EVALUATION OF ALUMINUM DROSS FOR CEMENT REPLACEMENT IN CONCRETE MIXTURE

By

NUR HIDAYAH BINTI MOHD ZAHARI

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

August 2024

FK 2025 3

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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Chairman : Associate Professor Ts. Salmiaton binti Ali, PhD
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The increasing global aluminum market presents both opportunities and challenges, particularly with the production of aluminum dross, which poses significant environmental concerns. In 2023, the global aluminum market size was 70, 593 million tonnes, which indirectly generating approximately 1, 411 million tonnes of aluminum dross, a hazardous by-product. Aluminum dross is considered as a toxic waste in which each tonne of dross is expected to produce 12 tonnes of gaseous pollutants, some of which are explosive, poisonous, and smelly. Presently, particularly in Malaysia, the industry faces challenges in managing aluminum dross as the treatment process involves an intensive cost of up to RM 2000 per tonne. Hence, there is a need for its utilization as an engineering material by using it as a filler material in concrete production.

The cement industry is facing several difficulties, particularly due to raw materials shortages and environmental concerns relating to carbon dioxide, CO_2 emissions into the atmosphere. In this context, the current research work intends to use aluminum dross as a cement replacement material to develop an eco-friendly concrete of M40 grade concrete. This research practice corresponds with the sustainability goals and promotes the circular economy by recycling aluminum dross. In the first stage of study, all six aluminum dross samples provided by Cenviro Sdn. Bhd. were undergone a treatment process prior to use in the concrete mixture to remove foreign matter, salts, and oxides. The first objective of the study characterized all the six treated aluminum dross samples by using X-Ray Fluorescence (XRF) analysis and ammonia test. Based on the outcome, aluminum dross sample 3 (S3) was selected to be substituted into the concrete mixture as it has the highest aluminum content of 53.1% and the lowest ammonia concentration of 75 ppm.

The second objective compared the workability of the concrete-aluminum dross mixture based on the slump test and compressive strength. The results of control concrete, COM1 were compared to those of concrete samples containing aluminum dross by 5% (COM2), 10% (COM3), and 15% (COM4) weight of cement. Among aluminum dross concrete mixture, COM3-S3 (10% aluminum dross sample 3) recorded the highest slump flow at 113 mm, 7 mm lower than the control concrete. COM3-S3 also has the highest compressive strength than control concrete, COM1 at 41.3 MPa.

The third objective of the study evaluated the mechanical, durability, chemical, and toxicity properties of the best treated aluminum dross replacement concrete mixture.

It was discovered that the best percentage of aluminum dross S3 was 10% yielding better outcomes that standard concrete. It recorded the highest compressive strength of 41.3 MPa. Thermogravimetric analysis found that, concrete mix, COM3-S3 was more stable as it had 7.9% lesser percentage of calcium hydroxide compared to control concrete mix, COM1 due to pozzolanic reaction. Scanning electron microscopy analysis showed that the density of concrete increased owing to the formation of ettringite needles and calcium silicate hydrate in voids. Moreover, the toxicity analysis revealed that the ammonia content and the leaching of heavy and trace elements from the concrete were low and within acceptable limits. In a nutshell, aluminum dross discloses positive results to be as an additional cementitious material in concrete making to overcome environmental problems related to dross management and reduction in cement utilization producing an eco-friendly concrete.

Keywords: Industrial waste; Aluminum dross; Ammonia; Eco-friendly; Cement.

