed the final drawings and specifications are reviewed and approved by the pertinent Permitting Agencies before construction work commenced.

The design of Saint Paul Oncology Excellence Center has been reviewed and approved by the Addis Ababa Municipality Construction Bureau. Additionally, the designs have also been checked and approved by the Ethiopian Radiation Protection Authority for compliance with national and international guidelines. The Ethiopian Radiation Protection Authority is the sole radiation energy concerned governmental authority in the country and one of whose duty is approving the designs of radiotherapy bunkers.

### 5.3.4. Construction of the Facility

#### *5.3.4.1. Materials Used for Construction*

Three major types of construction materials are used for the construction of the radiation barriers slabs and walls, doors, and toxic waste disposal. The primary construction material utilized is concrete. Reinforced concrete with quality C-30, 400 kg of cement/$m^3$ is used for the walls and slabs of the Radiotherapy rooms of the Oncology center. The second material used is earth. Since the radiotherapy rooms are constructed in the basement, Earth can also be considered as one of the construction materials used to shield radiation energy. The embankment at either side of the radiotherapy center is used to reduce the level of radiation energy. The boronated lead is used to construct a 150x290 cm doors. The boronated lead door is made of 15 cm boron with 5 cm and 2.5 cm thick lead layer on external and internal part of the boron respectively finally covered with 4mm thick sheet iron on both sides. For non-domestic waste water drainage, HDPE pipes with diameter of 50mm, 75mm, and 110mm are used. The HDPE are wrapped with lead to shield radiation leakage. Hot laboratory sink unit with lead lined storage bay for storage until decay and waste water drainage line wrapped with lead is fixed for nuclear medication. A 25*6*8 cm thick Double brick wall imbedded in cement mortar (1:3) is also used to construct the walls for the rooms.

#### *5.3.4.2. Method of Construction*

The project is one of its kinds in uniqueness, complexity, and magnitude; therefore, the contractor had organized a site visit and experience sharing tour to Mekelle and Gondor where there are two similar projects under construction. Following the visits, the construction firm has established a method of work which is appropriate to the type of work at hand.

Basically, the major activities performed in the construction of the barrier walls are fixing formworks, pouring concrete and finishing. Since, the concrete used is a mass concrete especial consideration must be taken into account. Mass concrete is used; therefore, a typical local formwork fixing procedures cannot be implemented. The mass concrete exerts huge amount of force on the formwork, so, a special formwork which has a metal rod known as form ties to connect the two opposite sides of the formwork is proposed. The form ties pass through the concrete, connecting the formwork panels with each other. The rods are welded on either side of the end point.

The rooms are used for providing maximum shielding against radiation energy; therefore, the concrete is expected to have almost no joints. Consequently, a monolithic filling of concrete at one go is proposed. An especial formwork which permits the casting of the concrete monolithically was being procured from abroad during the time of the research interview.

#### *5.3.4.3. Challenges*

The primary challenge is the extremely large thickness of walls reaching up to 3 meters for primary barrier and 1.5 meters thick secondary barrier. This type of concrete work is not common and the contractor is not familiar with the operation. The second challenge identified is the availability of local formwork that can allow monolithic casting of the walls and slabs. The formwork type is not available locally in Ethiopia; therefore, it was to be procured from western countries. Design and construction material selection for the radioactive waste from patients is another challenge. The wastage from patients who are receiving brachytherapy is not disposed using the normal sewer line. The waste from brachytherapy has an active source of radiation, therefore, separate sewer lines designed using distinct materials is to be used for construction. This is additional challenge for the construction company building the facility.

## 5.4.Yehuleshet Referral Hospital

### 5.4.1. Project Description

Yehuleshet Referral Hospital is the other radiotherapy facility which is under construction in Addis Ababa. The project is a private hospital owned by a local investor known as Dr. Guta Zenebe. The project started in 2009 G.C. and now it is about 90% completed. The initial estimate of the project was about 80 million Ethiopian birr; however, because of the extended project duration and inflation the project cost is generally accepted to be much higher.

The project delivery system utilized for the project is a Force Account i.e., the project owner is directly engaged to undertake the project. Two Ethiopian consulting firms by the name

Amint Consulting and Hightech Consultants have engaged in different stages of the project. The project includes an MRI center, CT Scan center, X-ray center and a Radiotherapy center.

Table 5.4.1: Dimension of the Yehulashet Radiotherapy rooms

| **Room Dimensions** | **Size (m)** | **Height (m)** | **Note** |
|---|---|---|---|
| Scan Room | 7.00 × 4.47 | 4.24 | From Floor to Ceiling |
| Machine Room | (1.85+5.33)/2 × 6.04 | 4.24 | From Floor to Ceiling |
| Operator Room | 5.10 × 4.54 | 4.24 | From Floor to Ceiling |

### 5.4.2. Summary of Project Description

- Project: Yehuleshet Referral Hospital
- Location: Churchill Road, Piazza, Addis Ababa
- Owner/Employer: Dr. Guta Zenebe
- Consultant: Toshiba Medical Systems (China) Co. Limited, Amint Consulting, and Hightech Consultants
- Contractor: The project delivery system utilized for the project is a Force Account.
- Contract price: The initial estimate of the project cost was about 80 million ETB
- Project start time: 2009 G.C.
- Project completion time: The construction of the hospital has been ongoing since 2009 G.C. and it is expected to be completed in 2020 E.C.
- Percentage Completion: 90% completed

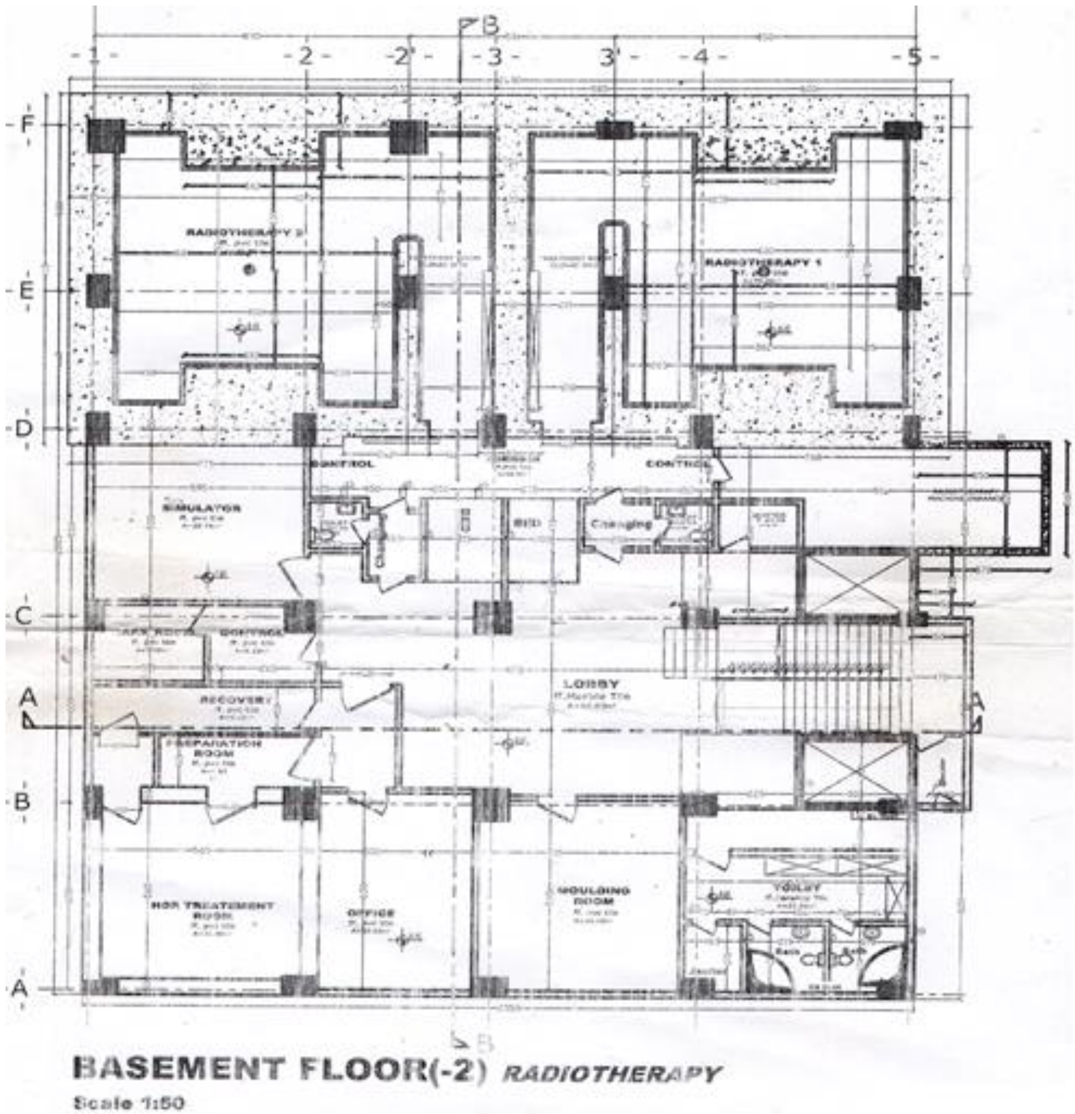



Figure 5.4.2: Floor plan of Yehuleshet Hospital Radiotherapy Center

### 5.4.3. Design of the Facility

The design of Yehuleshet Referral Hospital radiotherapy bunker is conducted by the Chinese medical equipment manufacturing company known as Toshiba Medical Systems (China) Co. Limited. Two local consulting firms Amint Consulting and Hightech Consultants are also involved in different phases of the project.

Before construction of any radiotherapy facility commences, the final drawings and specifications should also be reviewed by the qualified expert and by the pertinent federal, state, or local agency. Congruently, the designs of Yehuleshet Referral Hospital radiotherapy bunker have been approved by the Addis Ababa Municipality Construction Bureau. However, the radiation shielding design is not checked and approved by The Ethiopian Radiation Protection Authority.

### 5.4.4. Construction of the Facility

#### *5.4.4.1. Construction Materials*

The MRI center, CT scan center, and X-ray center are constructed in the second floor. The three centers are constructed out of the same type of materials. The walls are constructed of a double brick and lead and slabs are made of C-30 concrete. The radiotherapy room is constructed out of normal weight concrete with varying thickness, ranging from 1.5-2.5 m. The concrete used is a ready mixed concrete with C-40 grade and is obtained from Ovid, National premix Construction PLC, and Accurate Construction Supplier.

#### *5.4.4.2. Method of Construction*

The method of construction utilized for the radiotherapy room is somewhat different from the other rooms of the Hospital project. The concrete construction is not required to have any joint, therefore, the slabs, beams and walls are cast monolithically, and the casting is done day and night. A mass concrete is used to construct the large thickness of the barrier walls. Consequently, the large amount of concrete produces an enormous amount of force on the formwork. To counteract the concrete pressure, the formwork is held together by welding the opposing sides together using reinforcement bars.

#### *5.4.4.3. Challenges*

The first challenge is lack of experience of work of similar nature and absence of experienced and organized construction firm in the execution of the project. The contract is a Force Account type, so, the Employer has relied on a few Civil Engineers of his own to oversee all the construction supervision tasks. However, the Engineers are not fully versed and familiar with construction of radiotherapy centers. The second challenge is the provision of large primary barrier wall mounting to 2.5 meters and 1.5 to 2 meters thick secondary barrier. The third challenge is the availability of appropriate formwork that can allow monolithic casting of the walls and slabs. Formworks which allow monolithic casting of slabs and walls are not readily available in Ethiopia.

## 5.5. Compliance Assessment of the Radiotherapy Centers to the Recommendations of the NCRP Report No. 151

Internationally accepted guidelines for the design of structural shielding for radiation therapy installations are given in the National Council for Radiation Protection report number 151 (NCRP, 2005). By interviewing the consultants and contractors, and by studying the contract documents, the methodology employed for the design of the radiotherapy centers is understood. Then, the acquired information is compared with guidelines of the NCRP Report No. 151 to determine the level of compliance.

### 5.5.1. Designing and Design Approval Authority

According to NCRP 151 (2005) radiation shielding shall be designed by a certified Medical Physicist to ensure the required degree of protection is achieved for the radiotherapy bunker. A brief interview and investigation of the contract documents indicated that the design of Yehuleshet Referral Hospital radiotherapy bunker is conducted by the Chinese medical equipment manufacturing company known as Toshiba Medical Systems (China) Co. Limited. Two local consulting firms Amint Consulting and Hightech Consultants are also involved in different phases of the project. However, the local consultants are not actively engaged in the design and the appropriate local experts are not included in the design of the radiation therapy center. The designs are simply shipped from the foreign equipment manufacturer. For the case of Saint Paul Oncology Excellence Center, a local consulting firm by the name AT-CON Engineering and Architectural Consulting PLC designed the facility. The compliance of the design process is better for this facility; nevertheless, there is no indication that a certified Medical Physicist is engaged in the design of the Oncology Excellence Center.

Therefore, both projects are not designed by a certified Medical Physicist, as per the recommendations of NCRP 151 (2005). Hence, it is difficult to conclude that the designs meet the NCRP 151 regulation concerning appropriate design authority. This is partly due to the fact that most of the local consulting firms are in their infant stage and they don’t integrate professionals from varied fields in their design teams. The second reason is the availability of inadequate number of trained and certified Medical Physicist in the country.

The second factor assessed in this category is the approval of the designs. NCRP 151 (2005), states that the final drawings and specifications should be reviewed by a qualified expert and by the pertinent federal, state, or local agency before construction begins. The designs of Yehuleshet Referral Hospital radiotherapy bunker has been approved by the Addis Ababa Municipality Construction Bureau. However, the radiation shielding design is not checked and approved by the Ethiopian Radiation Protection Authority. This fact illuminates a violation to the recommendation, because, the Ethiopian Radiation Protection Authority is the sole radiation energy concerned governmental authority in the country and one of whose duty is approving the designs of radiotherapy bunkers. On the other hand, the designs for Saint Paul Oncology Excellence Center have been checked and approved by The Ethiopian Radiation Protection Authority for compliance with national and international guidelines.

### 5.5.2. General Guide lines of the Structural Detail

According to NCRP 151 (2005) the shielding requirements for therapy equipments can vary considerably due to the wide variety of radioactive source energies, types of equipment and clinical techniques used.

The NCRP Report 151 stipulates that location is a prime factor in designing radiotherapy bunkers. Radiotherapy facilities are often constructed below ground level as the most economical strategy to minimize shielding costs associated with exterior walls. For rooms on or above ground, the outside walls almost always require shielding, using concrete, brick, stone or other suitable material.

The radiotherapy bunker for Yehuleshet Referral Hospital is constructed on the ground surface; therefore, considerably thick concrete walls are built in relation to the radiation energy to shield the primary and secondary radiations. On the other hand, radiotherapy rooms of Saint Paul Oncology Center are located in the basement of the structure. The soil which is located in the periphery of the basement walls helps in shielding and reducing the radiation level emitted to the surrounding environment.

The other factor that needs due consideration is provisions for future needs. NCRP Report 151 states that cost and problem of future alterations may be reduced by providing additional rooms initially or by allowing for future enlargement of rooms to accommodate replacement equipment of larger size, higher energy, and with increased workload. The entrance and inner maze openings should be adequate for transport of equipment and patients in and out of the room, but small enough to minimize scattered radiation to the maze door.

The Radiotherapy rooms and door openings in Yehuleshet Referral Hospital are sufficiently large to contain the proposed LINAC. A special opening on the floor of the lobby is designed and constructed in order to facilitate the ease of transporting the equipment to the radiotherapy rooms. Besides that, an additional radiotherapy room is also constructed for future need.

The Radiotherapy rooms in the Saint Paul Oncology Center are also designed with sufficient size and the door openings and the mazes are also compatible with size of the proposed machine. However, additional rooms for future provision and future enlargement of the rooms are not considered in the design.

Interlocks and warning lights shall also be provided so that the radiation beam status is observable from both inside the treatment room and at the control console (NCRP, 151). This hazard can be reduced by having "emergency-off" buttons and warning signs at appropriate positions. Considering interlocks and warning lights of radiotherapy rooms, both Saint Paul Oncology Center and Yehuleshet Referral Hospital are compliant with the regulations of NCRP Report 151.

NCRP (2005) states that the control console shall be located outside the treatment room and it should be beyond a secondary barrier in order to keep the console shielding thicknesses to a minimum and to achieve radiation doses to staff that are consistent with the ALARA principle.  Accordingly, in both cases the control console is designed outside the radiation room and it is located adjacent to a barrier wall. The entrance to the treatment room is also visible from the control console. Additionally, different visual and audio communication equipments for communication between physicists and the patient are provided in the designs.

### 5.5.3. Barriers

Primary protective barriers for megavoltage installations will usually be composed of concrete several meters thick, or the equivalent thickness of other materials that provide equivalent shielding. The primary barrier can be irradiated directly by photons from the target or source, while the secondary barrier receives radiation resulting from scatter of the primary beam by the patient and/or the surfaces of the treatment room in addition to the radiation transmitted through the accelerator head. Secondary radiation is emitted in all directions and covers all of the treatment room surfaces. Primary radiation, however, is limited in direction by the placement of the accelerator in the treatment room and the maximum beam size (NCRP, 2005).

The primary and secondary barrier of the Saint Paul Oncology Center is designed using NCRP and IAEA design guide lines. The thickness of primary barrier walls range from 2.0 to 3.0 meters and the secondary barrier has a thickness of 1.5 meters. The Yehuleshet Referral Hospital radiotherapy room's primary barrier is found to have a thickness of 2.50 meter and the secondary barrier has a wall thickness in the range of 1.50 to 2.0 meter. However, the standard implemented for the design is not indicated on the contract document and the supervision team is not familiar with the guidelines used by the Toshiba Medical Systems (China) Co. Limited which designed the radiation bunker.

### 5.5.4. Shielding Materials

According to NCRP (2005) the materials that have been used for shielding purpose are: ordinary concrete, heavy concrete, lead, steel, polyethylene or paraffin, earth, and wood. Ordinary concrete is usually considered to have a density of 2.35 g $cm^{-3}$. On the other hand, heavy Concrete is often used in construction of radiation therapy rooms. Any concrete with a density of >2.35 g $cm^{-3}$ can be considered heavy concrete. Lead has a very high density of 11.35 g $cm^{-3}$ and is an excellent shielding material for x and gamma rays where space is at a premium. Steel is also relatively expensive (in comparison to concrete) and its density is ~7.8 g $cm^{-3}$. Form ties are used to completely penetrate the concrete shield and hold the form work together. They are very heavy double wires or steel rods 2.5 cm (1 inch) or more in diameter that are cut to release the forms.

Accordingly, an ordinary concrete is used for the primary and secondary shielding wall for both Saint Paul Oncology Center and Yehuleshet Referral Hospital. Reinforced concrete quality C-30, 400 kg of cement/$m^3$ is used for the walls and slabs of the Radiotherapy rooms of the Saint Paul Oncology center. Earth is also used as a shielding material by designing the accelerator rooms completely underground. According to the Resident Engineer, initially steel beam was proposed to be used with concrete, however, due to design complications the proposed design was not used and the design was later changed to ordinary concrete shielding walls. For radiotherapy rooms in Yehuleshet Referral Hospital, ready mixed ordinary concrete with C-40 grade is used and it is obtained from Ovid, National premix Construction PLC and Accurate Construction Suppliers. In both cases, lead is used in the design of the treatment doors. The lead blocks are procured and imported from Western Countries. Form ties are also incorporated in the specification to support and hold the form work and bear/support the load from the mass concrete. However, Paraffin, polyethylene and wood are not incorporated in the design of both of the radiotherapy centers.

### 5.5.5. Joints, Concrete Slab Junctions

Protective barriers of solid block construction should have mortar of at least the same density as the block. Openings in protective barriers for doors, windows, ventilating ducts, conduits, pipes, etc. may require radiation baffles to ensure that the required degree of overall protection is maintained (NCRP 151, 2005).

