



***ULTRAHIGH PERFORMANCE CONCRETE AS RADIATION SHIELDING
WITH MIXTURE OF HIGH DENSITY MINERAL***

NOOR AZREEN BIN MASENWAT

FK 2020 31



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By

NOOR AZREEN BIN MASENWAT

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfilment of the Requirements for the Degree of Master of
Science**

August 2019

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DEDICATION

I am grateful to Allah S.W.T for the gift of strength and patience in preparing this thesis. I am humbly dedicate this thesis to my greatest parents, Hajjah Zoraidah Mohd Noor and Haji Masenwat Sanusi as a symbol of sacrifice in educating me as a useful human being. To my dearest wife, Ezalin Syalma Zaidan who never stopped encouraging the soul, illuminated my life with hope and support. To my beloved daughters and son, Iman Soffiya, Iman Sufy Sarah & Raziq Syaheed for the smile and wisdom of life. To my beloved sisters (Yong and Adik) and all my family as a symbol of love and giving.

To all the people in my life, who touch my heart.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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August 2019

Chair: Prof. Madya Ir. Raizal Saifulnaz Muhammad Rashid, PhD

Faculty: Engineering

Radiation shielding linear attenuation coefficients μ (cm^{-1}) is highly depends on the density of the material used. Previous studies have shown the mineral known as barite can be effectively used to increase the specific density of concrete structures. Barite in Malaysia is limited; therefore, a locally available alternative source must be identified to meet the requirements of high-density concrete for radiation shielding. With the aim to explore the possibilities, to be further developed for the application in the hot cell, radiation generating equipment and storing radioactive waste. This study selected steel fiber-reinforced ultra-high-performance concrete (UHPC) samples with different inert materials, namely, silica sand (2700kg/m^3), amang (4000kg/m^3), hematite (2967kg/m^3), barite (4400kg/m^3) and lead glass (3038kg/m^3), as the study object and tested them experimentally for their mechanical properties and radiation absorption capabilities. The UHPC samples showed compressive strength values exceeding 155 MPa at 28 days. Meanwhile, UHPC with lead glass underwent decreased of compression strength in a long period, and UHPC with amang caused an issue related to radiological safety despite that it was effective as a γ -ray shield, UHPC with hematite and barite is very good in radiation absorption but cause an issue of practicality and country reserve. Thus, the use of UHPC with silica sand is practical for constructing nuclear facilities because of the abundance and cost-effectiveness of the involved materials.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

**KONKRIT BERPRESTASI ULTRA-TINGGI DENGAN GABUNGAN
MINERAL BERKETUMPATAN TINGGI BERTINDAK SEBAGAI PENYERAP
RADIASI**

Oleh

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Pengukuran pekali pengecilan linear μ (cm^{-1}) sebagai unit penentuan penyerap radiasi sangat bergantung kepada ketumpatan material tersebut. Kajian terdahulu menunjukkan mineral yang dikenali sebagai barit digunakan dengan berkesan dalam peningkatan ketumpatan spesifik struktur konkrit. Oleh kerana sumber barit di Malaysia adalah terhad, mineral alternatif tempatan lain telah dikenalpasti untuk memenuhi keperluan konkrit berketumpatan tinggi sebagai pelindung sinaran. Dengan tujuan untuk meneroka kemampuannya, untuk dibangunkan lebih lanjut untuk aplikasi di dalam sel panas, peralatan penjanaan radiasi dan penyimpanan sisa radioaktif. Kajian ini menggunakan sampel konkrit berprestasi ultra-tinggi dengan keluli fiber (UHPC) dengan campuran bahan-bahan, iaitu pasir silika (2700kg/m^3), amang (4000kg/m^3), hematit (2967kg/m^3), barit (4400kg/m^3) dan kaca plumbum (3038kg/m^3) sebagai objek kajian dan diuji secara mekanikal dan keupayaan dalam penyerapan radiasi. Sampel UHPC menunjukkan nilai kekuatan mampatan melebihi 155 MPa pada 28 hari. Sementara itu, UHPC dengan kaca plumbum mengalami penurunan kekuatan mampatan dalam tempoh yang panjang, UHPC dengan amang menyebabkan isu yang berkaitan dengan keselamatan radiologi walaupun ia berkesan sebagai perisai γ -ray, UHPC dengan hematit dan barit sangat baik dalam penyerapan radiasi tetapi menyebabkan isu praktikal dan rizab negara. Oleh itu, penggunaan UHPC dengan pasir silika adalah praktikal untuk membina kemudahan nuklear kerana kebolehdapatan dan keberkesanan dari segi kos yang terlibat.