SDG: GOAL 7: Affordable and Clean Energy, GOAL 9: Industry, Innovation and Infrastructure, GOAL 11: Sustainable Cities and Communities

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN SISA ALUMINUM UNTUK BAHAN PENGGANTIAN SIMEN DALAM PEMBUATAN KONKRIT

Oleh

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Pasaran aluminium global yang semakin meningkat menawarkan peluang dan cabaran, terutamanya dengan pengeluaran sis aluminium, yang menimbulkan kebimbangan alam sekitar yang ketara. Pada tahun 2023, saiz pasaran aluminium global adalah 70,593 juta tan, yang secara tidak langsung menghasilkan kira-kira 1,411 juta tan sisa aluminium, produk sampingan berbahaya. Sisa aluminium dianggap sebagai sisa toksik di mana setiap tan terak dijangka menghasilkan 12 tan pencemar gas, beberapa daripadanya adalah meletup, beracun, dan berbau busuk. Pada masa ini, terutamanya di Malaysia, industri menghadapi cabaran dalam menguruskan sisa aluminium kerana proses rawatannya melibatkan kos yang tinggi sehingga RM 2000 setiap tan. Oleh itu, terdapat keperluan untuk penggunaannya sebagai bahan kejuruteraan dengan menggunakannya sebagai bahan pengisi dalam pengeluaran konkrit. Industri simen menghadapi beberapa kesukaran akibat kekurangan bahan mentah dan kebimbangan alam sekitar berkaitan dengan pelepasan karbon dioksida, CO_2 ke atmosfera. Dalam konteks ini, kerja penyelidikan semasa bertujuan untuk menggunakan sisa aluminium

sebagai bahan pengganti simen untuk menghasilkan konkrit mesra alam gred M40. Amalan penyelidikan ini selaras dengan matlamat kelestarian, dan mempromosikan ekonomi kitaran dengan mengitar semula terak aluminium. Pada peringkat pertama kajian, enam sampel sisa aluminium yang disediakan oleh Cenviro Sdn. Bhd. telah menjalani proses rawatan sebelum digunakan dalam campuran konkrit untuk mengeluarkan bahan asing, garam, dan oksida.

Objektif pertama kajian ini adalah untuk mencirikan semua enam sampel sisa aluminium yang dirawat dengan menggunakan analisis X-Ray Fluorescence (XRF) dan ujian ammonia. Hasil mendapati, sampel sisa aluminium 3 (S3) dipilih untuk digantikan ke dalam campuran konkrit kerana ia mempunyai kandungan aluminium tertinggi sebanyak 53.1% dan bacaan ammonia terendah sebanyak 75 ppm.

Objektif kedua membandingkan kebolehlaksanaan berdasarkan ujian *slump* dan kekuatan mampatan campuran konkrit-sisa aluminium. Keputusan konkrit kawalan, COM1 dibandingkan dengan sampel konkrit yang mengandungi sisa aluminium sebanyak 5% (COM2), 10% (COM3), dan 15% (COM4) daripada berat simen. Antara campuran konkrit sisa aluminium, COM3-S3 (10% sisa aluminium sampel 3) mencatat bacaan *slump* tertinggi pada 113 mm, 7 mm lebih rendah daripada konkrit kawalan. COM3-S3 juga mempunyai kekuatan mampatan tertinggi berbanding konkrit kawalan, COM1 pada 41.3 MPa.

Objektif ketiga kajian ini menilai sifat mekanikal, ketahanan, kimia, dan toksikologi campuran konkrit pengganti sisa aluminium yang terbaik. Ditemui bahawa peratusan terbaik sisa aluminium S3 adalah 10% yang menghasilkan keputusan yang lebih baik daripada konkrit standard. Ia mencatat kekuatan mampatan tertinggi sebanyak 41.3 MPa. Analisis termogravimetrik mendapati bahawa, campuran konkrit, COM3-S3 lebih stabil kerana ia mempunyai peratusan kalsium hidroksida yang 7.9% lebih rendah berbanding campuran konkrit kawalan, COM1 disebabkan oleh tindak balas pozzolan. Analisis mikroskop elektron pengimbasan menunjukkan bahawa ketumpatan konkrit meningkat disebabkan oleh pembentukan jarum ettringite dan kalsium silikat hidrat dalam rongga. Tambahan pula, analisis ketoksikan mendedahkan bahawa kandungan ammonia dan elemen berat dari konkrit adalah rendah dan dalam had yang boleh diterima. Secara ringkas, sisa aluminium menunjukkan hasil positif sebagai bahan tambahan simen dalam pembuatan konkrit untuk mengatasi masalah alam sekitar yang berkaitan dengan pengurusan sisa dan pengurangan penggunaan simen, menghasilkan konkrit mesra alam.