Saint Paul Oncology Center and Yehuleshet Referral Hospital use only ordinary concrete for the primary and secondary barrier walls therefore, no protective barrier is implemented. There is also a sufficiently large overlap between the doors and walls.

### 5.5.6. Access to Radiation Vault

Access to radiation treatment rooms involves either a maze entry or a direct-shielded door. A maze arrangement generally is the most economical approach, as the shielding of the door can be greatly reduced. Height and width of doorways, elevators and mazes should be adequate to permit delivery of equipment into treatment rooms, unless other provisions are made. Lead door sill is often recommended (NCRP, 2005).

At the time of site visit, construction of the radiotherapy center at Saint Paul Oncology Center was not commenced; however, the concrete work for the radiation therapy at Yehuleshet Referral Hospital was completed. Both the Saint Paul Oncology Center and Yehuleshet Referral Hospital incorporate short mazes and doorways with a sufficient height and width. So, they are not directly shielded doors.

### 5.5.7. Ducts

NCRP (2005) indicates that there should be different ducts according to function and the related size. Ducts for HVAC purposes, machine cables, electrical and water ducts are usually provided. Ducts should never be placed in the primary barriers, no matter how small. To decrease the chance of leakage radiation through the ducts, for low-energy machines (<10 MV) no additional shielding around the duct is generally required. If the total dose equivalent is high added shielding is needed and the preferred arrangement is to bend the ducts immediately after they have exited the maze. If that is not possible, the ducts should be wrapped with lead and BPE. A third alternative is to use the concrete shielding as a baffle. In concrete baffles, overlapping sections of concrete provide a vertical "mini-maze."

A review of Saint Paul Oncology Center's drawings/design indicates that two ducts for HVAC and a circular duct for machine cables and electricity is placed in various position of the secondary barrier walls. Whereas, radiotherapy rooms of Yehuleshet Referral Hospital have only one circular duct with relatively larger size to accommodate the machine cables, electricity and other miscellaneous needs. The ducts for Yehuleshet Referral Hospital are designed at a 45º inclined angle to shield the leakage of radiation through them. For the case of Saint Paul Oncology Center the appropriate way to shield the radiation is still not completely determined at the time of the interview.

# CHAPTER 6 RAW MATERIALS, CONCRETE MIXTURE DEVELOPMENT AND EXPERIMENTAL DESIGN

## 6.1.Introduction

Kosmatka et al., (2003) defined Concrete as a solid material made up of two major components: aggregates and paste. The aggregates are sand and gravel which act as a filler. The paste is a mixture of cement, water and sometimes admixtures. Besides the various important applications, concrete has a capability of attenuating photons and neutrons, therefore, is used to construct Radiotherapy Bunkers.

Production of heavyweight concrete for radiation shielding requires the incorporation of aggregates with high density and atomic number. Hematite is one of the high density aggregates which can be used to produce a heavyweight concrete able to shield living things from harmful rays of ionizing radiation sources (Mamlouk and Zaniewski, 2011).

The following chapter presents the major ingredients used for the production of heavyweight concrete, the particular tests employed to assess the aggregate quality, and the chemical composition of the aggregates. Then concrete mixture proportioning process and mixture development is explained in detail. Finally, the equipments and methods involved in the experimental investigation are clearly elaborated.

The chapter organizationally is divided into seven major sections. The first section gives an introduction of the chapter. Section two explains the raw materials used to produce heavyweight concrete. The third section covers the physical analysis of the coarse and fine aggregates used in the research.

In the fourth section, the physical properties of the blended coarse aggregates are determined. The fifth section encompasses the mix design for the heavyweight concrete. In the sixth section, the procedures used for casting and curing the concrete samples are explained systematically. The last section contains explanation of the methodology and equipments used in the experimental study.

## 6.2.Raw Materials for Heavyweight Concrete Production

### 6.2.1. Hematite Ore

Hematite is chosen for this research study because of its heavyweight and abundance. Hematite is the most common iron ore mineral exploited for the production of iron all over the world. Hematite has a chemical formula of $Fe_2O_3$ and is a non-magnetic iron mineral. Hematite in its pure form has a hardness of 5 to 6 on Mohs' scale, and a specific gravity of 5.26. The color varies from bright red to dull red to steel gray. It is also nonmagnetic (ASTM C 638, 1997).

Rocks which have hematite ore as a primary component differ from one deposit to the other. The ores may differ by their specific gravity, compactness, toughness, amount of impurities and other parameters. Hematite ores can be used as aggregates to produce a dense concrete capable of shielding radiation (ASTM C 638, 1997)**.**

The Hematite ore for this research is obtained from Northern Amhara Region, Wag-Himra special zone, Sekota Woreda, Tsemera Kebele. Due to the lack of transportation facilities at the time of the ore mining process, it was not possible to travel through the direct route linking Bahirdar and Sekota. Therefore, the researcher traveled via the lengthy road passing through Woldia, Alamata and Korem to reach Sekota town.

Tsemera Kebele is located about 20 Km North of Sekota town. The hematite ore is evident lying on the surface of a small valley close to the dirt road linking Tsemera kebele to Sekota Town. Due to the lack of machineries, funds and time, the hematite is collected with only a minor excavation using manual labor. No deep excavation is conducted to acquire a superior quality ore. The Tsemera hematite obtained has a dull reddish color. The rocks are broken down from the surface using sledgehammers and collected. Then, the ore is transported to Addis Ababa Institute of Technology for further processing.


Figure 6.2.1a: A map showing Bahirdar-Sekota route

The Hematite ore aggregate is used to partially substitute the coarse aggregate to produce heavyweight concr-ete. Hematite ore is prepared as an aggregate by manually crushing the ore using Sledgehammers/ Mallets. Daily laborers crushed the ore with a close supervision from the researcher in order to produce a well graded aggregate. Then, the crushed hematite is sieved using 25 mm sieve. Before producing the concrete an experimental investigation on the property of hematite aggregate is conducted.

Figure 6.2.1b: Hand crushed hematite ore obtained from Tsemera/Sekota

### 6.2.2. Basalt Coarse Aggregate

The different coarse aggregate sizes commonly used in the Ethiopian construction industry are 01, 02, 03 and 04. A 01, 02, 03 and 04 coarse aggregates have a maximum aggregate size of 10 mm, 20 mm, 30 mm and 40 mm respectively.

For this research a maximum size of coarse aggregate of 25 mm is chosen and the aggregate is acquired from one of the local aggregate producers/suppliers in Akaki area (Addis Ababa). The maximum size of the heavyweights aggregate is obtained by crashing the hematite ore using sledgehammers and then sieving the crushed aggregate in sieves of specified sizes.

Figure 6.2.2: Basalt aggregate obtained from Akaki (Addis Ababa)

### 6.2.3. Sand

Aggregates with size less than 4.75 mm are termed as fine aggregate. The most commonly used fine aggregate is river sand. The sand for this research experiment is “Meki” sand and it is obtained from a local distributer in Addis Ababa City.

A) Measuring the weight of sand

B) Measured sand samples

Figure 6.2.3: The processes of proportioning sand

### 6.2.4. Cement

Cement is one of the main ingredients of concrete. Cement mixed with water forms the paste that binds coarse and fine aggregates together forming a solid concrete. The cement used in all the concrete mixtures is a 52.5 N normal Portland cement. The cement manufactured at Dangote cement factory is used in the experimental investigation.

### 6.2.5. Water

Water containing even small quantities of acid, oil and other impurities will result in setting time retardation, reduction of strength, and other problems. Generally speaking, if water is potable, it is satisfactory for the production of a good concrete. Potable tap water without any salts and chemical impurities is used in the experimental study to produce the concrete mixtures. The water used for concrete is clean and free from dirt or organic matter. The water source is the Addis Ababa Water and Sewage Authority Potable Water Line.

## 6.3. Physical Property Analysis of Aggregates

Before preparing the mix design, enquiry on the major physical properties is conducted on the coarse aggregates and fine aggregate (sand) to ensure conformity to international standards. The result of the physical tests is incorporated in the design of the concrete mixtures.

### 6.3.1. Dry Rodded Unit Weight of Hematite Ore and Basalt Coarse Aggregates

ASTM C 566 (1997) defines unit weight ($\gamma$) as the weight of a given volume of graded aggregate. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them.

The unit weight is simply measured by filling a container of known volume and weighting it based on ASTM C 566.

#### *6.3.1.1.Dry Rodded Unit Weight of Hematite Aggregate*

Table 6.3.1.1: Dry Rodded Unit Weight of Hematite Aggregate

| Parameters | Values |
| --- | --- |
| Combined mass (oven-dry aggregate and the bucket (G)) | 41.27 Kg |
| Mass of bucket alone (T) | 4.85 Kg |
| Volume of bucket (V) | 0.0141 $m^3$ |
| Percentage absorption determined by ASTM: C 127 (A) | 1% |
| $M_{SSD=}$ (G – T)*(1 + A/100)/V | (41.27 Kg – 4.85 Kg)*(1 + 1/100)/0.0141 $m^3$ |
| $M_{SSD}$ | 2608.8Kg/ $m^3$ |

#### *6.3.1.2.Dry Rodded Unit Weight of Basalt Aggregate*

Table 6.3.1.2: Dry Rodded Unit Weight of Basalt Aggregate

| Parameters | Values |
| --- | --- |
| Combined mass (oven-dry aggregate and the bucket (G)) | 27.63 kg |
| Mass of bucket alone (T) | 4.85 Kg |
| Volume of bucket (V) | 0.0141 $m^3$ |
| Percentage absorption determined by ASTM: C 127 (A) | 0.93% |

| | |
|---|---|
| $M_{SSD=}$ (G – T)*(1 + A/100)/V | (27.63 – 4.85 Kg)*(1 + 0.93/100)/0.0141 $m^3$ |
| $M_{SSD}$ | 1630 kg/ $m^3$ |

### 6.3.2. Specific Gravity and Absorption of Aggregates

ASTM C 127 (1993) describes the test methods used to determine specific gravity and absorption of aggregates. This test method covers the determination of Specific Gravity and Absorption of both coarse and fine aggregates.

The specific gravity is expressed as bulk specific gravity, bulk specific gravity SSD or apparent specific gravity. The bulk specific gravity and absorption are based on soaking of aggregate for 24 hour in water.

#### *6.3.2.1.Specific Gravity and Absorption of Coarse Aggregates*

The following formula is used to determine the specific gravities and percentage absorption.

- Bulk specific gravity (OD) = $\frac{A}{B-C}$ Eqn. (6.3.2.1a)
- Bulk specific gravity (SSD) = $\frac{B}{B-C}$ Eqn. (6.3.2.1b)
- Apparent specific gravity = $\frac{A}{A-C}$ Eqn. (6.3.2.1c)
- Absorption (%) = $\frac{(B-A)*100}{A}$ Eqn. (6.3.2.1d)

Table 6.3.2.1: Specific Gravity and Absorption of Coarse Aggregates

Coarse Aggregates: ASTM Designation: C 127

| **Sample size: Hematite 5.1 kg and Basalt 3 Kg** | **Hematite** | **Basalt** |
|---|---|---|
| (A) Wt. oven-dry sample (g) | 5.025 | 2.909 |
| (B) Wt. SSD sample (g) | 5.075 | 2.936 |
| (C) Wt. saturated sample in water (g) | 3.731 | 1.875 |
| Bulk specific gravity (OD) | 3.74 | 2.74 |
| Bulk specific gravity (SSD) | 3.78 | 2.77 |
| Apparent specific gravity | 3.88 | 2.81 |
| Absorption, % | 1.0 | 0.93 |

### *6.3.2.2.Specific Gravity and Absorption of Fine Aggregates*

The following formula is used to determine the specific gravities and percentage absorption.

- Bulk specific gravity (OD) = $\frac{A}{B+500-C}$ Eqn. (6.3.2.2a)
- Bulk specific gravity (SSD) = $\frac{500}{B+500-C}$ Eqn. (6.3.2.2b)
- Apparent specific gravity = $\frac{A}{B-C+A}$ Eqn. (6.3.2.2c)
- Absorption (%) = $\frac{(500-A)*100}{A}$ Eqn. (6.3.2.2d)

Table 6.3.2.2: Specific Gravity and Absorption of Fine Aggregate

| **Fine Aggregate: ASTM Designation: C 127** | |
|---|---|
| **Sample size of 497.2gm** | **Sand** |
| (A) Wt. oven-dry sample in air (g) | 498.3 |
| (B) Weight of pycnometer filled with water (g) | 1,280.6 |
| (C) Weight of pycnometer with sample in water (g) | 1,585.1 |
| Bulk specific gravity (OD) | 2.55 |
| Bulk specific gravity (SSD) | 2.56 |
| Apparent specific gravity | 2.57 |
| Absorption, % | 0.34 |

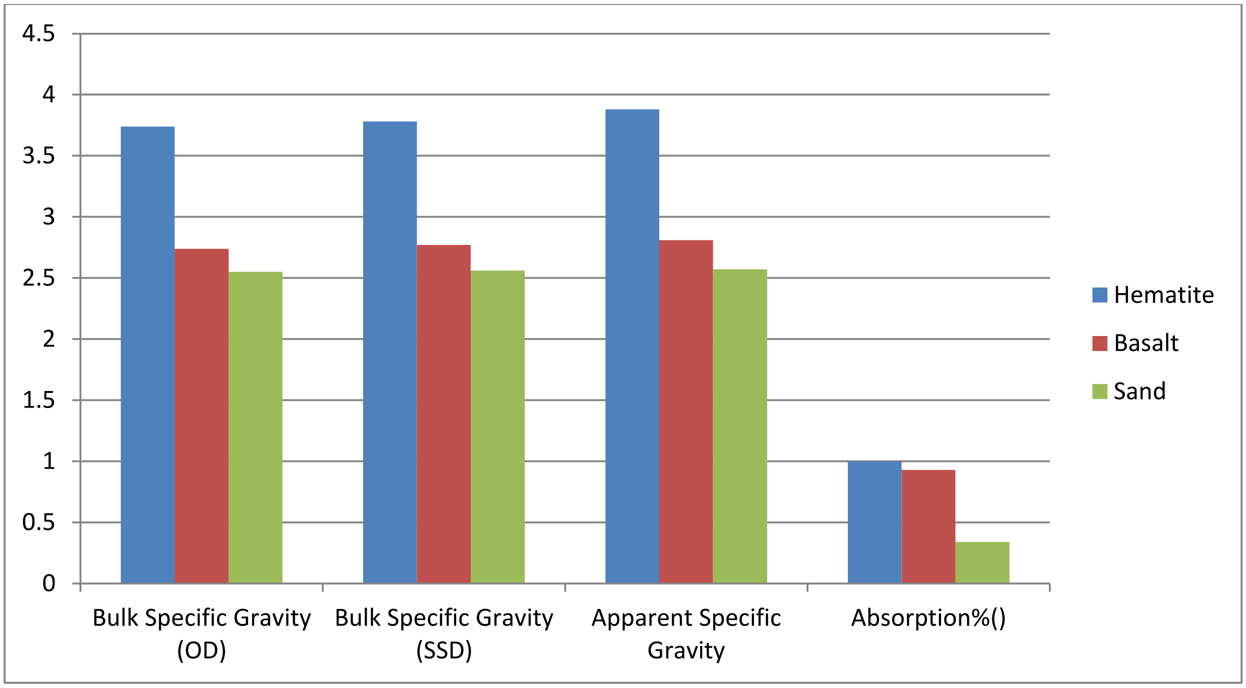



Figure 6.3.2.2: Specific gravity and absorption of coarse and fine aggregates

### 6.3.3. Gradation of Aggregates

Li (2011) defines gradation as the particle size distribution of aggregates. The particle size distribution is an important attribute of the aggregates. The size of aggregate particles differs from aggregate to another, and for the same aggregate the size is different. Grading determines the paste requirement for a workable concrete since the amount of voids among aggregate particles requires the same amount of cement paste to fill out in the concrete mixture. To obtain a grading curve for an aggregate, sieve analysis has to be conducted.

So, in this test the particle size distribution of fine aggregate is determined by sieve analysis method. The fineness modulus value obtained from the test is later incorporated in the design of the concrete mixture.

The fineness modulus is a factor obtained by adding the percentage of material in the sample that is coarser than each of the following sieves (cumulative percentage retained) and dividing the sum by 100.

Table 6.3.3: Sieve Analysis for Fine Aggregate (ASTM Designation: C 136)

| **Sieve Size (mm)** | **Weight of Sieve (gm)** | **Wt. of Sieve and Retained (gm)** | **Weight of Retained (gm)** | **Percent. Retained (%)** | **Cumulative Coarser (%)** | **Cumulative Passing (%)** |
|---|---|---|---|---|---|---|
| 4.75 mm | 431.4 | 431.4 | 0 | 0.00 | 0.00 | 100 |
| 2.36 mm | 387.4 | 423.6 | 36.2 | 7.31 | 7.31 | 92.69 |
| 1.18 mm | 373 | 501.59 | 128.59 | 25.95 | 33.26 | 66.74 |
| 600µm | 324.9 | 469.2 | 144.3 | 29.12 | 62.38 | 37.62 |
| 300 µm | 302.9 | 419.4 | 116.5 | 23.51 | 85.89 | 14.11 |
| 150 µm | 283.1 | 353 | 69.9 | 14.11 | 100.00 | 0.00 |
| **Total** | | | 495.49 | 100.00 | 288.84 | |

$$\mathbf{FM}=\frac{\sum \textit{Cumulative percetage Coarse}}{\mathbf{100}} = \mathbf{2.89}$$

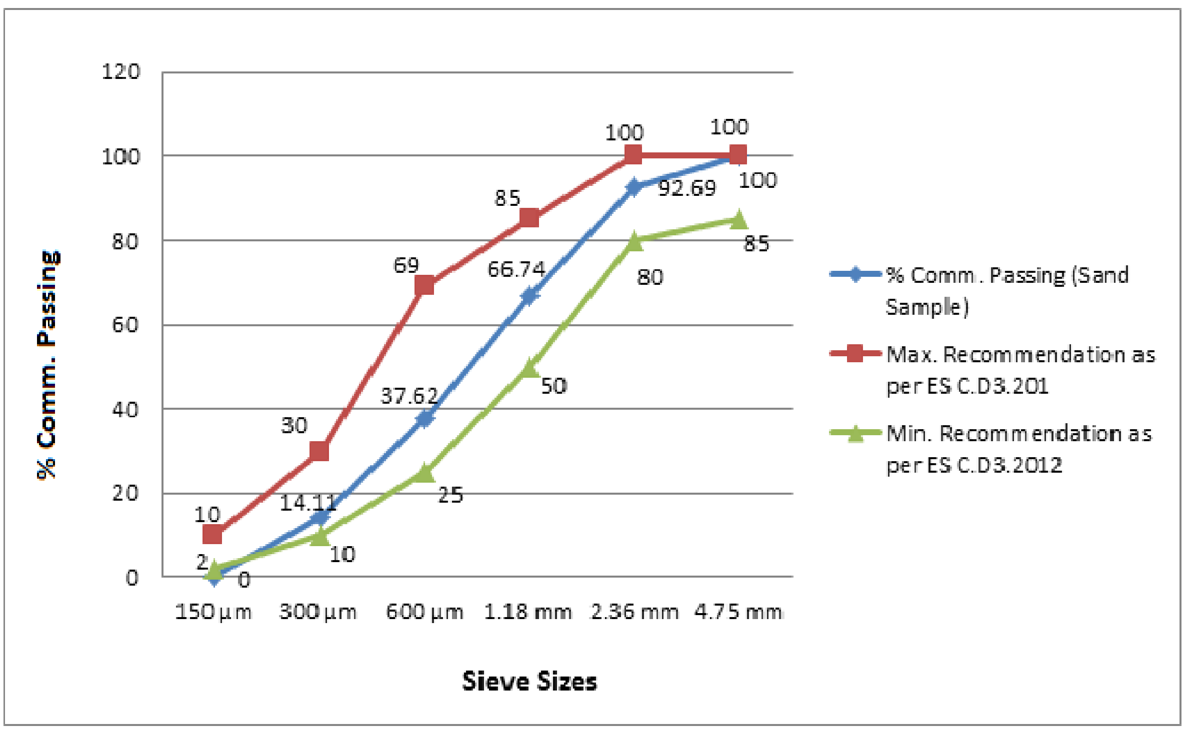



Figure 6.3.3 Grading curve of sand used for the concrete mix Vs Ethiopian Standard (ES C.D3.201)

### 6.3.4. Moisture Content of Aggregates

Abebe Dinku (2002) stated that moisture content of aggregates affect the consistency and strength of concrete mixtures. The amount of moisture present in an aggregate needs to be known before starting the mix design process.