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LIST OF ABBREVIATIONS

TNT	Tri Nitro Toulene
IAEA	International Atomic Energy Agency
UHPC	Ultrahigh Performance Concrete
SS	Silica Sand
B	Barite
H	Hematite
A	Amang
LG	Lead Glass
UPV	Ultrasonic Pulse Velocity
EXAFS	Extended X-Ray Absorption Fine Structure
HVL	Half Value Layer
TVL	Tenth Value Layer
μ_m	Mass Attenuation Coefficient
μ	Linear Attenuation Coefficient
ρ	Density
OPC	Ordinary Portland Cement
PWR	Pressurized Water Reactors
WH	Westinghouse

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CHAPTER 1

INTRODUCTION

1.1 Nuclear & People Perception

The word ‘nuclear’ touches the public’s sensitivity whereby the majority tend to have negative perception as though as the history of nuclear bombing and nuclear related accidents are still fresh in mind. Of course, people should be worried. The following will be the description of the nuclear bombing incident in Hiroshima and Nagasaki back in 1945 during World War II.

“The first world atomic bomb, power by 855g of uranium with energy of 15 kilotons of TNT. After detonation, the bomb creates approximately 410m mushroom cloud with high temperature and high pressure fire ball. Radioactive material spread in a form of black rain and 350,000 human life suffered the direct effect of the bombing. Estimated 140,000 of death reported by the end of 1945 alone” (Yamamura 2013). Figure 1.1 shows mushroom cloud of atomic bomb in Hiroshima and Nagasaki.

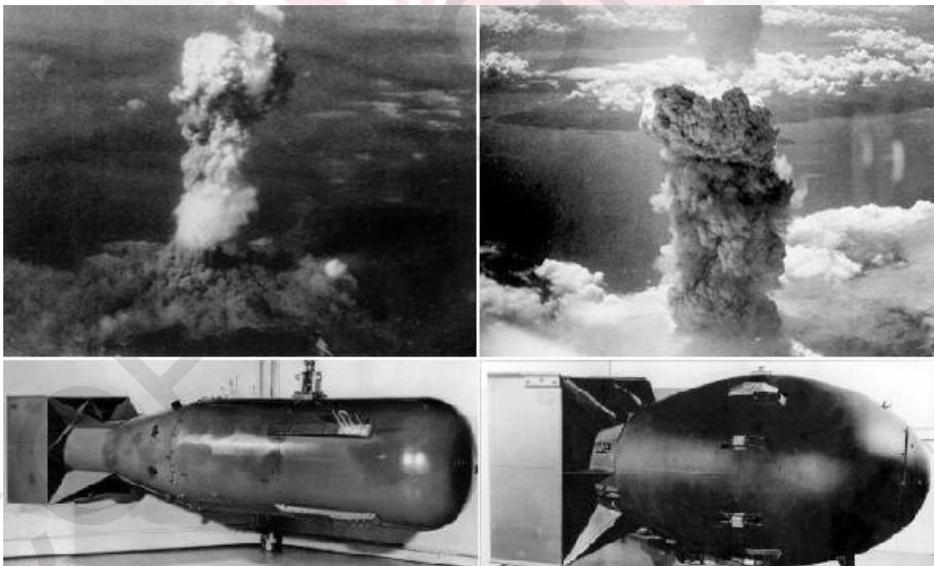


Figure 1.1: Mushroom cloud of atomic bomb in (a) Hiroshima by ‘Little Boy’ and (b) Nagasaki by ‘Fat Man’ in year 1945

The long term effect of the atomic bombing is radiation spreading. Radiation effects human cell, the more radiation source energy absorbed by cell, the greater the biological damages. After effect of radiation exposure may leads to chronic diseases such as chronic aplastic anaemia, angina, cancer of the large intestine, and prostate cancer (McCurry 2015). The facts are, estimated 280,000 people had been exposed to

the atomic bombs in either Hiroshima or Nagasaki. Reported that almost half of the survival are still alive with increased risk of leukaemia, solid tumours, and radiation-induced cataracts (Remembering Hiroshima, 1946). Figure 1.2 shows the situation after the bombing and the survival awaiting for emergency medical treatment in Hiroshima.