Kata kunci: Sisa industri; sisa aluminium; Amonia; Mesra alam; Simen.

SDG: MATLAMAT 7: Tenaga Bersih dan Berpatutan, MATLAMAT 9: Industri, Inovasi dan Infrastruktur, MATLAMAT 11: Bandar dan Komuniti Mampan.

ACKNOWLEDGEMENT

السلام عليكم ورحمة الله وبركاته

In the name of Allah, the Most Gracious and the Most Merciful

Alhamdulillah, thanks to Allah S.W.T., the Almighty, for His blessings that He bestowed upon us, and for making it possible to accomplish this study successfully. I would like to take this opportunity to express my highest gratitude and appreciation to all individuals who were involved directly or indirectly throughout the accomplishment of this study. I would like to express my thankfulness and special appreciation to my beloved parents, Mohd Zahari and Wan Jasmani, and my siblings for their love, support, and tremendous encouragement. They have contributed a lot by giving an abundance of support throughout this journey. Special thanks to my respected supervisor, Associate Professor Dr. Salmiaton Ali for her supervision, advice, knowledge, and support in making this study successful. Besides, not to forget, a lot of thanks to all my friends for their kindness, support as well as encouragement to make this study possible.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science in Chemical Engineering. The members of the Supervisory Committee were as follows:

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Date: 13 January 2025

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LIST OF ABBREVIATIONS

CO_2	Carbon dioxide
SW	Schedule Waste
EQA	Environmental Quality Act
Kg	Kilogram
PAD	Primary alumiunm dross
SAD	Secondary aluminum dross
GJ	Giga Joules
t	tonne
h	hour
Al	Aluminum
Al_2O_3	Aluminum oxide
NaCl	Sodium chloride
KCl	Potassium chloride
Al_4C_3	Aluminum carbide
AlN	Aluminum nitride
US	Unites States
US EPA	United States Environmental Protection Agency
DOE	Department of Environment
WMC	Waste Management Center
MgO	Magnesium oxide
$MgAl_2O_4$	Magnesium aluminate
WTE	Waste-to-Energy
N_2	Nitride
H_2O	Hydrogen oxide
H_2	Hydrogen
SiO_2	Silicon oxide
Si	Silicon
NH_3	Ammonia
Al_5O_6N	Corundum

CH_4	Methane
Al_3C_3	Aluminum carbide
HCN	Hydrogen cyanide
AlP	Aluminum phosphate
PH_3	Phosphine
Al_2S_3	Aluminum sulphide
H_2S	Hydrogen sulphide
Ni	Nickel
g	Gram
ppm	Parts per million
GDR	Glycerol dry reforming
m3	Meter cubic
RSF	Rotary Salt Furnaces
°C	Degree Celsius
s	second
MPa	Mega Pascal
XRF	X-Ray Fluorescence
CaO	Calcium oxide
GGBS	Ground Granulated Blast Furnace Slag
M40	Mix 40 grade concrete
M20	Mix 20 grade concrete
M30	Mix 30 grade concrete
Fe_2O_3	Iron oxide
SiO_2	Sulphur oxide
TiO_2	Titanium oxide
Na_2O	Natrium oxide
XRD	X-Ray Diffraction
SEM	Scanning Electron Microscopy
BET	Brunauer-Emmett-Teller
TGA	Thermogravimetric analysis
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy

BS	British Standard
MOE	Modulus of Elasticity
OPC	Ordinary Portland Cement
ASTM	American Society for Testing and Materials
Kg/m^3	Kilogram per cubic metre
Cl	Chloride
LOI	Loss in ignition
min	Minimum
max	maximum
min	minute
mm	millimetre
MS	Malaysia Standard
CML	Construction Material Laboratory
AlD	Aluminum Dross
µm	micrometre
K	Kelvin
w/c	Water-to-cement ratio
WAC	Waste Acceptance Criteria
H_2SO_4	Sulphuric acid
ml/min	Millimetre per minute
TCLP	Toxicity Characteristic Leaching Procedure
MCL	Material Characterization Laboratory
MnO	Manganese oxide
K_2O	Potassium oxide
CuO	Copper oxide
Cr	Chromium
S1	Sample 1
S2	Sample 2
S3	Sample 3
S4	Sample 4
S5	Sample 5

S6	Sample 6
COM1	Concrete mix 1
COM2	Concrete mix 2
COM3	Concrete mix 3
COM4	Concrete mix 4
GPa	Giga Pascal
Ca $(SO)_4$	Calcium sulphate
$CaCO_3$	Calcium carbonate
CASH	Calcium aluminum silicate hydrate
CSH	Calcium silicate hydrate
OSHA PEL	Occupational Safety and Health Administration Permissible Exposure Limits
SCM	Supplementary Cement Material

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter is on the introduction of the research work. The chapter composes the background of study, problem statement, research objectives, significance of study, scope and limitation, and also the structure of thesis. The background of study is a brief information on aluminum dross and concrete development. The problem statement part shows issues on aluminum dross generation and management, and recycling in concrete technology. Then this chapter continues with the research objectives of the aroused problem. The most crucial part of conducting this research is the significant study. The scope and limitation of the research is also highlighted. Lastly, the structure of thesis is to outline the formulation of the research work.

1.2 Background of Study

Cement is the primary binding material in concrete production. Globally, the total volume of cement production in 2023 was estimated as 4.1 billion metric tonnes (Jaganmohan, 2024). Malaysia produced over 23 million metric tonne of cement in 2023, a 20% increase from the previous year (Siddharta, 2024). Due to population growth, the manufacture of cement has increased, consuming a large number of natural resources and energy while emitting 50,000 ppm to 70,000 ppm of total CO2 through the combustion of limestone and fossil fuels (Mohsen et al., 2021). This issue also had been reported by Naqi and Jang (2019) that the manufacturing of one-tonne cement produced 900 kg of CO_2 which lead to global warming issues. Owing to these issues, the usage of industrial wastes is essential to minimize disposal costs and reduce environmental concerns. One of the best resolutions to cater to these problems is by utilizing wastes to replace fully or partially cement materials in concrete production.

In the last few decades, the generation of waste and depletion of natural sources have become issues in the industrial sector (Mahinroosta and Allahverdi, 2018). Due to the rise of worldwide awareness in the environmental sector, the utilization and recycling of industrial wastes in concrete technology have been increasing rapidly on a daily basis (Oyejobi et al., 2024). To minimize the generation of pollution at source and risk to human health as well as the environment, one should implement the 12th principle in Green Engineering Principles which is, 'Designs should be based on renewable and readily available inputs throughout the life cycle' (Anastas and Zimmerman, 2003).

A number of scientists have been driven to revolve into eco-friendly materials whilst investigating industrial waste as an alternative source in the manufacturing of products (Teara, Ing, and Tam, 2018). Recent studies found that various types of pozzolanic materials are combined with cement to produce high-quality concrete, in terms of its strength and durability. Pozzolanic materials are defined as siliceous or siliceous and aluminous materials that reacts with calcium hydroxide to form cement (Ayub et al., 2021).

Most of the pozzolanic materials are by-product from industries, for instance, fly ash, quarry dust, silica smoke, rice husk ash, aluminum dross, and other materials (Mailar et al., 2016). Waste materials as cement replacements have become gradually treasured in concrete production (Khankhaje et al., 2024). In short, industrial waste or recycled materials can be used as an alternative building material in concrete production.