It is necessary to know the moisture content of aggregates in order to determine the net water-cement ratio. The net water-cement ratio affects directly the compressive strength of concrete and the workability/consistency of the concrete mixture.

#### *6.3.4.1.Moisture Content of Coarse Aggregates*

Table 6.3.4.1: Moisture Content of Coarse Aggregate

| **Aggregate Type** | **Basalt** | **Hematite** |
|---|---|---|
| (A)Weight of empty Container | 0.565 Kg | 0.565 Kg |
| (B)Weight of Sample | 3.565 Kg | 5.665 Kg |
| (D)Weight of Oven Dry Sample | 3.474 Kg | 5.59 Kg |
| Moisture Content % = [ ( B – D ) / ( D – A )] x 100 | 3.13 | 1.49 |

#### *6.3.4.2.Moisture Content of Fine Aggregates (Sand)*

Table 6.3.4.2: Moisture Content of Fine Aggregate (Sand)

| **Aggregate Type** | **Sand** |
|---|---|
| (A)Weight of empty Container | 302.8 g |
| (B)Weig.ht of Sample | 800 g |
| (D)Weight of Oven Dry Sample | 793.5 g |
| Moisture Content % = [ ( B – D ) / ( D – A )] x 100 | 1.32 |

## 6.4. Physical Properties of the Blended Aggregates

When two or more aggregates from different sources are blended, some of the properties of the blend can be calculated from the individual components. With the exception of specific gravity and density, the properties of the blend are simple weighted average of the properties of the components (Mamlouk and Zeniewskii, 2011).

A) Hematite and basalt aggregates B) Shovel is used to mix aggregates

Figure 6.4: Preparation of Hematite-Basalt Blend

The relationship can be expressed as: $X = P1X1 + P2X2 + P3X3$ Eqn. (6.4)

Where:

- X- Composite property of the blend
- $X_1$, $X_2$ and $X_3$ are properties of the fractions 1, 2 and 3 decimal
- $P_1$, $P_2$ and $P_3$ are decimal fractions by weight of aggregates 1, 2 and 3 used in the blend, where the total is 1 (Mamlouk and Zeniewskii, 2011)

Accordingly, the dry rodded unit weight, water absorption and the moisture content for the blended aggregates can be calculated using the above formula.

Table 6.4a: Dry rodded Unit weight, Water Absorption and Moisture Content of the Blended Aggregates

| Properties | Hematite (H) | Basalt (B) | Fraction of by weight of Aggregate (H & B) | Blend |
|---|---|---|---|---|
| Dry rodded Unit weight (Kg/m$^3$) | 2608.8 | 1630 | H 25% & B 75% | 1874.7 |
| | | | H 50% & B 50% | 2119.4 |
| | | | H 75% & B 25% | 2364.1 |
| Water Absorption (%) | 1 | 0.93 | H 25% & B 75% | 0.95 |
| | | | H 50% & B 50% | 0.97 |
| | | | H 75% & B 25% | 0.98 |
| Moisture Content (%) | 1.49 | 3.13 | H 25% & B 75% | 2.72 |
| | | | H 50% & B 50% | 2.31 |
| | | | H 75% & B 25% | 1.91 |

Whereas, the Composite specific gravity of a mixture of different aggregates is obtained by the formula:

$$G = \frac{1}{\frac{P1}{G1}+\frac{P2}{G2}+\frac{P3}{G3}} \quad \text{Eqn. (6.4a)}$$

Where: G- Composite specific gravity

- $G_1$, $G_2$ and $G_3$ are specific gravities of fractions 1, 2 and 3.
- $P_1$, $P_2$ and $P_3$ are decimal fractions by weight of aggregates 1, 2 and 3 used in the blend, where the total is 1 (Mamlouk and Zeniewskii, 2011).

Table 6.4b: Bulk specific gravity (OD), Bulk specific gravity (SSD), and Apparent specific gravity of Blend Aggregates

| Properties | Hematite (H) | Basalt (B) | Fraction of by weight of Aggregate (H & B) | Blend |
|---|---|---|---|---|
| Bulk specific gravity (OD) | 3.74 | 2.74 | H 25% & B 75% | 2.94 |
| | | | H 50% & B 50% | 3.20 |
| | | | H 75% & B 25% | 3.45 |
| Bulk specific | 3.78 | 2.77 | H 25% & B 75% | 2.94 |
| | | | H 50% & B 50% | 3.22 |

| | | | | |
|---|---|---|---|---|
| gravity (SSD) | | | H 75% & B 25% | 3.45 |
| Apparent specific gravity | 3.88 | 2.81 | H 25% & B 75% | 3.03 |
| | | | H 50% & B 50% | 3.22 |
| | | | H 75% & B 25% | 3.57 |

## 6.5. Heavy Weight Concrete Mix Design

Kaplan (1989) stated that Heavyweight concrete for radiation shielding can be proportioned using the ACI Method of absolute volumes developed for normal concrete. The absolute volume method is generally accepted and is considered to be more convenient for heavyweight concrete. Therefore, the absolute volume method of concrete mix proportioning is used to obtain the heavyweight concrete samples.

Recommendations from ACI 211.1 (2002) are used to design the concrete mix. In Appendix 4, ACI 211.1 (2002) clearly stipulates the methods used to design heavyweight concrete mix. Accordingly a concrete mixture with compressive strength of 30 MPa is designed for this research experiment. 30 MPa is chosen because of the common use of the specified type of concrete for Radiotherapy room walls and slabs in the construction industry. Concrete samples for the experimental investigation are proportioned following the mix design criteria. All the test samples have similar water to cement ratio and maximum cement content.

### 6.5.1. Preparation of Concrete Mixtures

In this research two type of concretes are produced, the experimental group and control group. The experimental group is prepared by substituting Basalt coarse aggregate with varying percentage of hematite ore aggregate. Concrete with 25%, 50%, 75%, and 100% of hematite ore contents per total volume of coarse aggregate are produced. However, the control group is a normal concrete produced with same cement content, and water to cement ratio as the experimental group.

- Mixture 1 is the control group. It is normal plain concrete made of basalt aggregate, sand, cement and water. It is used as a reference in order to evaluate the performance of experimental groups.

- Mixture 2 is a concrete developed by using a blend of two coarse aggregates. The hematite and basalt coarse aggregate are blended by a proportion of 25:75 respectively.
- Mixture 3 is has a 50:50 blend of hematite and basalt coarse aggregate.
- Mixture 4 is produced by blending the hematite and basalt coarse aggregate by a proportion of 75:25 respectively.
- Mixture 5 is a concrete developed by using hematite aggregate only. The coarse aggregate used in this mixture is 100% hematite aggregate.

Table 6.5.1: Mix detail for C 30 Grade Concrete mixtures for unit $m^3$ with varying percentage of hematite by volume of coarse aggregate

| **Mix Code** | **Cement (Kg)** | **Water (Kg)** | **Sand (Kg)** | **Aggregates (Kg)** | |
|---|---|---|---|---|---|
| | | | | **Basalt** | **Hematite** |
| **CG** | 409 | 179 | 627 | 1200 | - |
| **EG25** | 409 | 179 | 627 | 997.2 | 465.6 |
| **EG50** | 409 | 179 | 627 | 664.8 | 931.2 |
| **EG75** | 409 | 179 | 627 | 332.4 | 1396.8 |
| **EG100** | 409 | 179 | 627 | - | 1862.4 |

### 6.5.2. Mixing Procedure

The following mixing procedure is adopted to blend the ingredients of the concrete. First the course aggregates is put in to the mixer. The fine aggregates and cement will is added and dry mixed. After the ingredients are dry mixed for 1 minute, 80 % of mixing water is added.

Following 1.5 minutes of mixing, the rest of the mixing water is added. All batches are mixed for a total time of 5 minutes; in order to prevent fresh concrete from segregation. After systematically mixing the ingredients, casting of the samples follow.

Figure 6.5.2: Revolving Pan Mixer

## 6.6. Casting, Vibration and Curing Concrete Samples

### 6.6.1. Casting of Concrete Samples

The concrete samples are molded in two ways. For the compressive strength test, concrete cubes of 150 mm sides are cast. In the case of radiation attenuation test, concrete samples with sides 200*200 mm and thickness (D) 100 mm are prepared accordingly.

Table 6.6.1a: Concrete Samples for Gamma Radiation Attenuation Test

| **Percentage of Hematite Content** | **Total Number of samples 200*200mm and thickness (D) 100mm ( D=100mm)** |
|---|---|
| Normal Concrete (0%) | 3 |
| 25% | 3 |
| 50% | 3 |
| 75% | 3 |
| 100% | 3 |
| Grand Total | 15 |

Table 6.6.1b: Concrete Samples for Compressive Strength Test

| Percentage of Hematite Content | Concrete Samples for Compressive Strength Test (150*150*150 mm) | | | Total Number |
|---|---|---|---|---|
| | 7th Day | 14th Day | 28th Day | |
| Normal Concrete (0%) | 3 | 3 | 3 | 9 |
| 25% | 3 | 3 | 3 | 9 |
| 50% | 3 | 3 | 3 | 9 |
| 75% | 3 | 3 | 3 | 9 |
| 100% | 3 | 3 | 3 | 9 |
| Grand Total | 15 | 15 | 15 | 45 |

A sum total of 15 samples for the radiation attenuation and 45 concrete cubes for the compressive strength are prepared.

A) B) C)

Figure 6.6.1: A) 150 * 150 mm and 200*200*100 mm molds, B) Mold oil, C) Concrete samples setting inside molds

### 6.6.2. Vibration of Concrete Samples

After depositing concrete into molds, it is compacted right away. Vibration is a process which increases the consolidation/density of concrete by liberating entrapped air. The purpose of compacting is to remove the air entrapped during concrete placement and to consolidate plastic concrete into all the spaces in the molds. For the research experiment, a table vibrator is used to consolidate the concrete mixtures.

### 6.6.3. Curing of Samples

Moisture is necessary for the proper hardening of concrete. The hydration reaction takes place only in the presence of water. The amount of water normally used at the time of mixing is adequate for this purpose. However, the loss from evaporation from the time the concrete is mixed and placed is usually so rapid that there may not be enough of it left for full hydration. Following casting, the concrete samples are allowed to set inside the molds. After 24 hours are passed the concrete samples are removed from the molds (de-molded).

A) De-molded 150 * 150 mm cube samples B) De-molded 200*200*100 mm samples

Figure 6.6.2a: De-molded concrete samples for compressive strength test and radiation shielding experiment

The de-molded concrete samples are cured at room temperature in a curing tank. The test samples for radiation attenuation test are cured for 14 days, while the curing for the compressive strength test samples are applied for 28 consecutive days. Then, the cured samples are subjected to a series of experimental investigations.

Figure 6.6.2b: Concrete Samples Cured in Water Tank

## 6.7. Design of the Research Experimental

### 6.7.1. Experiment One: Assessment of the Chemical Composition of Hematite Ore and Basalt Aggregate.

**I.** Location: The chemical analysis tests on hematite ore and basalt aggregate is conducted at The Geological Survey of Ethiopia laboratory which is located around Sar-Bet, Addis Ababa.

**II.** Analytical Method: The hematite ore is characterized by $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETIC and AAS methods.

**III.** Analytical Result: Major and Minor oxides are determined in Percentage.

Figure 6.7.1: Atomic Spectroscopy

**6.7.2. Experiment Two: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on essential concrete properties.**

***6.7.2.1.Effect of Hematite on Consistency of Fresh Concrete***

The slump test is the most generally accepted method used to measure the consistency of concrete. The slump is measured according to ASTM C143. The slump is the vertical distance the concrete settles, measured to the nearest 5 mm; a ruler is used to measure from the top of the slump cone (mold) to the displaced original center of the subsided concrete.

***6.7.2.2.Effect of Hematite on Density of Concrete***

The density (unit weight) of the freshly mixed concrete is determined in accordance with ASTM C 138. A digital balance or scale and container are used to measure weight. The size of the container used is a 7-litter air meter container. The concrete is consolidated adequately by means of a table vibrator. The extra concrete is strike off from the top of the surface using a flat plate so that the container is filled to a flat smooth finish. The density of fresh concrete samples is determined by way of dividing the density with volume of the samples. The density is expressed in kilograms per cubic meter.

To determine the hardened concrete density a digital balance and a ruler are used. First the dimension of the concrete samples is measured by means of ruler and the volume is calculated. Then the weight of the concrete samples is measure by a digital balance. Finally the density of the concrete samples is determined by dividing the density with volume of the samples. The density is articulated in kilograms per cubic meter.

$$D_{sample} = \frac{W_{sample}}{V_{sample}} \qquad \text{Eqn. (6.7.2.2)}$$

### *6.7.2.3.Effect of Hematite on Compressive Strength of Concrete*

Compressive strength is one of the most significant properties of hardened concrete. During the mix design process compressive strength is the principal consideration, since the structural element is required to carry the imposed loads. The maximum value of stress during the loading test is taken as the compressive strength value.  The compressive strength tests is carried out with a digital compressive strength testing machine with a maximum capacity of 3000 KN force. Before testing the specimens, the dimension and weight of each specimen are accurately recorded. The machine is calibrated by the National Metrology Institute Calibration in a regular pattern; therefore the accuracy of the measurements is good. Calibration is an important procedure to ensure accurate measurement of mechanical parameters.


A)  Certificate of calibration  B) Digital compressive strength testing machine

Figure 6.7.2.3a: AAiT's Calibrated Digital Compressive Strength Testing Machine

The 7, 14 and 28-days compressive strength of each mix is determined in accordance with the ASTM C109 code. For a cube specimen, BSI sets 0.2–0.4 MPa/sec as the standard loading rate. Accordingly, the load was applied at a constant rate of 0.28 MPa/s and the compressive strength was measured to the nearest two digits after a decimal.

The average of the test results of three specimens belonging to a specific mix is accepted as the compressive strength of that mix for the testing day. The specimens were tested in such a way that the direction of loading is 90 degree to the direction of casting.

Figure 6.7.2.3b shows hematite and basalt aggregates imbedded into the broken concrete samples after the compressive strength test.

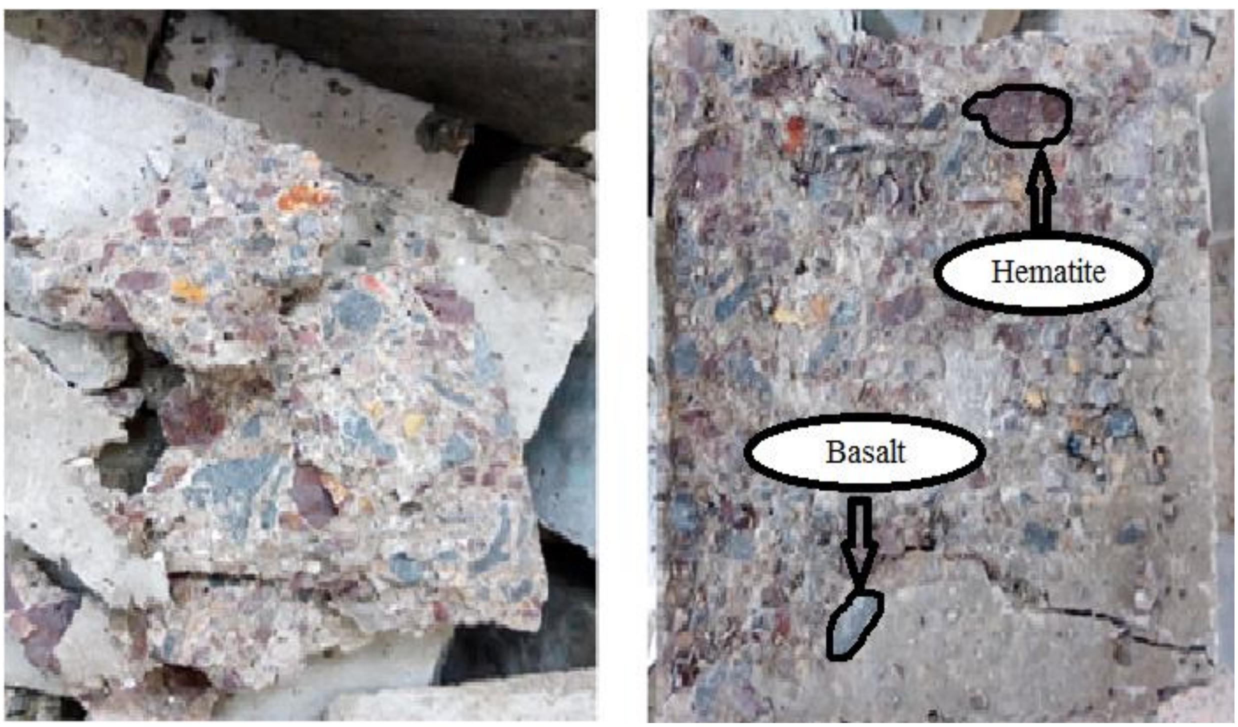



Figure 6.7.2.3b: Left side, broken sample after compressive strength test and right side, hematite and basalt aggregates are visible in broken samples after the compressive strength test

### 6.7.3. Experiment Three: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on photon radiation shielding property of concrete.

The Gamma ray penetration test is conducted using two gamma ray emitting sources: Cesium-137 and Cobalt-60 isotopes. The Gamma radiation shielding investigation using

Cesium 137 isotope is carried out at The Ethiopian Radiation Protection Agency and the radiation shielding test using Cobalt-60 is conducted at Addis Ababa University, Tikur Ambessa Hospital-Radiotherapy Department.

#### *6.7.3.1.Radiation Shielding Property Test of Concrete Using Cesium-137 Isotope*

**A. Photon attenuation coefficient (μ)**

Coefficient of Radiation Attenuation is one of the most important factors required to perform shielding calculation. The value of μ for the shield/Absorber is determined using the radiation transmission (Beer Lambert) equation.

$$I(x) = I_0 e^{-\mu x} \qquad \text{Eqn. (6.7.3.1a)}$$

Two important devices are used to conduct the experimental investigation for determining the Photon attenuation coefficient (μ):  Cesium-137 Isotope and. The Cesium-137 Isotope serves as radiation emitting source and the Radiation Survey Meter is employed to measure the maximum intensity of radiation emanating from the Cesium-137 Isotope at 1 m from the source. The devices are obtained from Ethiopian Radiation Protection Agency and the experiment is conducted at the Agency's Radioactive Source Storage and Processing Facility Located in Kality close to Kadisco Paints P.L.C. The measurements where conducted with a close supervision of a Senior Physicist and the facility manager.

Figure 6.7.3.1a: Radiation survey meter used for assessing the maximum radiation intensity

The initial photon intensity and the photon intensity after passing through the absorber/shield are determined using the transmission obtained by directing a collimated narrow beam of gamma radiation from a cesium-137 source. The initial photon intensity $I_0$ is determined first before placing concrete samples/ absorbers between the Survey meter and the radiation source. Then other measurements with concrete samples as shields/absorbers are taken from radiation survey meter and defined as I(x). The concrete samples/ absorbers are positioned in front of the radiation source at 1m straight distance and the photon intensity after passing through the absorber/shield of thickness 100mm I(x) are determined. Finally, the photon attenuation coefficient (μ) is calculated by inserting the variables ($I_0$ and I(x)) into the Beer Lambert equation. Figure 6.7.3.1b demonstrates the experimental setup arranged to determine the initial photon intensity and the photon intensity after passing through the absorber/shield. In this experiment, the initial photon intensity and the photon intensity after passing through the absorber/shield are obtained at the same time and under the same experimental conditions. The distance between the Survey Meter and the Radiation source is 1 m for both of the measurements.