Figure 1.2: Survival await for emergency medical treatment in Hiroshima

With this description, why nuclear implicates worry and frighten finally answered. Starting from the first atomic bomb, research with intention on using nuclear fission for peace to generate power were further explored in the west especially America and

Soviet Union (Nuclear Power Today, 2018). Despite of electric generated from fossil fuel (gas and coal), nuclear power plant said to be better option and far beneficial in cases of carbon emission and country energy security. As burning process of coal for electricity produce high amount of carbon dioxides and eventually cause global warming (Jenkins et al. 2018), nuclear power plant also faces a lot of issue about safety if accident occurred. Figure 1.3 shows one of the world's first nuclear power reactors, which operated for nearly 50 years.



Figure 1.3: One of the world's first nuclear power reactors, which operated for nearly 50 years



Figure 1.4: Ariel photo of Fukushima Daiichi incident

The latest major disaster related to nuclear facilities is Fukushima Daiichi incident in 2011. This incident related to earthquakes and tsunami, caused operational and safety infrastructure destruction on the site. The combined effect of earthquakes and tsunami led to loss of electrical power supply off-site and on-site. Finally resulted overheat reactors as well as at the spent fuel pools. The nuclear fuel melted and the containment vessels were breached. Hydrogen was released and lead to explosions inside the reactor buildings. Radionuclides were spread to the atmosphere and were deposited on land and on the ocean (Fukushima Daiichi Incident Report, 2015).

Impacts of Fukushima Daiichi incident in Southeast Asia, it is clear that a few countries would not be able to finalise policy responses on their nuclear power program. Most country delayed their nuclear power program, owing to public safety and cost concerns (Miyasaka 2013). Several countries still considered nuclear power generation to their energy mix supply, but still contemplating between public acceptance and economic growth (Nuclear Energy Agency 2017). Figure 1.4 shows ariel photo of Fukushima Daiichi incident.

1.2 Problem Statement

Nuclear power seems to be an alternative option used around the world to generate electricity as it is more economical and cleaner compared to other power generation systems. However, it needs more specific preparation and planning to ensure the safety of the public and environment. The research on the safety of radiation shielding structure for nuclear facilities using high density concrete has started since year 1987 as shown in Table 2.3. These safety issues as explained in section 1.1 are the main factors which contributed to this research on the usage of high density minerals mixed in Ultrahigh Performance Concrete (UHPC), Ultrasonic Pulse Velocity (UPV) as measuring tool to determine baseline data and the ability of the material in absorbing radiation.

There are various types of concrete used depending on their application. Research carried out between 1996 till 2016 mainly focused on normal strength high density concrete to capture the radiation absorption capacity and mechanical properties. This type of concrete used high density coarse aggregates as the main ingredient in the mixture and the highest compression strength achieved among the researcher was 67 Mpa using Magnetite by Ouda in 2015. The main issue with this kind of concrete type is non-homogeneity thus lead to inconsistency in UPV reading. These inconsistency in the values make it difficult to determine the quality and to estimate compression strength of the concrete when the concrete structure is hit by high forces or pressures such as accidents, natural catastrophe or additional loads incurred on the structure. Concrete structure which are used as nuclear facility requires maintenance through collective data from Non-Destructive Test using UPV to determine that the structure is safe even after being exposed to the environment such as rain, heat, flood and radiation throughout its life span.

The inconsistency in the UPV reading can be resolved when the concrete used are homogenous and can only occur by mixing process through UHPC procedure.

Research using UHPC mixed with high density mineral as a radiation absorption material has yet been explored until 2016, Jankovic' et al used UHPC mixed with Barite mineral in his research for radiation absorption testing. However, the research on obtaining UPV data and mechanical properties on UHPC were not investigated. Therefore, this work studied on the minerals such as Silica Sand, Barite, Hematite, Lead Glass dan Amang as the main materials mixed in UHPC and to observe the UPV readings, mechanical properties and radiation absorption capacity.