In the industrial sector, aluminum is the most-demand metal in the world. Over the years, the market size of aluminum has risen sharply by about 8.6%, reaching 249, 830 million tonnes in 2024 due to the corrosion resistance feature of aluminum (Global Aluminum Market, 2024). The global aluminum demand will increase by over 40% in 2030 in which it is projected to grow from 86.2 million tonnes to 119.5 million tonnes in 2030 (International Aluminum Institute, 2024). With the high demand for aluminum around the world, mass production of aluminum has been generated. This process produced waste which is aluminum dross that has become a serious threat to the environment as well as affect human health. To reduce the adverse environmental impact in the construction industry sector, aluminum dross had been proposed to be used in this research work.

Generally, aluminum dross is a mixture of metallic aluminum and non-metal mostly composed of aluminum oxide. It is generated from the aluminum smelting process (Mahinroosta & Allahverdi, 2018). Aluminum dross can be divided into primary aluminum dross (PAD) and secondary aluminum dross (SAD). Primary aluminum dross is a waste formed during the extraction process of aluminum from aluminum oxide.

Commonly, secondary aluminum dross is obtained from the pyrometallurgical processing where it involves the remelt of primary aluminum dross (Lv et al., 2022; Lin et al., 2022). Presently, the problem of PAD has been solved by extracting aluminum. However, the disposal of SAD remains an issue. This study utilized secondary aluminum dross as the replacement material for cement in the concrete development. Secondary aluminum dross is classified as toxic industrial waste as it possesses hazardous characteristics (Samara et al., 2020). As stated in the safety data sheet, aluminum dross will produce flammable and toxic gases including ammonia, hydrogen, and methane when it comes in contact with water (Gases, 2015). The emission of toxic gases can irritate skin and eyes, trigger allergic skin reactions, and even cause cancer by inhalation. Malaysia produced an average of 97 million tonne of aluminum yearly, which results in approximately 31 million tonne of aluminum dross being generated of (Li and Sobri, 2022). The enormous growth in the amount of aluminum dross has led to many problems for both environment and human. In humid environment, the aluminum dross released toxic and harmful gases that can lead to groundwater pollution (Jiang & Lee, 2024). Furthermore, direct disposal of aluminum dross allows heavy metals such as cadmium and chromium to penetrate into the soil and water, causing harm to all ecosystem (Zhu et al., 2020). The Environmental Quality (Scheduled Wastes) Regulations of 2005 has classified aluminum dross as a scheduled waste coded SW 104 for dust, slag, dross or ash containing arsenic, mercury, lead, cadmium, chromium, nickel, copper, vanadium, beryllium, antimony, tellurium, thallium or selenium excluding slag from iron and steel factory (Malaysia EQA Scheduled Waste, 2005). Regarding the elevated number of aluminum dross, it possesses the amount of recycled aluminum that creates a favourable condition for the growth of the aluminum recycling sector in Malaysia.

According to Zauzi et al., (2016), aluminum dross has been used widely in the refractories industry, as a filler in composite, and also being used as an adsorbent. In addition, the use of aluminum dross as cement replacement in concrete has been broadly researched. Discovered by Mailar et al., (2016), aluminum dross was used in the production of concrete for hot weather concreting conditions. Based on their studies, an amount of 85.14 kg aluminum dross (20% replacement value) improved the mechanical and durability properties of the concrete produced. Another study by Galat et al., (2017), 15% aluminum dross replacement (52.28 kg/m3) obtained highest compressive strength at 27 MPa compared to control concrete at 25 MPa. To put it simply, due to the issue in the cement manufacture, a new formulation by adding aluminum dross to concrete production has been introduced to produce high-quality concrete with lower environmental impacts.