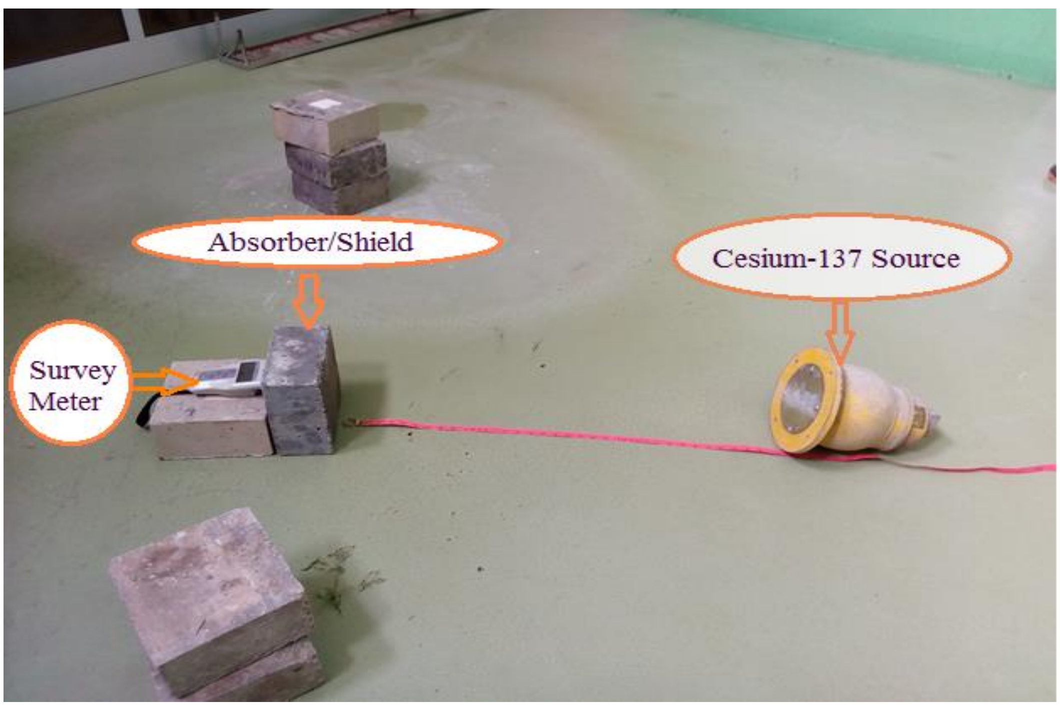



Figure 6.7.3.1b: Measuring the radiation intensity of a collimated narrow beam passing through an absorber/ shield placed at a distance of 1 meter from a Cs-137 source

**B. Half-Value and Tenth-Value Layers**

The effectiveness of the radiation shielding is described in terms of the half value layer (HVL) or the tenth value layer (TVL) of a material. The HVL is the thickness at which an absorber will reduce the radiation from Cesium-137 isotope to half, and the TVL is the thickness at which an absorber will reduce the radiation to one tenth of its original intensity. The HVL and TVL are expressed in units of distance (mm). The values are calculated using the photon attenuation coefficient (μ) of the samples obtained in prior.

$$\text{HVL} = x_{1/2} = \frac{0.693}{\mu} \qquad \text{Eqn. (6.7.3.1b)}$$

$$\text{TVL} = x_{1/10} = \frac{2.3026}{\mu} \qquad \text{Eqn. (6.7.3.1c)}$$

***6.7.3.2.Radiation Shielding Property Test of Concrete Using Cobalt-60 Isotope***

***A. Photon attenuation coefficient***

The gamma radiation source for this experiment is a Cobalt-60 Teletherapy Machine. The radioactive cobalt-60 source consists of a small container which encapsulates disks of cobalt with an activity of about 200 TBq. The source is housed within a large shielded safe which has a shutter mechanism to transport the source into the exposed position. Figure 6.7.3.2a shows a typical Cobalt-60 Teletherapy Machine used at Tikur Ambesa Hospital.

The value of the photon attenuation coefficient (μ) for the shield/Absorber is obtained by directing collimated narrow gamma rays from the Cobalt-60 Teletherapy Machine onto the different absorbers/samples with an ionization chamber placed behind each absorber. Figure 6.7.3.2b shows the experimental setup for measuring the radiation intensity of collimated narrow gamma rays generated from Co-60 Teletherapy Machine.

Figure 6.7.3.2a: Tikur Ambesa Hospital-Cobalt-60 Teletherapy Machine

The photon attenuation coefficient (μ) of the concrete samples is calculated by inserting the measured values of the Initial Exposure Rates and the Exposure Rates after passing through the absorber/shield obtained from the experiment into equation 2.4.2 (Beer Lambert Eqn.).

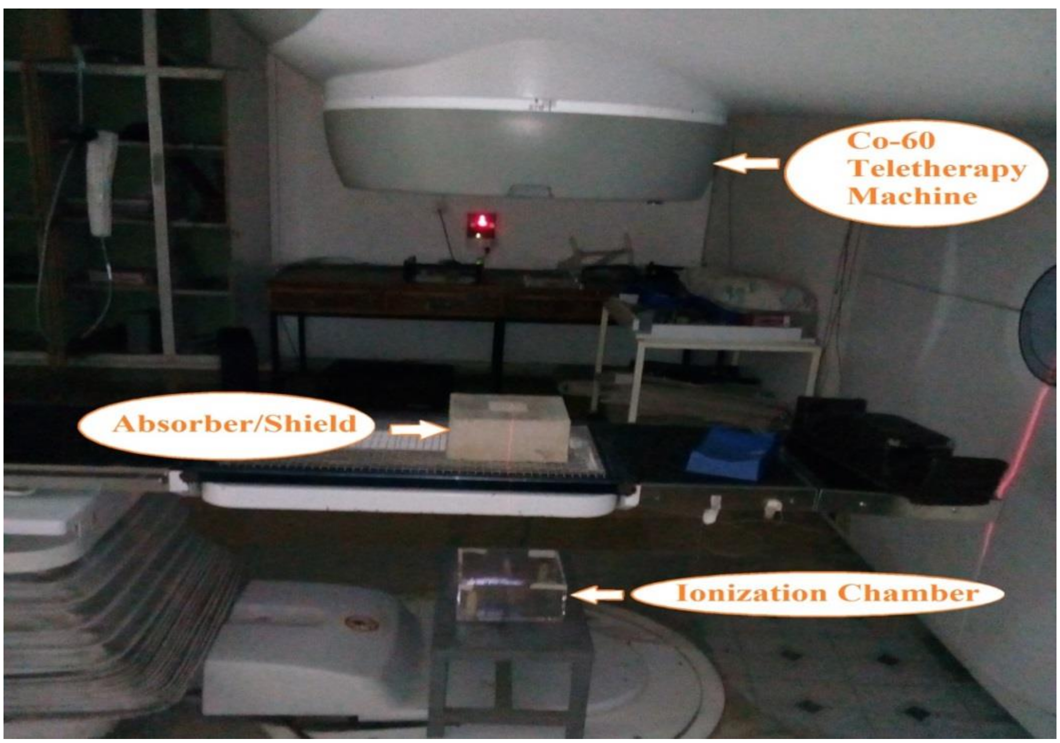



Figure 6.7.3.2c: Measuring the radiation intensity of collimated narrow gamma rays generated from Co-60 Teletherapy Machine

In order to keep the alignment between the line of radiation transfer and the center line of the absorbers/ concrete samples, a laser beam is employed to locate the center of the samples and align the center with the line of radiation flow. Figure 6.7.3.2d below illustrates the method used to align line of radiation transport.

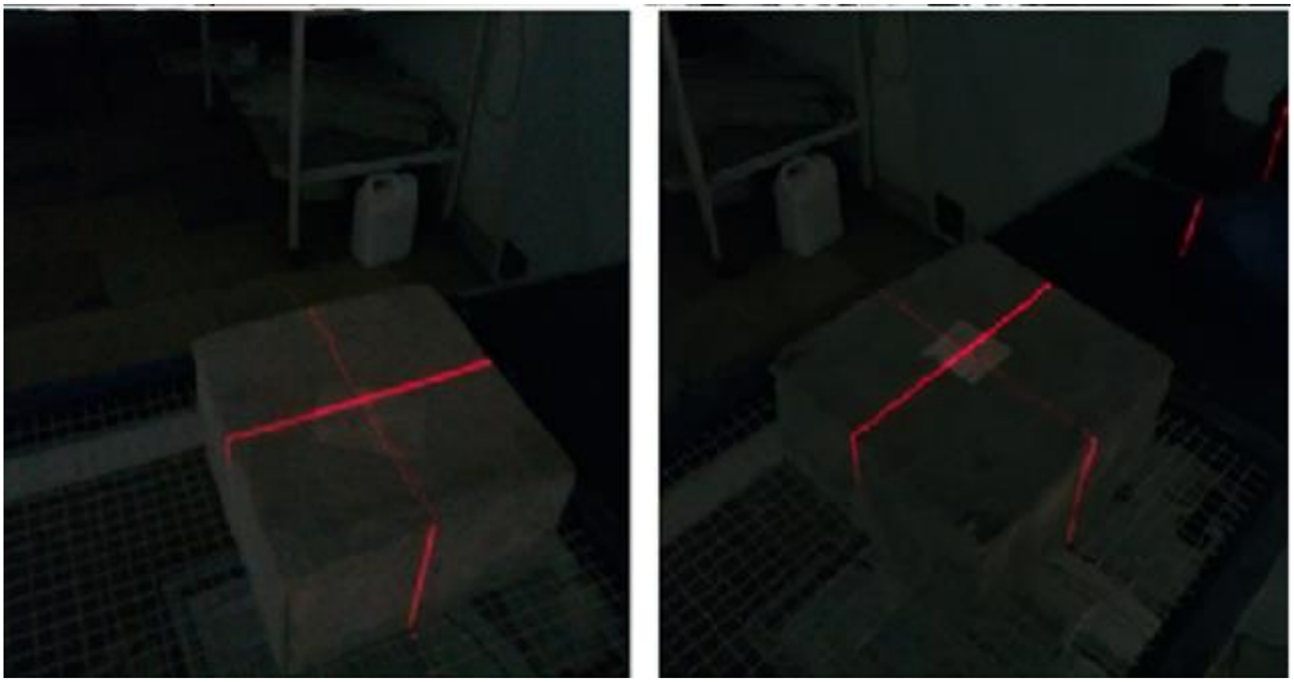


Figure 6.7.3.2d: Concrete Samples aligned in straight line with the radiation source using Laser beams

An Ionization Chamber which is connected with an Electrometer is used to measure radiation Dose and current produced. Ionization chamber is the most widely used type of dosimeter for precise measurements, such as those required in radiotherapy. Such chambers are commercially available in a variety of designs for different applications, and may be constructed in a machine shop when special designs are required.

When Gamma radiation is emitted from the Co-60 Teletherapy Machine it passes through the absorber/shield and hit an Ionization Chamber placed directly behind the concrete samples. The ionization chamber for the research is filled with $1cm^3$ of air. The gamma radiation that hit the ionization chamber will ionize the air and liberate ion pairs. The ionized gas acts like an electric field and movement of ion pairs are measured as a current, which is proportional to exposure rate.

Figure 6.7.3.2e: Left-Ionization chamber, right-Ionization chamber fixed in a glass enclosure and bottom-Electrometer used to measure the current (Devices used together to measure the amount of charge produced in Air by the Cobalt-60 isotope)

Accordingly, the current produced by the ionization process is measured using electrometer and expressed in Microcoulomb (μC). The magnitude of charge or current measured from ionization chambers is estimated from the fact that an exposure of 1 Rontgen (R) generates a charge of $\approx 3\times10^{-10}$ C in 1 $cm^3$ of room-temperature air at a pressure of 1 atm. Figure 6.7.3.2f shows the Electrometer used to measure the current produced in the Ionization chamber.

**B. Half-Value and Tenth-Value Layers**

The half value layer (HVL) and the tenth value layer (TVL) of the shielding materials required to reduce the radiation to half and one tenth of the original value are used to describe the efficiency of the absorber/shielding material. The HVL and TVL are expressed in units of distance. The two values are calculated by introducing photon attenuation coefficient (μ) into equation 2.4.4a and equation 2.2.4b of chapter two, respectively.

# CHAPTER 7 EXPERIMENTAL TEST RESULTS AND DISCUSSION

## 7.1.Introduction

In the previous chapter, concrete making materials are introduced and their properties are assessed thoroughly. Using the measured properties a detailed mix design is prepared for all the mix groups. ACI 121 1 (2002) is used to calculate the mix proportion of the concrete samples. Then five mixture groups are prepared at the Addis Ababa Institute of Technology, Material Laboratory. The mixture groups represent a control group (0% hematite) and experimental groups containing 25%, 50%, 75% and 100% of hematite by volume of total coarse aggregate. After the concrete samples are produced, the Engineering properties of the concrete samples are assessed thoroughly. The consistency of fresh concrete, density of concrete, compressive strength and Gamma radiation shielding property of both the experimental group and the control group is measured systematically.

Based on the research objective, the influence of heavyweight aggregate (hematite) on the gamma radiation shielding and essential concrete properties is assessed using the three experiments designed in chapter 6.

- Experiment One: Assessment of the chemical composition of hematite ore obtained from Sekota/Tsemera iron mine and basalt aggregate from Addis Ababa city.
- Experiment Two: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on workability of concrete.
- Experiment Three: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on density of concrete.
- Experiment Four: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on the compressive strength of concrete.
- Experiment Five: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on gamma radiation shielding property of concrete using Cs-137.
- Experiment Six: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on gamma radiation shielding property of concrete using Co-60.

## 7.2. Experiment One: Assessment of the chemical composition of hematite ore and basalt aggregate.

### 7.2.1. Experimental Results

According to the experimental investigation for the chemical composition, the hematite ore obtained from Sekota is composed of primarily $Fe_2O_3$ and $SiO_2$. It is composed of 81.40% $Fe_2O_3$, 12.36% $SiO_2$, and other minor compounds.

Table 7.2.1a: Complete Silicate Analysis Report of Sekota (Tsemera) hematite

| **Compound** | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | MnO | $P_2O_5$ | $TiO_2$ | $H_2O$ | LoI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Amount (%)** | 12.36 | 2.48 | 81.40 | <0.01 | 0.24 | <0.01 | <0.01 | <0.01 | 0.12 | 0.22 | 0.84 | 2.24 |

On the other hand, the chemical analysis of the basalt aggregate obtained from Akaki (Addis Ababa) showed that it is composed of primarily of $SiO_2$, $Al_2O_3$, $Fe_2O_3$ and CaO. The basalt contains 48.28% $SiO_2$, 16.15% $Al_2O_3$, 13.62% $Fe_2O_3$ and 8.52% CaO

Table 7.2.1b: Complete Silicate Analysis Report of Addis Ababa Basalt

| **Compound** | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | MnO | $P_2O_5$ | $TiO_2$ | $H_2O$ | LoI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Amount (%)** | 48.25 | 16.15 | 13.62 | 8.52 | 5.02 | 3.29 | 0.98 | 0.2 | 0.10 | 2.36 | 0.8 | 0.71 |

The chemical compositional analysis brought to light the difference in chemical makeup of hematite ore and basalt aggregate. As it is clearly evident on the figure 7.2, there is a major difference in the chemical composition of hematite ore and basalt aggregate. The hematite ore has a large amount of $Fe_2O_3$ content, whereas the primary compound that is present in basalt aggregates is $SiO_2$.

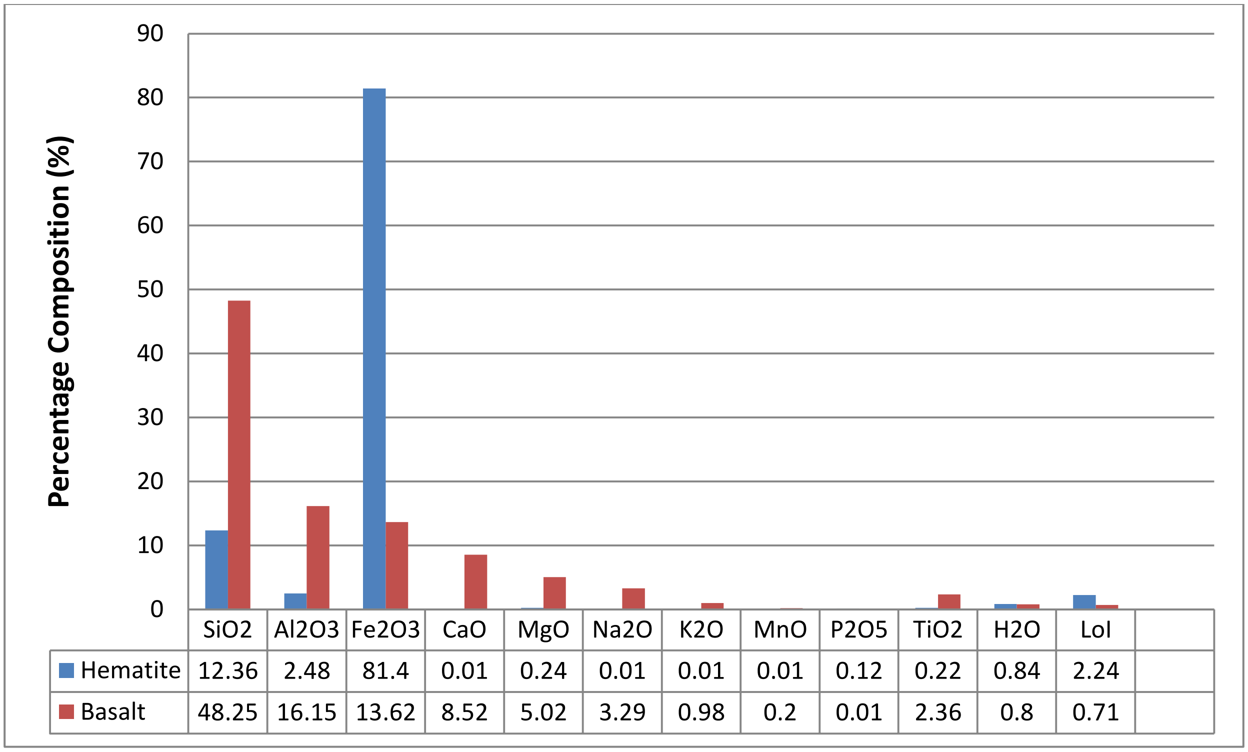



Figure 7.2.1: Comparison of compositional analysis of hematite ore and basalt aggregate

### 7.2.2. Discussions and Interpretations of the Results

Tsemera Hematite is composed of predominantly (>81%) with Iron Oxide. Birhan Getachew (2017) stated high-grade iron ore generally has Fe in excess of 60%. Therefore, the Tsemera Hematite ore can be categorized under high-grade hematite ore.

On the other hand, the Addis Ababa basalt aggregate is composed predominantly of $SiO_2$, $Al_2O_3$, $Fe_2O_3$ and CaO. Karstaedt (1995) in his study of building raw materials in the surrounding of Addis Ababa found the Basalt rocks around Addis Ababa Bole international Airport to be composed of 49% $SiO_2$, 16.1% $Al_2O_3$, 13.74% $Fe_2O_3$ and 8.2% CaO. The result of the composition analysis for the research is very close to the one put forward by Karstaedt.

## 7.3. Experiment Two: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on consistency of concrete.

### 7.3.1. Experimental Results

The slump test is conducted for every mixture prepared to determine the effect of partial substitution of basalt aggregate with hematite ore on consistency. According to the experimental results, the slump values for all concrete mixtures are found to be above the lowest anticipated slump of 50 mm. All the concrete mixtures have slumped evenly all round, so the slump is a true slump. Table 7.3.1 shows slump values of the concrete mixtures.