From 2012 till 2016, research involving UHPC usually uses silica sand as the main material and has never been tested with high density materials to test on radiation absorption. This research takes into consideration on the density of the materials as the main ingredient in the UHPC mix to be compared to earlier research of concrete mixes using coarse aggregates. Besides that, this research involves the usage of Monte Carlo software to simulate radiation scattering in Dry Cask Storage which have yet to be dwelled upon by earlier researches carried out by El-Khayatt (2010), Gencil et al. (2011) dan Stanković et al. (2010) using winXcom code software, Monte Carlo software and XCOM code. Nevertheless, in their earlier researches they have only simulate cube concrete samples against their experimental results.

1.3 Significant of Study

Concrete has proven to be an excellent and versatile material as radiation shielding. However, with unpredictable climate, heavy monsoon rain leads to heavy flood where the most devastating disaster in Malaysia (D/iya, Barzani Gasim, Ekhwan Toriman, & Abdullahi, 2014). Therefore, it is importance to carry on research to give better solution on the public safety to avoid leaching and migration of the radionuclides to surroundings.

The most advanced concrete technology nowadays is the invention of Ultrahigh Performance Concrete (UHPC) where this cementitious composite can achieve compressive strengths and flexural strength beyond 100 MPa respectively (Richard & Cheyrezy 1995) ductility comparable to steel (Kusumawardaningsih et al. 2015). Conventional reinforced concrete material normally has a specific density range between 2300 kg/m^3 to 2400 kg/m^3 , which might be an issue on safety, toughness and durability if being used in severe environment. The previous research only uses concrete containing high density coarse aggregates (Akkurt et al. 2006) for radiation shielding. However, there have yet to find any research on UHPC. Therefore, in this research the usage of high density minerals have been selected as a replacement to sand in the mixture with UHPC.

Other than that, this research also focus on the maintenance program of UHPC due to lack of quality control methods (Shi et al. 2015) using non-destructive test mainly using ultrasonic pulse velocity (UPV). The results obtain will give bigger picture of UHPC quality and uniformity compared to steel and normal concrete. Previous research only focus on Ultrasonic Pulse Velocity value on concrete containing coarse aggregates. However, there have yet to find any research on UPV value on UHPC. The

information gathered in this study gives input on the baseline data which useful for future research.

1.4 Scope of Study

This study focuses on UHPC mixed with high density mineral mainly from natural minerals (barite and hematite), process waste (lead glass) and secondary by product (Amang). All the UHPC mixed were compared to normal UHPC mixed with silica sand on the mechanical properties (compressive strength, flexural strength and modulus of elasticity). All the materials were obtained in Malaysia.

All UHPC samples were tested for radiation absorption, γ -ray were obtained from ^{137}Cs (2.5 mCi) and ^{60}Co (3 mCi) source which emit photons of 0.66 MeV and 1.33 MeV respectively. A case study on dry cask storage using Monte Carlo software being conducted in this study to simulate radiation absorption capacity through the material. Ultrasonic Pulse Velocity (UPV) measurement was taken as non-destructive test (NDT) to access the quality of the UHPC. The propagation of ultrasonic pulses value were measured using direct and indirect technique.

1.5 Objectives of Research

The objectives of conducting the research are:

- i. To determine mechanical and physical properties of Ultrahigh Performance Concrete with mixture of high density minerals.
- ii. To initiate Ultrasonic Pulse Velocity database for Ultrahigh Performance Concrete with mixture of high density minerals.
- iii. To simulate shielding attenuations of Ultrahigh Performance Concrete mixed of high density minerals/materials with ordinary UHPC and ordinary concrete using γ -ray and Monte Carlo software.

1.6 Organisation of The Thesis

The thesis begin with a quick general background of the study (Chapter 1) mainly on the people perception on nuclear including the significant of the study. Chapter 2 consist of literature review on the current study as well as work have been done by other researchers basically on the mineral addition in concrete for radiation shielding. Technique, method and test conducted in the study explained in Chapter 3. The relationship and influenced of SS-UHPC, H-UHPC, B-UHPC, A-UHPC and LG-UHPC on the mechanical properties, radiation absorption and ultrasonic pulse velocity will be detailed in Chapter 4. The study will be concluded in Chapter 5, which will also include potential future research.

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