Table 7.3.1: Slump Values of the Concrete Mixtures

| Mix Code | Slump values, (mm) | Slump Type | Degree of workability as per ASTM C 143-05a |
|---|---|---|---|
| **CG** | 53 | True Slump | Medium |
| **EG25** | 59 | True Slump | Medium |
| **EG50** | 62 | True Slump | Medium |
| **EG75** | 65 | True Slump | Medium |
| **EG100** | 71 | True Slump | Medium |

Furthermore, the slump values for the mixtures show an increasing tendency with increase in the percentage of heavyweight aggregate (hematite). Accordingly, the lowest slump value of 53 mm is recorded from sample CG (0% hematite) which is composed of only basalt aggregate as a coarse aggregate. And the highest slump of 71 mm is recorded for sample EG100 which is composed of 100% hematite aggregate. Figure 7.3.1 illustrates the increase in slump with the increase in hematite content of the concrete samples.

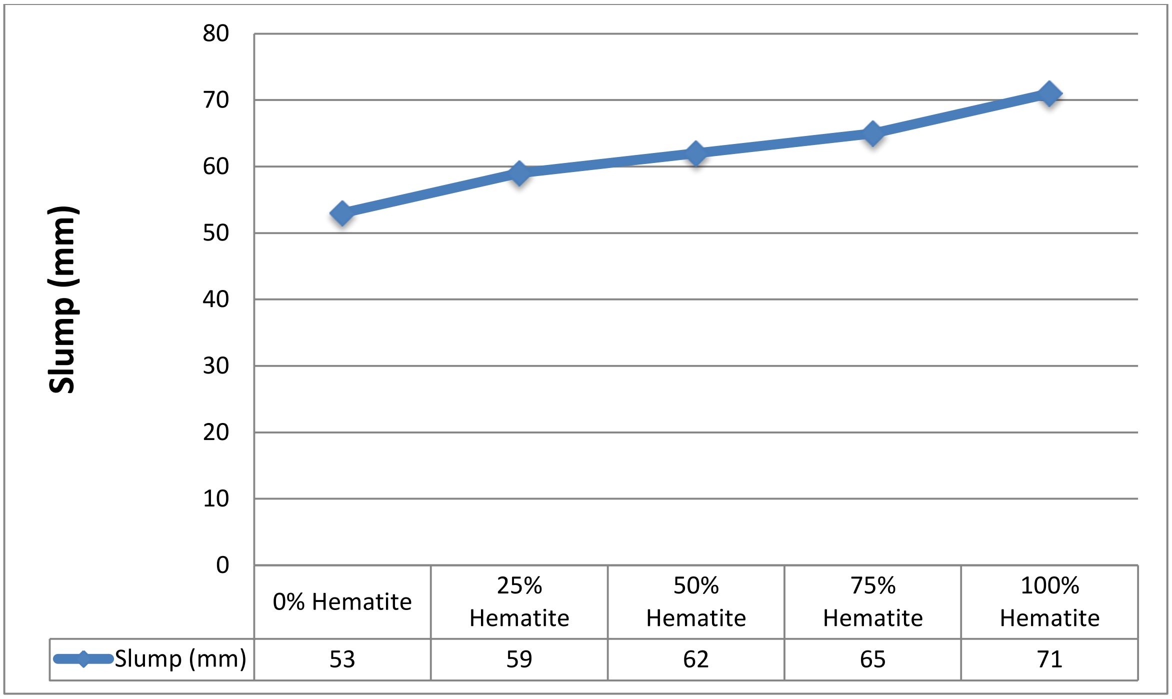



Figure 7.3.1 Effect of hematite content on slump value of fresh concrete

Hence, taking the control group (CG) which is a normal concrete as a reference, the slump of concretes in the experimental group increased as follows: 11.32% for EG25 (25% hematite), 16.98% for EG50 (50% hematite), 22.64% for EG75 (75% hematite), and 33.96% for EG100 (100% hematite).

### 7.3.2. Discussions and Interpretations of the Results

All the slump values range between 53 mm to 71 mm; hence, the degree of workability can be classified as medium range as per ASTM C 143-05a. On the other hand, all the concrete mixtures are slumped evenly, so the consistency is categorized as a true slump. The true slumps of the concrete mixtures indicate cohesion of the mixes.

Additionally, concrete work in radiotherapy bunker construction is categorized under mass concreting because of the large thickness of the walls and slabs requiring huge amount of concrete. ACI 121.1 recommends 25-75mm slump for mass concrete construction. Hence, all the slumps of experimental concrete as well as the control group comply with ACI 121.1 slump recommendations for mass concrete.

## 7.4. Experiment Three: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on Density of Concrete

### 7.4.1. Experimental Results

According to the measurements carried out, the lowest fresh concrete density is recorded for the normal concrete (CG) with a measured density of 2.36 $gcm^{-3}$. The succeeding concrete mixes with 25%, 50% and 75% hematite replacement, showed an increase in fresh concrete density.

The maximum fresh concrete density was obtained from the last mix which is made by replacing 100% of basalt aggregate with hematite coarse aggregate. A fresh concrete density of 3.35 $gcm^{-3}$ is obtained for EG100 (100% hematite concrete). Therefore, the fresh concrete density increased with the rise in hematite content. The results of the fresh concrete densities are shown in Table 7.4.1a.

Table 7.4.1a: Density of fresh concrete for the various mix types and the concrete category

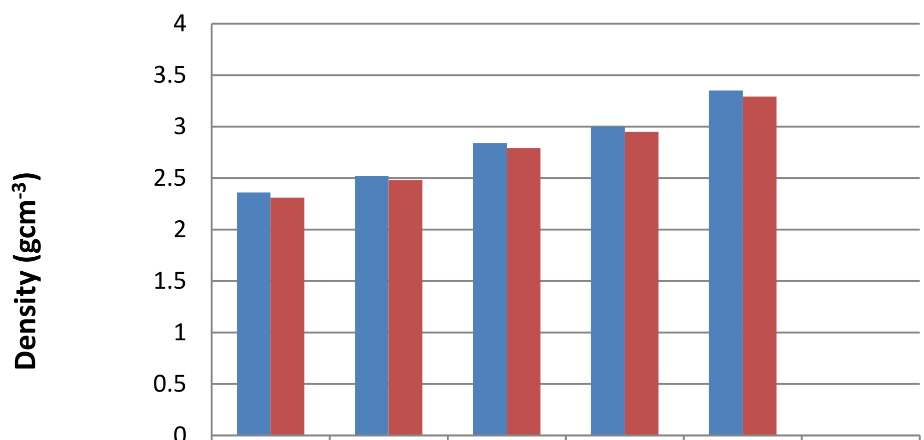
| Mix Name | Volume of Concrete ($cm^3$) | Weight of Concrete (gm) | Density (ρ) of Concrete ($gm/cm^3$) | Concrete Category based on NCRP 151 |
|---|---|---|---|---|
| **CG** | 7000 | 16520 | 2.36 | Normal Concrete |
| **EG25** | 7000 | 17660 | 2.52 | Heavyweight Concrete |
| **EG50** | 7000 | 19890 | 2.84 | Heavyweight Concrete |
| **EG75** | 7000 | 21010 | 3.00 | Heavyweight Concrete |
| **EG100** | 7000 | 23420 | 3.35 | Heavyweight Concrete |

The second parameter assessed concerning concrete density is the hardened concrete density. Based on the experiment, it is evident that the $28^{th}$ day hardened density for the concrete samples showed an increase with the rise in the percentage of hematite content. The maximum hardened concrete density of 3.29$gcm^{-3}$ is achieved for the mixture with 100% hematite content. The average density of the hardened concrete samples for each mix is shown in the Table 7.4.1b. The detailed raw data for the $28^{th}$ day density of all the concrete samples is attached in the appendix.

Table 7.4.1b: Average 28 day dry concrete density versus hematite content

| **Mix Name** | **Volume ($cm^3$)** | **Weight (gm)** | **Density (ρ) $gm/cm^3$** | **Concrete Category based on NCRP 151** |
|---|---|---|---|---|
| **CG** | 3375 | 7810 | 2.31 | Normal Concrete |
| **EG25** | 3375 | 8370 | 2.48 | Heavyweight Concrete |
| **EG50** | 3375 | 9420 | 2.79 | Heavyweight Concrete |
| **EG75** | 3375 | 9950 | 2.95 | Heavyweight Concrete |
| **EG100** | 3375 | 11090 | 3.29 | Heavyweight Concrete |

The third important factor assessed by the experiment is the difference in density between fresh and hardened concrete samples for similar mixture groups. The density of the hardened concrete for all concrete samples decreased from the initial density in the fresh concrete state. The density decreased from fresh to hardened state as follows: 2.16% for CG (0% hematite), 1.61% for EG25 (25% hematite), 1.79% for EG50 (50% hematite), 1.69% for EG75 (75% hematite) and 1.82% for EG100 (100% hematite). Figure 7.4.1a below shows the decrease in density from fresh to hardened concrete.




| | CG | EC25 | EG50 | EG75 | EG100 | |
|---|---|---|---|---|---|---|
| Fresh Concrete Density (g/cm3) | 2.36 | 2.52 | 2.84 | 3.00 | 3.35 | |
| Hardened Concret Density (g/cm3) | 2.31 | 2.48 | 2.79 | 2.95 | 3.29 | |

Figure 7.4.1a: Comparison b/n Fresh and Hardened Concrete Density

### 7.4.2. Discussions and Interpretations of the Results

Based on the experimental results, three trends concerning concrete density are identified. Both fresh and hard concrete density increased with an increase in the percentage of hematite content. The density of concrete is found to be directly proportional to the percentage of hematite aggregate. The highest density is recorded for the concrete group with 100% hematite ore as a coarse aggregate.

The results obtained showed a similarity with the experiment conducted by Singh and Ramana (2014). The research conducted by Singh and Ramana shows that an increase in the percentage of hematite coarse aggregate increases the concrete density. The increase in the density is attributed to heavy density of Fe (iron) which is the major compound in hematite ores.

According to NCRP 151 (2005), heavyweight concrete is usually considered to have a density of >2.35 $g/cm^3$. Therefore, based on the NCRP 151 definition, mix CG (0% hematite) is categorized as a normal weight concrete. Mix EG25, EG50, EG75, and EG100 with hematite contents of 25%, 50%, 75%, and 100% respectively can be classified as heavyweight concretes.

Density of concrete is also found to decrease with the process of hardening. The density of the concrete samples decreased by an average amount of 1.82% during the 28 day curing period. The decrease in density from fresh to hardened state can be attributed to the liberation of mixing water.

## 7.5. Experiment Four: Assessment of the effect of partial substitution of basalt aggregate with hematite ore on Compressive Strength Concrete.

### 7.5.1. Experimental Results

#### *7.5.1.1. Effect of Curing Age on the Compressive Strength of Concrete*

The average compressive strength of three concrete cubes is used to represent the compressive strength value of the mix for the curing day. The experimental output show that the compressive strength of all the five mixture groups increased considerably with an increase in the curing age.

The experimental results complement ACI 206 regulations. According to ACI 206, the compressive strength in the first 7 days may reach 65 to 75% of 28 days compressive strength and compressive strength at the 14 days can reach 80-90% of 28 days compressive strength. Figure 7.5.1.1 presents the increase in the average compressive strength of concrete mixtures with curing age.

The following relation is obtained from the rate of strength development of the concrete:

- The ratio of the $7^{th}$ /$28^{th}$ day and $14^{th}$/$28^{th}$ day compressive strength for the control group is 70.33% and 90.13%.
- The ratio of the $7^{th}$ /$28^{th}$ day compressive strength for the experimental groups (Concretes with varying percentage of hematite) is between 69.25% and 72.12%.
- The ratio of the $14^{th}$ /$28^{th}$ day compressive strength for the experimental groups is between 86.85% and 90.13%.

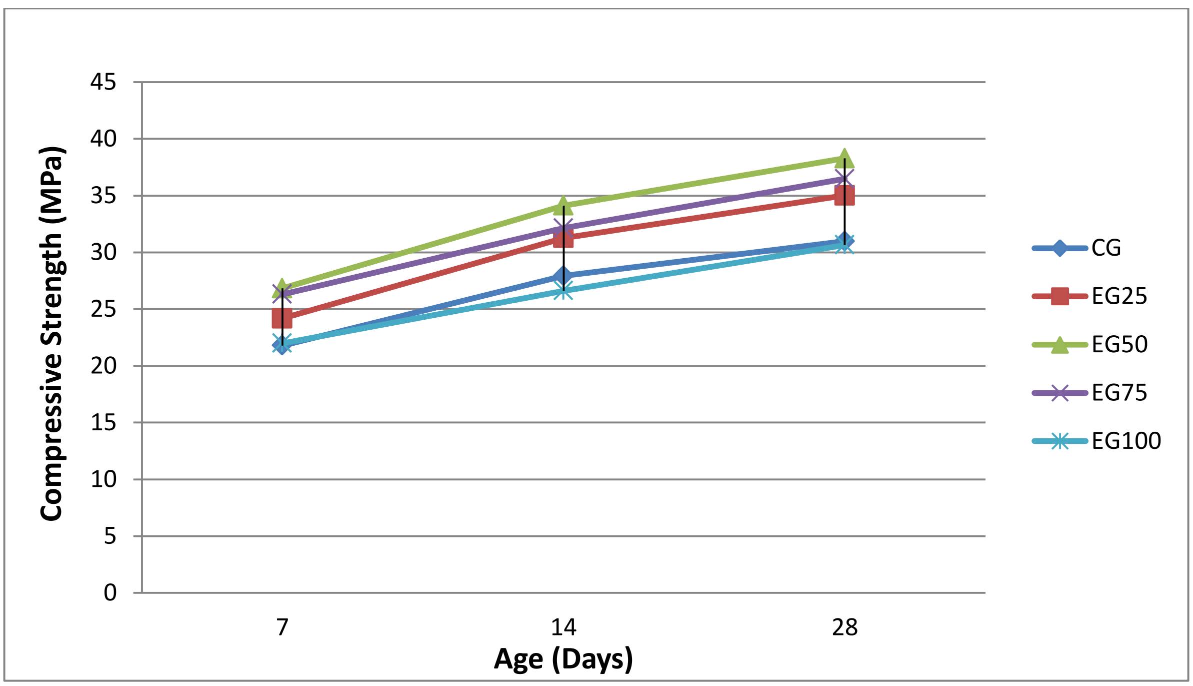



Figure 7.5.1.1 Effect of curing age on compressive strength of concrete samples

### *7.5.1.2. Effects of Hematite Content on the Compressive Strength of Concrete*

The experimental results indicate that with an increase in the hematite content, the compressive strength of the concrete samples increased for all curing ages up to 50%

replacement of basalt with hematite aggregate. The 28$^{th}$ day compressive strength increased from 30.98 MPa for 0% hematite content to 35.01 MPa for 25% hematite replacement of concrete. The maximum compressive strength of 38.28 MPa is reached at 50% replacement of basalt aggregate with hematite aggregate. An increase in the hematite content above 50% replacement of hematite caused the compressive strength of concrete samples to decline. A lowest 28$^{th}$ day compressive strength of 30.65 MPa is recorded for EG100 (concrete with 100% hematite content). The effect of hematite content on the average compressive strength of concrete is shown in Table 7.5.1.2a below.

Table 7.5.1.2a: Effect of Hematite content on the Compressive strength of concrete

| **Mix ID** | **Hematite Content (%)** | **Average Compressive Strength (MPa)** | | |
|---|---|---|---|---|
| | | **7$^{th}$ day** | **14$^{th}$ day** | **28th day** |
| **CG** | 0 | 21.79 | 27.92 | 30.98 |
| **EG25** | 25 | 24.18 | 31.27 | 35.01 |
| **EG50** | 50 | 26.82 | 34.12 | 38.28 |
| **EG75** | 75 | 26.31 | 32.13 | 36.48 |
| **EG100** | 100 | 21.99 | 26.62 | 30.65 |

Taking the control group as reference, the increase in 28$^{th}$ day compressive strength of concretes with a rise in hematite content can be concluded as follows: 13..00% increase for EG25 (25% hematite), 23.56% increase for EG50 (50% hematite), 17.75% increase for EG75 (75% hematite) , and 1.07% reduction for EG100 (100% hematite).

The maximum compressive strength is reached at a 50 replacement of hematite. Hence, 50% replacement of basalt by hematite aggregate produced the maximum 28$^{th}$ day strength of 38.28 MPa. At 100% replacement of basalt by hematite aggregate, the lowest 28$^{th}$ day compressive strength is recorded among all the concrete mixtures.

Therefore, 50% replacement of basalt with hematite aggregate produces concrete with the optimum compressive strength. Increasing the amount of hematite per the total volume of aggregate beyond 50% reduces the compressive strength of the concrete mixture.

**A. Effect of 25% Hematite Replacement on the Mean Compressive Strength**

According the experimental results, the 28th day mean compressive strength of concrete samples has increased considerably with the replacement of 25% volume of basalt with hematite aggregate. Table 7.5.1.2b below compares the 28th day compressive strength Results of sample CG and EG25.

Table 7.5.1.2b: Mean Compressive Strength Results from CG and EG25

| **Cube Result Number** | **Strength @ 28 days – Ordinary Concrete (0% Hematite) (MPa)** | **Strength @ 28 days – EG50 (50% Hematite) (MPa)** |
|---|---|---|
| 1 | 31.57 | 34.52 |
| 2 | 29.79 | 34.42 |
| 3 | 31.58 | 36.08 |
| Mean | 30.98 | 35.01 |
| Standard Deviation (S) | 1.031 | 0.931 |

The shewhart chart in Figure 7.5.1.2a clearly shows that there is a 4.03 MPa 28th day concrete compressive strength difference between the two mixtures. Therefore, substitution of 25% of volume of basalt with hematite has increased the 28th day mean compressive strength by 4.03 MPa.

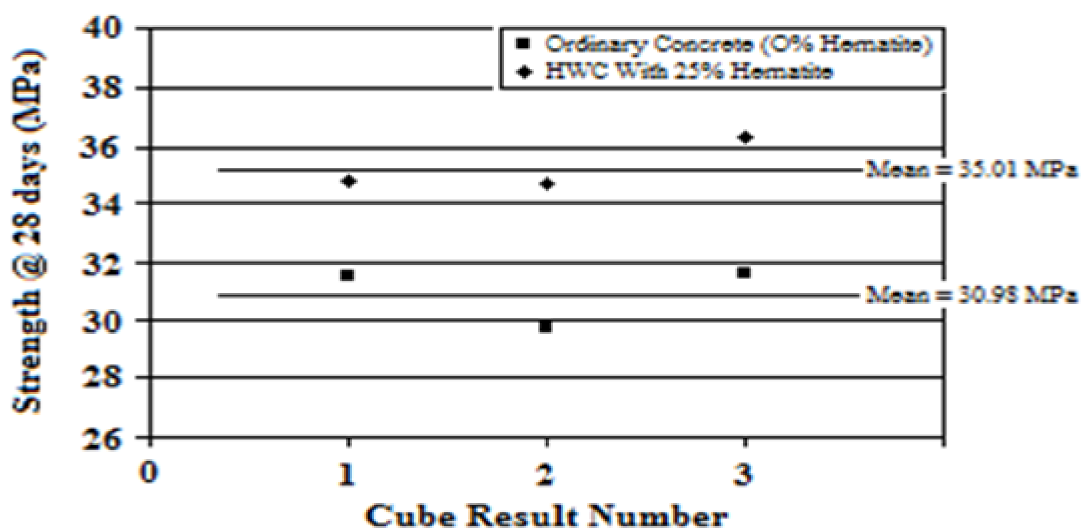



Figure 7.5.1.2a: Shewhart Chart for comparing compressive strength of CG and EG25

The confidence limits for the strength difference are as follows:

- Strength difference with confidence limits = ($Y_{m1}$ - $Y_{m2}$) ± t $\alpha_{/2}\sqrt{S_w^2\ (\frac{1}{n_1}+\frac{1}{n_2})}$ ; Where within-sample variation
  - $S_w^2$ = $[(n_1-1)S_1^2$ + $(n_2-1)S_2^2]$ / $[n_1+\ n_1-2\ ]$
  - $n_1 and\ n_1$= numbers of results in datasets 1 and 2 respectively
  - t $\alpha_{/2}$is based on $(n_1+\ n_1-2)$ degrees of freedom (DOF) = 4
  - α = 0.025 in each tail or 95% confidence
- Hence, $S_w^2$ = $[(3-1)\ 1.031^2$ + $(3-1)\ 0.931^2]$ / $[3+3-2\ ]$

  $S_w^2$ = [2.1259+ 1.7335] / 4 = 0.965

  t $\alpha_{/2}$ = 2.776
- Therefore, Mean strength difference = 4.03 ± 2.776 × 0.965 = 4.03 ± 2.68. The result of the Mean strength difference shows that a 25% replacement of hematite improved the concrete strength between 1.35 MPa and 6.71 MPa.

**B. Effect of 50% Hematite Replacement on the Mean Compressive Strength**

The experimental results indicate that a 50% replacement of volume of basalt with hematite aggregate increased the 28$^{th}$ day compressive strength for all concrete samples. Table 7.5.1.2c below compares the 28$^{th}$ day compressive strength results of sample CG and EG50. Additionally, the 28th day concrete compressive strength at 50% replacement of basalt with hematite aggregate is found to be highest among all concrete mixtures.

Table 7.5.1.2c: Mean Compressive Strength Results from CG and EG50

| Cube Number | Strength @ 28 days Ordinary Concrete (0% H) | Strength @ 28 days EG50 (50% H) |
|---|---|---|
| 1 | 31.57 | 38.35 |
| 2 | 29.79 | 38.56 |
| 3 | 31.58 | 37.94 |
| Mean | 30.98 | 38.28 |
| SD | 1.031 | 0.315 |

The shewhart chart in Figure 7.5.1.2b undoubtedly indicates that for 28 day of curing concrete there is a 7.3 MPa strength difference between the two mixtures. Therefore, substitution of 50% of volume of basalt with hematite has increased the 28$^{th}$ day mean compressive strength by 7.3 MPa.

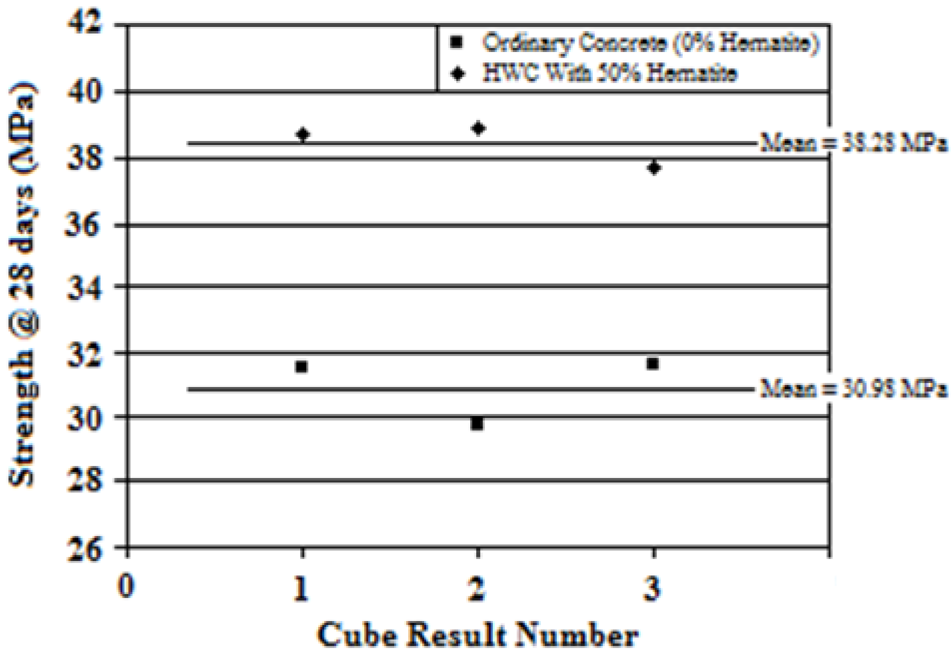



Figure 7.5.1.2b: Shewhart Chart for comparing compressive strength of CG and EG50

- Strength difference with confidence limits = ($Y_{m1}$ - $Y_{m2}$) ± t $\alpha_{/2}\sqrt{S_w^2\ (\frac{1}{n_1}+\frac{1}{n_2})}$ ; Where within-sample variation $S_w^2$ = [$(n_1 - 1)$ $S_1^2$ + $(n_2 - 1)$ $S_2^2$] / [$n_1 +\ n_1 - 2$ ]
    - $n_1 and\ n_1$= numbers of results in datasets 1 and 2 respectively
    - t $\alpha_{/2}$is based on $(n_1 +\ n_1 - 2)$ degrees of freedom (DOF) = 4
    - α = 0.025 in each tail or 95% confidence

- Consequently, $S_w^2$ = [$(3 - 1)\ 1.031^2$ + $(3 - 1)\ 0.315^2$] / [$3 + 3 - 2$ ]

  $S_w^2$ = [2.1259+ 0.1984] / 4 = 0.58

  t $\alpha_{/2}$ = 2.776

- Therefore, Mean strength difference = 7.3 ± 2.776 × 0.58 = 7.3 ± 1.61. The result of the Mean strength difference shows that a 50% replacement of hematite improved the concrete strength between 5.69 MPa and 8.91 MPa.

**C. Effect of 75% Hematite Replacement on the Mean Compressive Strength**

75% replacement of basalt (in volume) with hematite aggregate increased the 28$^{th}$ day compressive strength for all concrete samples. Table 7.5.1.2d presents the 28$^{th}$ day compressive strength Results of sample CG and EG50.

Table 7.5.1.2d: Mean Compressive Strength Results from CG and EG75

| Cube Result Number | Strength @ 28 days – Ordinary Concrete (0% H) | Strength @ 28 days – EG50 (50% Hematite) |
|---|---|---|
| **1** | 31.57 | 35.66 |
| **2** | 29.79 | 37.76 |
| **3** | 31.58 | 36.01 |
| **Mean** | 30.98 | 36.48 |
| **Standard Deviation (S)** | 1.031 | 1.125 |

The shewhart chart below shows the mean compressive strength at 28$^{th}$ day of curing concrete. Substitution of 75% of volume of basalt with hematite has increased the 28$^{th}$ day mean compressive strength by 5.5 MPa.

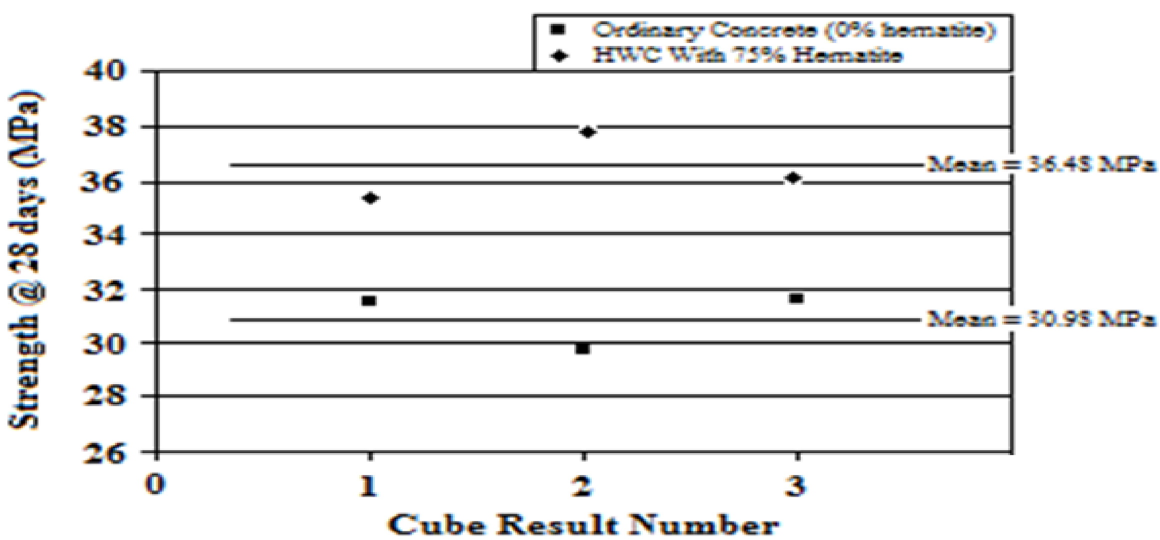



Figure 7.5.1.2c: Shewhart Chart for comparing compressive strength of CG and EG75

The confidence limits for the strength difference are as follows:

- Strength difference with confidence limits = ($Y_{m1}$ - $Y_{m2}$) ± t $\alpha_{/2}\sqrt{S_w^2\ (\frac{1}{n_1} + \frac{1}{n_2})}$ ; Where within-sample variation $S_w^2$ = [$(n_1 - 1)\ S_1^2$ + $(n_2 - 1)\ S_2^2$] / [$n_1 +\ n_1 - 2$ ]
  - $n_1 and\ n_1$= numbers of results in datasets 1 and 2 respectively
  - t $\alpha_{/2}$is based on $(n_1 +\ n_1 - 2)$ degrees of freedom (DOF) = 4
  - α = 0.025 in each tail or 95% confidence
- As a result, $S_w^2$ = [$(3 - 1)\ 1.031^2$ + $(3 - 1)\ 1.125^2$] / [$3 + 3 - 2$ ]

  $S_w^2$ = [2.1259+ 2.5312] / 4 = 1.16

  t $\alpha_{/2}$ = 2.776
- Therefore, Mean strength difference = 7.3 ± 2.776 × 1.16 = 5.5 ± 3.23. The result of the Mean strength difference shows that a 75% replacement of hematite improved the concrete strength between 2.27 MPa and 8.73 MPa.

**D. Effect of 100% Hematite Replacement on the Mean Compressive**

Based on the experimental results, with a replacement of 100% basalt (by volume) with hematite aggregate, the 28th day mean compressive strength of concrete samples has shown a decrease. Table 7.5.1.2e below summarizes the 28th day compressive strength Results of sample CG and EG100.

Table 7.5.1.2e: Mean Compressive Strength Results from CG and EG100

| Cube Result Number | Strength @ 28 days – Ordinary Concrete (0% H) | Strength @ 28 days – EG50 (50% Hematite) |
|---|---|---|
| **1** | 31.57 | 31.58 |
| **2** | 29.79 | 29.95 |
| **3** | 31.58 | 30.42 |
| **Mean** | 30.98 | 30.65 |
| **Standard Deviation (S)** | 1.031 | 0.704 |

The shewhart chart in Figure 7.5.1.2d point out that substitution of 100% basalt aggregate with hematite aggregate decreased the 28 day mean compressive strength by 0.33 MPa. Therefore, substitution of 100% of volume of basalt with hematite has reduced the 28th day mean compressive strength by 0.33 MPa.

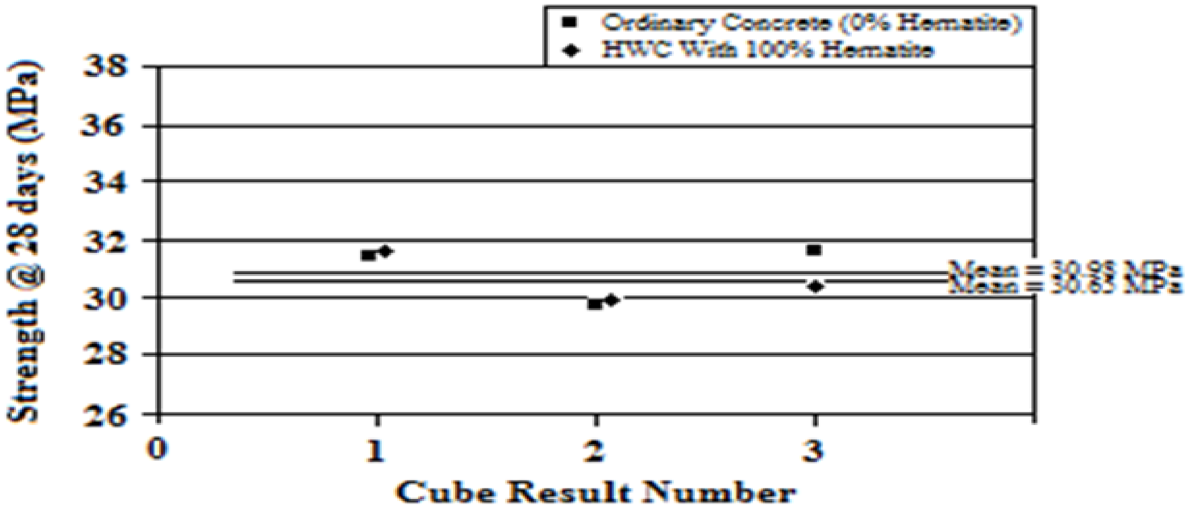



Figure 7.5.1.2d: Shewhart Chart for comparing compressive strength of CG and EG75

The confidence limits for the strength difference are as follows:

- Strength difference with confidence limits = ($Y_{m1}$ - $Y_{m2}$) ± t $\alpha_{/2}\sqrt{S_w^2\ (\frac{1}{n_1}+\frac{1}{n_2})}$ ; Where within-sample variation $S_w^2$ = [$(n_1-1)$ $S_1^2$ + $(n_2-1)$ $S_2^2$] / [$n_1+\ n_1-2$ ]
  - $n_1 and\ n_1$= numbers of results in datasets 1 and 2 respectively
  - t $\alpha_{/2}$is based on $(n_1+\ n_1-2)$ degrees of freedom (DOF) = 4
  - α = 0.025 in each tail or 95% confidence

- Therefore, $S_w^2$ = [$(3-1)\ 1.031^2$ + $(3-1)\ 0.839^2$] / [$3+3-2$ ]

  $S_w^2$ = [2.1259+ 1.4078] / 4 = 0.88

  t $\alpha_{/2}$ = 2.776

- Hence, Mean strength difference = -0.33 ± 2.776 × 0.88 = -0.33 ± 2.44. The result of the Mean strength difference shows that a 100% replacement of hematite improved the concrete strength between -2.77 MPa and 2.11 MPa.

#### 7.5.2. Discussions and Interpretations of the Results

Curing age of concrete is found to be one of the factors that affect compressive strength of concrete. For all concrete mixture groups the compressive strength increased with an increase in the number of curing days. The $28^{th}$ day curing age provided concretes with the highest compressive strength. The phenomenon is credited to the fact that the hydration reaction is undergoing throughout the 28 days of curing.

The second important point is the effect of hematite on the compressive strength of concrete. Compressive strength of concrete samples increased with an increase in percentage of hematite aggregate up to 50% replacement of basalt aggregate with hematite ore. The compressive strength decreased with hematite replacement in excess of 50%. This phenomenon can be attributed to the porous nature of hematite ore. Therefore, the optimum percentage of hematite that provides the maximum compressive strength of concrete is found to be 50% hematite by volume of coarse aggregate.

### 7.6. Experiment Five: Assessment of the effect of partial substitution of Basalt Aggregate with Hematite Ore on Gamma Radiation Shielding Property of Concrete Using Cesium-137 Isotope.

#### 7.6.1. Experimental Results

##### *7.6.1.1. Linear attenuation coefficient (LAC) (μ) and Mass attenuation coefficient (MAC)*

Background radiation emanating from the natural environment is present almost everywhere with varying intensity. Therefore, to obtain the exact value of radiation intensity, the background radiation is assessed first and subtracted from the photon intensities measured using radioactive source. The maximum background radiation measured at the facility is 0.08 μSv/h.

According to the experiment, the Cesium-137 source which is used for the research experiment has an average maximum intensity of 0.64 μSv/h at a straight distance of 1 meter away from the source. Hence, average maximum intensity of 0.64μSv/h is taken as the initial photon intensity ($I_0$). The experimental result shows that the maximum photon intensity after passing through the absorber (I(x)) of thickness 100 mm has shown a decrease with an increase in the percentage of hematite content in the concrete samples. Table

7.6.1.1a shows the average maximum photon intensity after passing through a shield for the five mixture groups.

Table 7.6.1.1a: Relationship between Hematite content and the average maximum photon intensity after passing through a concrete shield of thickness 100mm

| **Mix Code** | **Hematite Content (%)** | **Average Max. Intensity I(x) (μSv/hr)** |
|---|---|---|
| CG | 0 | 0.51 |
| EG25 | 25 | 0.48 |
| EG50 | 50 | 0.39 |
| EG75 | 75 | 0.30 |
| EG100 | 100 | 0.18 |

By inserting the measured initial photon intensity $I_0$ and the photon intensity after passing through the absorber/shield I(x), and thickness of the shield (100 mm) into Radiation Transmission equation the Linear Attenuation Coefficient (LAC) of the concrete samples for the five mix groups is determined. The Mass Attenuation Coefficient (MAC) is determined by dividing the LAC with the density of concrete.

Both the Linear Attenuation Coefficient (LAC) and Mass Attenuation Coefficient (MAC) of the concrete samples increased with an increase in the percentage of hematite content. Figure 7.6.1.1 depicts the rise in Linear Attenuation Coefficient (LAC) and Mass Attenuation Coefficient (MAC) values with the corresponding hematite content of the concrete samples.

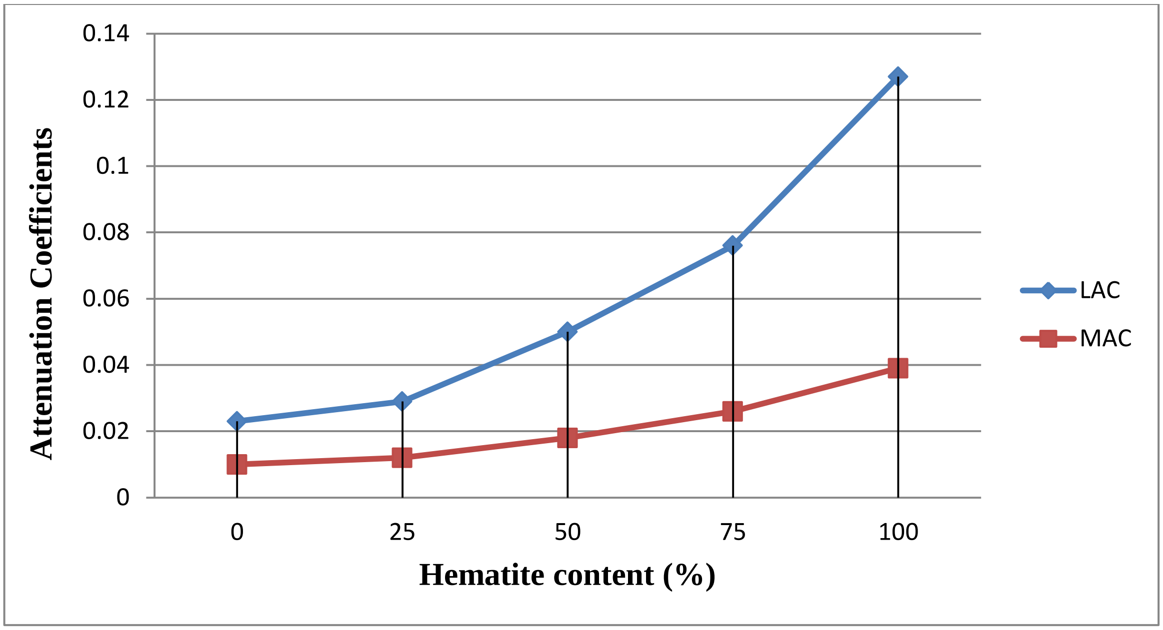



Figure 7.6.1.1: Effect of hematite content on the Linear Attenuation Coefficient and Mass Attenuation Coefficient of concrete mixtures

The linear attenuation coefficient and mass attenuation coefficient increase with an increase in unit weight of the concrete specimens. The lowest LAC and MAC is obtained for sample CG (ordinary concrete): 0.023 $\frac{1}{cm}$ and 0.010 $\frac{1}{cm}$ respectively. Whereas, the highest LAC and MAC values are attained for EG100: 0.127 $\frac{1}{cm}$ and 0.039 $\frac{1}{cm}$ respectively. Table 7.6.1.1b shows the relation between unit weight of concrete and linear attenuation coefficient and mass attenuation coefficient.

Table 7.6.1.1b: Attenuation Coefficients for the five concrete mixtures

| **Mix Code** | **Unit weight ($g/cm^3$)** | **Linear Attenuation Coefficient (1/cm)** | **Mass Attenuation Coefficient ($cm^2/g$)** |
|---|---|---|---|
| CG | 2.31 | 0.023 | 0.010 |
| EG25 | 2.48 | 0.029 | 0.012 |
| EG50 | 2.79 | 0.050 | 0.018 |

| | | | |
|---|---|---|---|
| EG75 | 2.95 | 0.076 | 0.026 |
| EG100 | 3.29 | 0.127 | 0.039 |

#### *7.6.1.2. Half-Value (HVL) and Tenth-Value Layer (TVL)*

The half-value and tenth-value layer of the concrete samples is calculated by inserting the value of linear attenuation coefficient determined above into the equation 2.4.4a and 2.4.4b respectively. Table 7.6.1.2 shows the correlation between Linear Attenuation Coefficient, and half-value and tenth-value layer of the concrete samples. Both the HVL and TVLs decreased with an increase in Linear Attenuation Coefficient or hematite content.

The half-value layer (HVL) showed a substantial decrease when the amount of hematite incorporated in the concrete is increased. Using the Control Group (0% hematite) as a reference, the required HVL and TVL decreased as follows: 21.09% for EG25% (25% hematite), 54.18% for EG50 (50% hematite), 70.03% for EG75 (75% hematite), and 82.12% for EG100 (100% hematite). Therefore, EG100 which is a shield/absorber made of 100% hematite aggregate gives the optimum shielding of gamma radiation emitted from a Cesium-137 isotope. The required HVL and TVL for the concrete sample with 100% hematite decreased by 82.12% relative to the Control group (0% hematite).

Table 7.6.1.2: Half-Value and Tenth-Value Layers

| **Mix Code** | **Linear Attenuation Coefficient (1/cm)** | **Half-Value Layer (cm)** | **Tenth-Value Layer (cm)** |
|---|---|---|---|
| CG | 0.023 | 30.53 | 101.41 |
| EG25 | 0.029 | 24.09 | 80.04 |
| EG50 | 0.050 | 13.99 | 46.49 |
| EG75 | 0.076 | 9.15 | 30.39 |
| EG100 | 0.127 | 5.46 | 18.15 |

### 7.6.2. Discussions and Interpretations of the Results

Two important points are observed from the experiment. The first point is the rise in linear attenuation with an increase in the percentage of hematite in the concrete samples. The increase in the LAC and MAC values can be credited to the high atomic number of iron (Fe) which is the major component of hematite aggregate. Hematite which is composed mainly of iron oxide has a higher combined atomic number than the traditional concrete making materials. The attenuation coefficient is dependent on the particular absorber medium and the photon energy (the material as well as the energy of the radiation). At any specific energy the values of linear attenuation generally increase as the Z (atomic number) of the absorber increases. Because of the high-Z effect, heavyweight aggregates such as hematite and barites are incorporated as concrete making materials in order to increase its effectiveness as a photon shield.

The second point is the decline in the half value and tenth value layers. The HVL and TVLs decreased with an increase in the percentage of hematite aggregate in the concrete samples. The reason behind the phenomenon is that, the density of hematite is higher than densities of other concrete ingredients. Increasing the density of the absorber/medium increased the linear attenuation coefficient.

Additionally, HVL and TVLs are inversely proportional to linear attenuation coefficient. Therefore, an increase in attenuation coefficient decreases the HVL and TVLs. Based on the results, it can be concluded that increase in hematite content decrease the thickness of shield required to reduce the original radiation intensity into half and tenth of its original value.

## 7.7.Experiment Six: Assessment of the effect of partial substitution of Basalt Aggregate with Hematite Ore on Gamma Radiation Shielding Property of Concrete Using Cobalt-60 Isotope.

### 7.7.1. Experimental Results

#### *7.7.1.1. Linear attenuation coefficient (LAC)*

The initial Exposure ($X_0$) is measured without the absorbers/ shield. When the Co-60 machine emits gamma rays at a straight line distance of 1m from the ionization chamber, an average charge of 3.654E-09 C is recorded from the Electrometer. Using the charge-exposure relationship, an average charge of 3.654E-09 C corresponds to an exposure of 12.18 R in 1 $cm^3$ of air. Hence, the initial photon exposure ($X_0$) is 12.18 R.

The photon exposure after passing through the absorber ($X_x$) is found by placing an absorber/shield of thickness 100 mm in between the radiation source and the ionization chamber. Table 7.7.1.1a presents the relation between hematite content and the average exposure (R) after passing through a shield. The average charge in air produced by the Cobalt-60 radiation in the ionization chamber after passing through an absorber showed a decrease with an increase in the hematite content of the shielding concrete samples. A maximum average charge of 9.52E-10 (exposure of 3.17 R) is produced using sample CG (0% hematite) as a shield and a lowest charge of 5.12E-10 (exposure of 1.71 R) is produced when using EG100 (100% hematite) as a shield.

Table 7.7.1.1a: Average maximum photon exposure (R) after passing through a shield

| **Mix Code** | **Hematite Content (%)** | **Average Charge (Coulomb) C per 1 $cm^3$ of Air** | **Exposure ($X_x$) (R)** |
|---|---|---|---|
| CG | 0 | 9.52E-10 | 3.17 |
| EG25 | 25 | 9.06E-10 | 3.02 |
| EG50 | 50 | 8.10E-10 | 2.70 |
| EG75 | 75 | 6.95E-10 | 2.32 |
| EG100 | 100 | 5.12E-10 | 1.71 |

1E-10 = $1*10^{-10}$

By substituting the initial exposure ($X_0$), photon exposure after passing through an absorber ($X_x$), and thickness of the concrete samples (100 mm) into Beer Lambert equation, the values for the linear attenuation coefficient of the concrete specimens is calculated. Table 7.7.1.1b presents the effect of unit weight of concrete in linear attenuation coefficient.

The lowest linear attenuation coefficient of 0.135 $\frac{1}{cm}$ is obtained for sample CG (0% hematite). For the subsequent mixtures the linear attenuation coefficient increased corresponding to the rise in hematite content. The highest linear attenuation coefficient value of 0.196 $\frac{1}{cm}$ is obtained for sample EG100 (100% hematite concrete). The LAC increased with a rise in unit weight of the concrete samples. Using CG (0% hematite) as a reference, the LAC of the succeeding mixtures increased as follows: 2.88% for EG25 (25% hematite), 10.6% for EG50 (50% hematite), 18.67% for EG75 (75% hematite) and 31.12% for EG100 (100% hematite).

Table 7.7.1.1b: Effect of unit weight of concretes on Linear Attenuation Coefficient

| **Mix Code** | **Hematite Content (%)** | **Unit weight (Kg/ $m^3$)** | **Linear Attenuation Coefficient (1/cm)** |
|---|---|---|---|
| CG | 0 | 2.31 | 0.135 |
| EG25 | 25 | 2.48 | 0.139 |
| EG50 | 50 | 2.79 | 0.151 |
| EG75 | 75 | 2.95 | 0.166 |
| EG100 | 100 | 3.29 | 0.196 |

#### *7.7.1.2. Half-Value and Tenth-Value Layers*

The half-value layer and tenth-value layers are computed by inserting the linear attenuation coefficient into their respective formula. With the increase in linear attenuation coefficient both the half-value layer and tenth-value layers decreased tremendously. Table 7.7.1.2 clearly shows the decrease in half-value layer and tenth-value layers due to rise of linear attenuation coefficient in the succeeding mixture groups.

Taking the control group (0% hematite) as a reference the HVL and TVL of the experimental groups decreased as follows: 3.51% for EG25 (25% hematite), 10.70% for EG50 (50% hematite), 18.82% for EG75 (75% hematite) and 31.44% for EG100 (100% hematite).

Table 7.7.1.2: Linear Attenuation Coefficient for the five concrete mixtures

| **Mix Code** | **Linear Attenuation Coefficient (1/cm)** | **Half-Value Layer (HVL) (cm)** | **Tenth-Value Layer (TVL) (cm)** |
|---|---|---|---|
| CG | 0.135 | 5.15 | 17.11 |
| EG25 | 0.139 | 4.97 | 16.51 |

| | | | |
|---|---|---|---|
| EG50 | 0.151 | 4.60 | 15.28 |
| EG75 | 0.166 | 4.18 | 13.89 |
| EG100 | 0.196 | 3.53 | 11.73 |

The half-value layer (HVL) and tenth-value layer (TVL) decreased with an increase in hematite content. According to the results, 100% hematite content concrete provides the optimum HVL and TVL. Therefore, concrete with 100% hematite is the optimum mix ratio and lesser thickness of the material is required to shield the radiation.

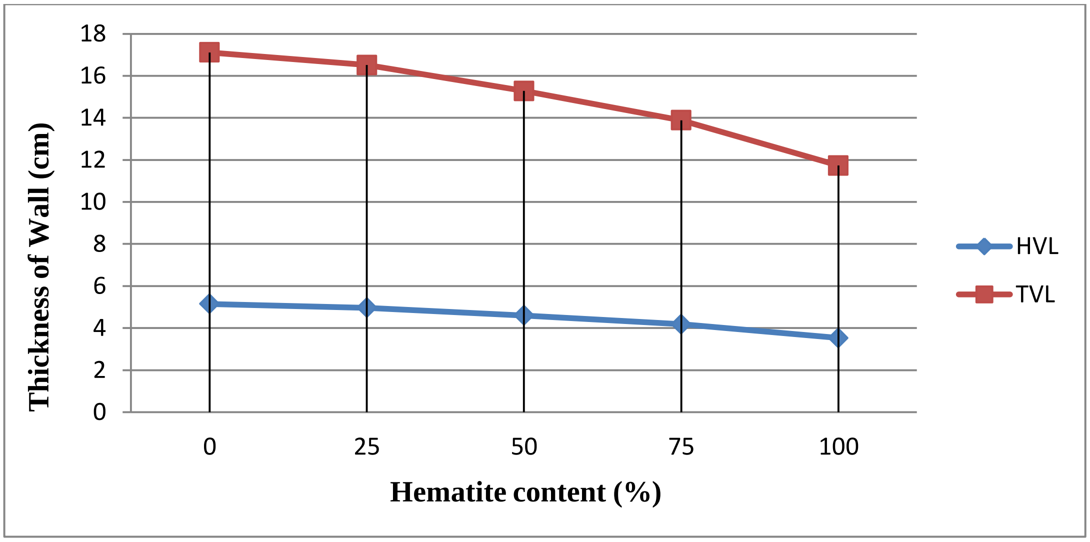



Figure 7.7.1.2: Relationship between hematite content of concrete and the HVL and TVL

### 7.7.2. Discussion and Interpretation of the Results

The experimental outputs depict that the linear attenuation coefficient of the concrete samples increase with an increase in hematite content. The highest attenuation coefficient is obtained for sample EG100 (100% hematite). This indicates that, the high atomic number of iron (Fe) which is the major component of hematite increase the attenuation coefficient of the concrete samples.

Consequently, the rise in linear attenuation coefficient in turn decreased the required half-value layer and tenth-value layers. The reason behind is the inverse relationship that exists between attenuation coefficient and HVL and TVLS. This indicates that it is possible to decrease the required half-value layer and tenth-value layers of shield material by incorporating hematite aggregate into the concrete mixes.

# CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

On the ground of the findings of the experiments, the optimum percentage of hematite that enhance the shielding and the compressive strength of concrete are identified. Based on the experimental work carried out in this particular study, the following conclusions are drawn out. Recommendations for future work are also presented in this chapter that may be taken in consideration.

## 8.1. Appraisal of the Research Objectives

### 8.1.1. Objective 1: Chemical Composition of Sekota/Tsemera hematite ore and basalt aggregate

The research indicates that the basalt aggregate produced at Akaki area (Addis Ababa) is composed of $SiO_2$, $Al_2O_3$, $Fe_2O_3$ and other minor compounds.

The research also indicates that the Sekota/Tsemera hematite ore contains $Fe_2O_3$ in the order of 81.40%. An iron ore which have in excess of 60% iron (Fe) is considered a high grade, therefore the sekota/Tsemera hematite is considered as high grade. High grade hematite ore has higher unit weight therefore, it is ideal for producing heavy weight concrete.

### 8.1.2. Objective 2: Effect of hematite aggregate on Engineering Properties of Concrete

**A. Slump/Consistency of Concrete**

The findings from the experiments showed that workability/slump values of concrete specimens increase with an increase in the content of hematite aggregate. After systematic investigation two main factors are identified as the reasons behind the rise in slump with an increase in hematite for the concrete mixtures in the experimental group.

1. Weight of hematite aggregate: hematite aggregate has a higher unit weight than normal aggregates. The hematite aggregates tend to relatively settle because of the heavy weight, which ultimately increases slump values.
2. Decrease in fine aggregate content: the other reason for the increase in slump is the reduction of fine aggregates in the mix with increase in hematite content. This makes the concrete heavier and susceptible to the effect of gravity.

**B. Unit weight/density of Concrete**

On the other hand, the outcomes of the experiments showed that the fresh concrete density increased from 2.36 $gcm^{-3}$ for the control group, to 3.35 $gcm^{-3}$ for experimental concrete with 100% hematite as coarse aggregate. The dry concrete density also showed a significant increase from 2.31 $gcm^{-3}$ to 3.29 $gcm^{-3}$.

The rise in the density of the concrete is due to the higher unit weight of the replaced hematite aggregate. According to the research hematite aggregate is found to have a higher density than normal gravel aggregate. Addition of hematite aggregate in the concrete mixture subsequently increases the unit weight of the concrete.

Additionally, a variation in density between the fresh and hardened concrete specimens is also observed. The slight decrease in density from fresh concrete to hardened concrete could be explained by the fact that evaporation consumes some amount of the mixing water. The weight of concrete is the cumulative sum of the aggregates including mixing water. In the process of hardening some of the mixing water is evaporated which ultimately reduces the density of concrete in the hardened state.

**C. Compressive strength of Concrete**

The research also gave a clear indication on the effect of hematite on concrete compressive strength. The research indicated that the 28$^{th}$ day compressive strength increased from 30.98 MPa at 0% of hematite to 38.28 MPa at 50% of hematite. After that, when the hematite to total coarse aggregate ratio was increased from 50% to100% concrete compressive strength decreased from 38.28 MPa at 50% of hematite to 30.65 MPa at 100% of hematite. The concrete mixture that performed best on the basis of the compressive strength is mixture which incorporates 50% hematite and 50% basalt as coarse aggregate.

Generally, based on the research it is evident that it is possible to use Sekota/Tsemera hematite ore to produce a heavyweight concrete with a considerable amount of density/unit weight with only one drawback. In all of these successful results, there was one challenge of the segregation of the concrete. The segregation effect was a result of the heavyweight nature of the hematite aggregate.

### 8.1.3. Objective 3: Effect of Hematite Aggregate on the Radiation Shielding property of concrete

The research results show that the radiation shielding capability of concrete improves with an increase in hematite content. The linear attenuation coefficient (μ) which is the best indication for radiation shielding proficiency increased tremendously with the respective increase in the hematite content.

The half-value layers and tenth-value layers which are inversely correlated with the linear attenuation coefficient decreased with the increase in the hematite content of the concrete specimens. This shows that incorporation of hematite in concrete mixtures reduces the thickness of the material required to reduce the photon radiation level to half and one-tenth of the original value. This in turn demonstrates the capacity of concrete with hematite contents to shield gamma rays effectively.

### 8.1.4. Objective 4: Optimum amount of Hematite Aggregate that produce the best quality Radiation Shielding concrete

According to the experimental investigation, concrete having 100% hematite content is found to perform best in relation to radiation shielding capability. In both of the experiments the concrete specimens with all of their aggregates replaced by hematite are found to have higher linear attenuation coefficient. A higher linear attenuation in turn implies a reduction in the half-value and tenth-value layers required to reduce the radiation from its original amount.

### 8.1.5. Objective 4: Evaluate the compliance of the design and construction of Saint Paul Oncology Excellence Center and Yehulashet Hospital Radiotherapy Centers NCRP 151 recommendations.

The method of construction, construction materials used and other important factors are studied for Saint Paul Oncology Excellence Center and Yehulashet Hospital Radiotherapy Centers the assesses. Based on the conducted case study, the radiotherapy rooms for both facilities are constructed using normal concrete. Hence, the designed and constructed walls are in the range of 1.5 to 2.5 meters.

Concerning compliance to NCRP recommendations, Saint Paul Oncology Excellence Center is rated better than Yehulashet Hospital Radiotherapy Center. The design of Saint Paul Oncology Excellence Center is approved the Ethiopian radiation Authority and the construction is being executed by a local grade 1 contractor. On the other hand, Yehulashet Hospital Radiotherapy Center is not approved by ERPA and the construction is executed using Force account method.

## 8.2. Contribution of the Research

The main contribution of this research is in enhancing the understanding of the correlation between hematite content and gamma radiation shielding property of concrete. The research indicated that with the increase in hematite content the linear attenuation coefficient of the concrete samples increased. The rise in linear attenuation reduced the thickness of material required to reduce the original intensity of the radiation to half and one-tenth of the original value (HVL & TVL). This phenomenon clearly indicated that the rise in hematite content increased the gamma radiation attenuation coefficient of the shielding materials. The maximum attenuation coefficient is recorded for EG100 (100% replacement of basalt with hematite). Therefore, 100% replacement of basalt with hematite aggregate is found to produce samples with highest capacity to attenuate/shield gamma radiation.

The other contribution is correlation between hematite aggregate and concrete properties such as slump, density, compressive strength and radiation shielding capability. The research started with a question, whether incorporating hematite aggregate enhances or hinder the most important properties of concrete. Based on the research it is clearly found that the addition of hematite aggregate as coarse aggregate improves the properties of concrete. The average compressive strength of concrete increased with the increase in hematite content. The maximum compressive strength is achieved at 50% replacement of hematite aggregate. An average 28$^{th}$ day compressive strength of 28.28 MPa is recorded for concrete with 50% hematite. Addition of hematite in excess of 50% is found to decrease the compressive strength. Therefore, the optimum amount hematite that will give the maximum average compressive strength is 50% replacement of hematite aggregate.

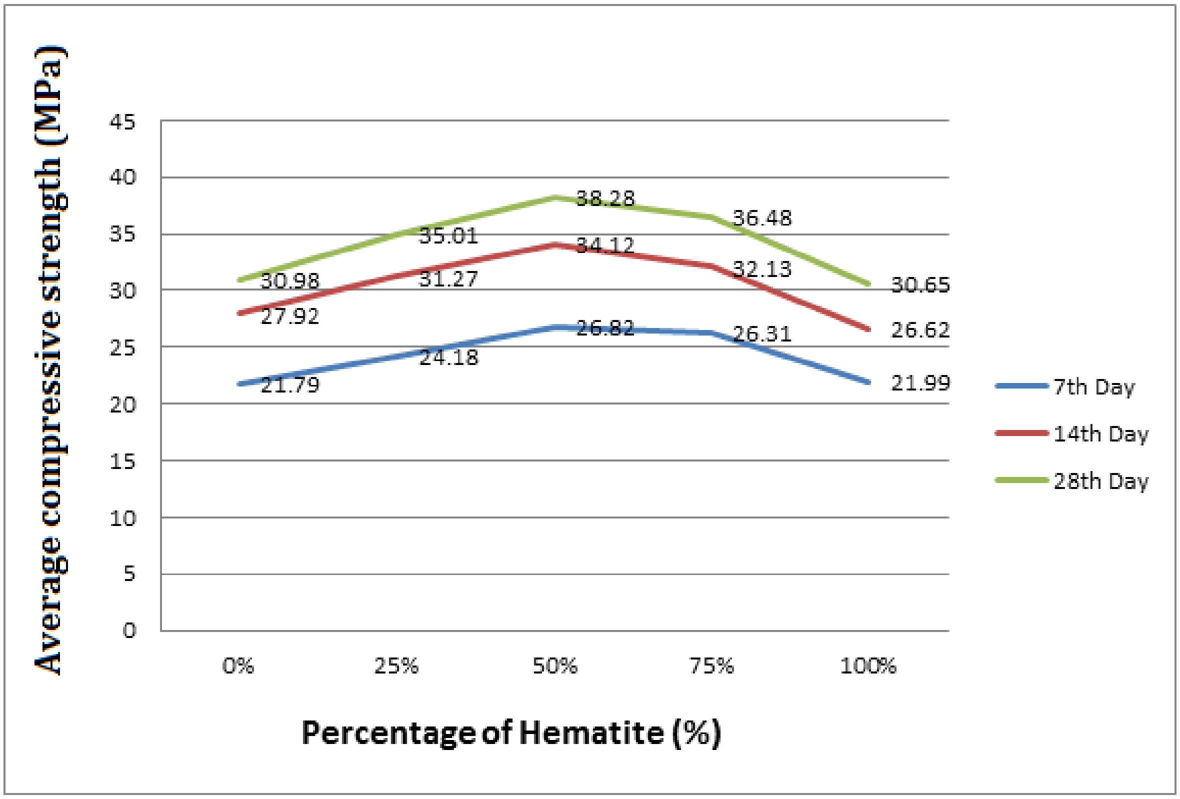



Figure 8.3: Correlation between average compressive strength and hematite content

## 8.3. Recommendations

The study has shown that hematite concrete can be produced to shield radiation energy without compromising the compressive strength and other relevant concrete properties. The following are general recommendations for The Ethiopian Government, construction firms, Universities and Research institutes, researchers and the public.

1. Local construction companies and consultancy firms should use heavyweight concrete such as hematite concrete in the design and construction of radiotherapy rooms.
2. The Ethiopian government should motivate investors to establish local radiation testing firms. The firms should provide radioactive sources and testing equipments.
3. Higher education learning institutions such as universities should motivate researchers to investigate further on new radiation shielding technologies.

The following are key areas identified by the research and which needs further exploration and study:

1. Assessment of the radiation shielding performance of radiotherapy rooms and other health centers that utilize radioactive sources should be conducted.
2. Segregation is one of the major problems in heavyweight concrete production. Heavyweight concrete segregation should be studied in-depth.
3. More investigations should be conducted to clearly learn about the X-ray radiation attenuation of concrete.
4. Additional studies of hematite concrete should be conducted by using different particle sizes of hematite aggregate, water to cement ratio and admixtures.

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# APPENDICES

## A-1: Hematite Chemical Composition Test Report

| | | | |
|---|---|---|---|
| | GEOLOGICAL SURVEY OF ETHIOPIA | Doc.Number: GLD/F5.10.2 | Version No: 1 |
| | GEOCHEMICAL LABORATORY DIRECTORATE | | Page 1 of 1 |
| Document Title: | Complete Silicate Analysis Report | Effective date: | May, 2017 |

Issue Date: -04/07/2019

Customer Name:- Samson Tesfaye

Request No:- GLD/RN/407/19

Report No:- GLD/TR/368/19

Sample type:- Rock

Sample Preparation: - 200 Mesh

Date Submitted: - 11/06/2019

Number of Sample:- One (1)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

| Collector's code | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | MnO | $P_2O_5$ | $TiO_2$ | $H_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sekota Hematite | 12.36 | 2.48 | 81.40 | <0.01 | 0.24 | <0.01 | <0.01 | <0.01 | [illegible] | 0.22 | 0.84 | 2.24 |

**Note:** - This result represent only for the sample submitted to the laboratory.

| Analysts | Checked By | Approved By | Quality Control |
|---|---|---|---|
| Yirgalem Abriham | | | |
| Tihitna Beletkachew | | | |
| Tizita Zemene | Dessie Abebe | Gosa Haile | Negash Worku |
| Yohanis Getachew | | | |
| Bethelhem Tefera | | | |

Figure A-1: Complete Silicate Analysis Report of Sekota/Tsemera Hematite Ore

**A-2: Research Photo Gallery**


A) Entrance Gate

B) Radioactive Source Storage

Figure A-2a: Ethiopian Radiation Protection Authority, Kality Radioactive Source Storage facility

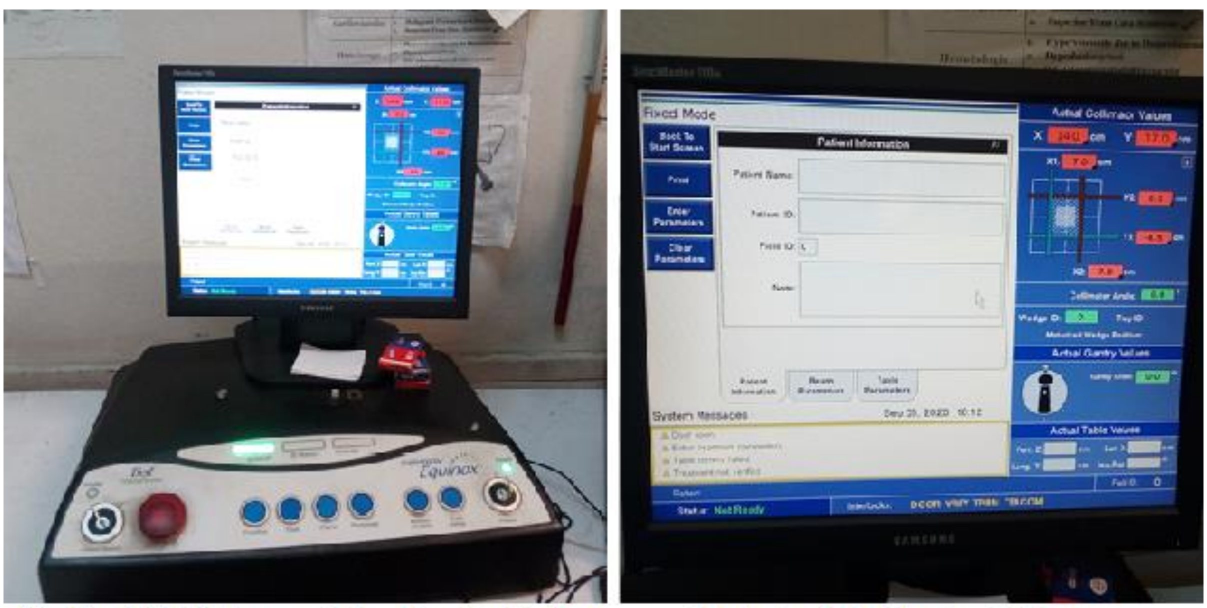
A) Special Interior Door
( Steel and Lead)

B) Normal Exterior Door
(Steel and Glass)

Figure A-2b: Interior and Exterior Gates to The Tikur Ambesa Hospital Cobalt-60 Teletherapy Machine


A) Machine Head B) Full Body of the Machine

Figure A-2c: Tikur Ambesa Hospital Cobalt-60 Teletherapy Machine




A) Co-60 Teletherapy Machine-Radiation Level and Collimator Monitor B) Actual Collimator Values

Figure A-2d: Cobalt-60 Teletherapy Machine Control Monitor

Figure A-2e: Personal Film Dosimeter which measure the Radiation intake of the researcher during the experiment

A) Air pressure Concrete Mold Remover

B) Machine Tip

Figure A-2f: Air pressure Mold Remover Machine

A) Mix 4 Radiation Attenuation Test Sample (75% Hematite)

B) Mix 4 Compressive Strength Test Sample (75% Hematite)

Figure A-2g: Concrete Specimens with 75% Hematite Content Setting inside Molds

A) 200*200*100 mm Normal Concrete Samples

B) 200*200*100 mm Concrete Samples with 50% Hematite Aggregate

Figure A-2h: 200*200*100mm Concrete Samples for Radiation Shielding experiment

### A-3: Raw Data from the Compressive Strength Test

### A-3.1: Data Sheet (ASTM C 39) for Mixture 1 (Normal concrete (100% Basalt))

- Date specimens were casted: 02/21/19
- Description of test specimens: 150*150 mm concrete cubes

Table A-3.1: Raw Data of Compressive Strength Test for Mixture 1 with 0% hematite content

| No. | Test Age (days) | Dimensions (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (KN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15 | 15 | 15 | 8167.50 | 3375 | 470.9 | 20.93 | 2.42 |
| 2 | | 15 | 15 | 15 | 8066.25 | 3375 | 487.6 | 21.67 | 2.39 |
| 3 | | 15 | 15 | 15 | 7998.75 | 3375 | 512.1 | 22.76 | 2.37 |
| | | | | | | Mean | 490.2 | 21.79 | 2.39 |
| 1 | 14 | 15 | 15 | 15 | 7593.75 | 3375 | 644.2 | 28.63 | 2.25 |
| 2 | | 15 | 15 | 15 | 8268.75 | 3375 | 616.5 | 27.40 | 2.45 |
| 3 | | 15 | 15 | 15 | 8167.50 | 3375 | 623.7 | 27.72 | 2.42 |
| | | | | | | Mean | 628.1 | 27.92 | 2.37 |
| 1 | 28 | 15 | 15 | 15 | 7762.50 | 3375 | 710.3 | 31.57 | 2.30 |
| 2 | | 15 | 15 | 15 | 8235.00 | 3375 | 670.3 | 29.79 | 2.44 |
| 3 | | 15 | 15 | 15 | 7863.75 | 3375 | 710.6 | 31.58 | 2.33 |
| | | | | | | Mean | 697.1 | 30.98 | 2.36 |

**A-3.2: Data Sheet (ASTM C 39) for Mixture 2 (25% Hematite and 75% Basalt Aggregate)**

- Date specimens were casted: 02/22/19
- Description of test specimens: 150*150 mm concrete cubes

Table A-3.2: Raw Data of Compressive Strength Test for Mixture 2 with 25% hematite content

| No. | Test Age (days) | Dimensions (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (KN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15 | 15 | 15 | 8775.00 | 3375 | 552.6 | 24.56 | 2.60 |
| 2 | | 15 | 15 | 15 | 8471.25 | 3375 | 531.9 | 23.64 | 2.51 |
| 3 | | 15 | 15 | 15 | 8167.50 | 3375 | 547.4 | 24.33 | 2.42 |
| | | | | | | Mean | 544.0 | 24.18 | 2.51 |
| 1 | 14 | 15 | 15 | 15 | 8268.75 | 3375 | 703.1 | 31.25 | 2.45 |
| 2 | | 15 | 15 | 15 | 8640.00 | 3375 | 696.8 | 30.97 | 2.56 |
| 3 | | 15 | 15 | 15 | 8302.50 | 3375 | 710.6 | 31.58 | 2.46 |
| | | | | | | Mean | 703.5 | 31.27 | 2.49 |
| 1 | 28 | 15 | 15 | 15 | 7863.75 | 3375 | 776.7 | 34.52 | 2.33 |
| 2 | | 15 | 15 | 15 | 8842.50 | 3375 | 774.5 | 34.42 | 2.62 |
| 3 | | 15 | 15 | 15 | 8437.50 | 3375 | 811.8 | 36.08 | 2.50 |
| | | | | | | Mean | 787.7 | 35.01 | 2.48 |

**A-3.3: Data Sheet (ASTM C 39) for Mixture 3 (50% Hematite and 50% Basalt Aggregate)**

- Date specimens were casted: 02/25/19
- Description of test specimens: 150*150 mm concrete cubes

Table A-3.3: Raw Data of Compressive Strength Test for Mixture 3 with 50% hematite content

| No. | Test Age (days) | Dimensions (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (KN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15 | 15 | 15 | 9517.50 | 3375 | 612.7 | 27.23 | 2.82 |
| 2 | | 15 | 15 | 15 | 9483.75 | 3375 | 607.7 | 27.01 | 2.81 |
| 3 | | 15 | 15 | 15 | 9585.00 | 3375 | 590.0 | 26.22 | 2.84 |
| Mean | | | | | | | 603.5 | 26.82 | 2.82 |
| 1 | 14 | 15 | 15 | 15 | 9146.25 | 3375 | 777.4 | 34.55 | 2.71 |
| 2 | | 15 | 15 | 15 | 9787.50 | 3375 | 758.9 | 33.73 | 2.90 |
| 3 | | 15 | 15 | 15 | 9483.75 | 3375 | 766.6 | 34.07 | 2.81 |
| Mean | | | | | | | 767.6 | 34.12 | 2.81 |
| 1 | 28 | 15 | 15 | 15 | 9180.00 | 3375 | 862.9 | 38.35 | 2.72 |
| 2 | | 15 | 15 | 15 | 9247.50 | 3375 | 867.6 | 38.56 | 2.74 |
| 3 | | 15 | 15 | 15 | 9855.00 | 3375 | 853.7 | 37.94 | 2.92 |
| Mean | | | | | | | 861.4 | 38.28 | 2.79 |

**A-3.4: Data Sheet (ASTM C 39) for Mixture 4 (75% Hematite and 25% Basalt Aggregate)**

- Date specimens were casted: 02/26/19
- Description of test specimens: 150*150 mm concrete cubes

Table A-3.4: Raw Data of Compressive Strength Test for Mixture 4 with 75% hematite content

| No. | Test Age (days) | Dimensions (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (KN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15 | 15 | 15 | 10833.75 | 3375 | 580.5 | 25.80 | 3.21 |
| 2 | | 15 | 15 | 15 | 9855.00 | 3375 | 594.2 | 26.41 | 2.92 |
| 3 | | 15 | 15 | 15 | 9517.50 | 3375 | 601.4 | 26.73 | 2.82 |
| | | | | | | Mean | 592.1 | 26.31 | 2.98 |
| 1 | 14 | 15 | 15 | 15 | 9956.25 | 3375 | 752.0 | 33.42 | 2.95 |
| 2 | | 15 | 15 | 15 | 10023.75 | 3375 | 710.1 | 31.56 | 2.97 |
| 3 | | 15 | 15 | 15 | 10091.25 | 3375 | 706.7 | 31.41 | 2.99 |
| | | | | | | Mean | 722.9 | 32.13 | 2.97 |
| 1 | 28 | 15 | 15 | 15 | 10158.75 | 3375 | 802.4 | 35.66 | 3.01 |
| 2 | | 15 | 15 | 15 | 9686.25 | 3375 | 849.6 | 37.76 | 2.87 |
| 3 | | 15 | 15 | 15 | 10057.50 | 3375 | 810.2 | 36.01 | 2.98 |
| | | | | | | Mean | 820.7 | 36.5 | 3.0 |

**A-3.5: Data Sheet (ASTM C 39) for Mixture 5 (100% Hematite Aggregate)**

- Date specimens were casted: 02/27/19
- Description of test specimens: 150*150 mm concrete cubes

Table A-3.5: Compressive Strength Test data for Mixture 5 with 100% hematite content

| No. | Test Age (days) | Dimensions (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (KN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15 | 15 | 15 | 11103.75 | 3375 | 508.5 | 22.60 | 3.29 |
| 2 | | 15 | 15 | 15 | 11272.50 | 3375 | 504.2 | 22.41 | 3.34 |
| 3 | | 15 | 15 | 15 | 11306.25 | 3375 | 471.4 | 20.95 | 3.35 |
| | | | | | | Mean | 494.7 | 21.99 | 3.33 |
| 1 | 14 | 15 | 15 | 15 | 11205.00 | 3375 | 585.9 | 26.04 | 3.32 |
| 2 | | 15 | 15 | 15 | 11070.00 | 3375 | 619.9 | 27.55 | 3.28 |
| 3 | | 15 | 15 | 15 | 11272.50 | 3375 | 591.3 | 26.28 | 3.34 |
| | | | | | | Mean | 599.0 | 26.62 | 3.31 |
| 1 | 28 | 15 | 15 | 15 | 10867.50 | 3375 | 710.6 | 31.58 | 3.22 |
| 2 | | 15 | 15 | 15 | 11272.50 | 3375 | 673.9 | 29.95 | 3.34 |
| 3 | | 15 | 15 | 15 | 11137.50 | 3375 | 684.5 | 30.42 | 3.30 |
| | | | | | | Mean | 689.6 | 30.65 | 3.29 |

## A-4: Raw Data from the Radiation Shielding Test

### A-4.1: Raw Data from the Cesium-137 Radiation Shielding Test

Table A-4.1: Raw Data of the Cesium-137 Radiation Shielding Test

| Mix Code | Hematite Content (%) | Intensity (μSv/hr) | Average Intensity (μSv/hr) |
|---|---|---|---|
| M1RATS1 | 0 | 0.49 | 0.51 |
| M1RATS2 | 0 | 0.52 | |
| M1RATS3 | 0 | 0.51 | |
| M2RATS1 | 25 | 0.49 | 0.48 |
| M2RATS2 | 25 | 0.45 | |
| M2RATS3 | 25 | 0.50 | |
| M3RATS1 | 50 | 0.40 | 0.39 |
| M3RATS2 | 50 | 0.35 | |
| M3RATS3 | 50 | 0.42 | |
| M4RATS1 | 75 | 0.32 | 0.30 |
| M4RATS2 | 75 | 0.30 | |
| M4RATS3 | 75 | 0.27 | |
| M5RATS1 | 100 | 0.18 | 0.18 |
| M5RATS2 | 100 | 0.11 | |
| M5RATS3 | 100 | 0.25 | |

## A-4.2: Raw Data from the Cobalt-60 Radiation Shielding Test

Table A-4.2: Raw Data of the Cobalt-60 Radiation Shielding Test

| Mix Code | Hematite Content (%) | Charge in Air (nC) | | | Average Charge in Air (nC) for Mix Group |
|---|---|---|---|---|---|
| | | Reading 1 (R1) | Reading 2 (R2) | Average (AV.) | |
| M1RATS1 | 0 | 0.948 | 0.948 | 0.948 | 0.952 |
| M1RATS2 | 0 | 0.958 | 0.959 | 0.959 | |
| M1RATS3 | 0 | 0.949 | 0.950 | 0.950 | |
| M2RATS1 | 25 | 0.916 | 0.916 | 0.916 | 0.906 |
| M2RATS2 | 25 | 0.880 | 0.880 | 0.880 | |
| M2RATS3 | 25 | 0.923 | 0.922 | 0.923 | |
| M3RATS1 | 50 | 0.819 | 0.822 | 0.821 | 0.810 |
| M3RATS2 | 50 | 0.765 | 0.765 | 0.765 | |
| M3RATS3 | 50 | 0.843 | 0.843 | 0.843 | |
| M4RATS1 | 75 | 0.723 | 0.721 | 0.722 | 0.695 |
| ``M4RATS2 | 75 | 0.701 | 0.701 | 0.701 | |
| M4RATS3 | 75 | 0.663 | 0.661 | 0.662 | |
| M5RATS1 | 100 | 0.519 | 0.519 | 0.519 | 0.512 |
| M5RATS2 | 100 | 0.484 | 0.484 | 0.484 | |
| M5RATS3 | 100 | 0.531 | 0.533 | 0.532 | |

## A-5: Interview Questions

- What is the Project name and description?
- What is the cost of the project?
- What is the duration of the project?
- Who is the owner of the project, the consultant and contractor?
- What kinds of materials are used in the construction of the radiotherapy centers?
- What is the standard used for the design and construction of the facility?
- What are the dimensions of the primary and secondary barrier of radiotherapy centers?
- What are the methodologies used in the construction of the radiotherapy centers?
- What are the major challenges faced during the construction of the radiotherapy centers?