1.3 Problem Statement

These days, concrete industries are confronting one of the biggest issues regarding the environmental impact of concrete manufacture. Cement makes up about 12% of the entire concrete mix, is not a green material. The manufacturing of cement not only diminishes large amount of natural resources but also emits significant amount of CO_2 and other greenhouse gases into the atmosphere. Additionally, Portland cement is one of the energy-intensive building materials, after steel and aluminum (Adesina, 2020). To overcome these problems, the substitution of aluminum dross in concrete technology seems to be a feasible solution. The majority component in aluminum dross is aluminum oxide, ranging about 65-80% (International Aluminium Institute, 2023). Aluminum oxide is one of the major compound that is essential in the concrete development as it provides strength to the concrete and offer rapid curing property (Shokravi et al., 2021). Lin et al., (2022) reported that it was estimated that 15-25 kg of dross is produced per metric tonne of molten aluminum.

Currently, the method of treating secondary aluminum dross is to separate the excess aluminum metal from the aluminum oxide, which can restore about 5%-15% of the initial composition. From this treatment, out of 31 million tonne of aluminum dross as mentioned by Li & Sobri, (2022), an average of 3.1 million tonne aluminum dross is reutilized, left approximately 27.9 million tonne of aluminum dross to be disposed. Then, the leftover by product from the treatment will be landfilled (Adeosun, 2014). In Peninsular Malaysia, the Malaysia government has given permit to the Kualiti Alam Sdn. Bhd. to operate an integrated scheduled waste management system by providing the site for scheduled treatment and disposable waste such as a secure landfill and an off-site storage facility. However, these strategies are no longer feasible due to the limiting of available disposal sites as the aluminum dross will keep piling up over time (Ramaswamy et al., 2019). This alarming activity affects the disposal facility in Kualiti Alam Sdn. Bhd. Therefore, recovering and recycling the aluminum dross is one of the practical ways to cater to the issues. Substituting aluminum dross in concrete development saves the dumping spaces and helps to maintain a clean environment.

Moreover, the landfilled aluminum dross can leach out toxic ions into the groundwater that can cause severe pollution towards the environment (Zauzi et al., 2016a). The polluted groundwater around the landfill sites can harm the flora and fauna, thus disrupting the ecological balance (Meshram and Singh, 2018). Mahinroosta and Allahverdi (2018) reported that harmful gases such as ammonia, hydrogen, and methane are released when aluminum dross comes in contact with water. Hence, aluminum dross requires effective recycling to significantly reduce environmental pollution.

Currently, a lot of studies have been conducted using waste to create alternative cement ingredients to improve the qualities of concrete development whilst reducing the usage of natural resources. Previous studies did not emphasize the importance of the pretreatment process of aluminum dross prior to its use in concrete development. Untreated aluminum dross can cause expansion in the concrete structure due to gas formation when it comes into contact with water. Consequently, this research emphasizes the usage of treated aluminum dross as cement replacement material in producing sustainable concrete.

1.4 Research Objectives

The research objectives are:

1. To characterize all the six treated aluminum dross samples for potential cement replacement material.
2. To compare the workability and compressive strength of the concrete-aluminum dross mix.
3. To evaluate the mechanical, durability, chemical and toxicity properties of the best treated aluminum dross replacement in concrete mixture.

1.5 Scope and Limitation

The treatment and management of secondary aluminum dross is the main scope in this study. There were six samples of secondary aluminum dross obtained from different company. The aluminum dross was pre-treated prior to be used in the concrete production. The most effective method to remove any potential oxide generation and toxic gas formation from aluminum dross sample is to wash it with water

(Panditharadhya et al., 2018). Sun dried and oven dried are the typical drying method after pretreatment prior to use as cement replacement.

Concrete design also plays an important role in this study. Primarily, the standard design will be used for the concrete mixing and aluminum dross will be incorporated in the concrete mixture as cement replacement.

To achieve the stated objectives, this study was carried out in two phases. In the first phase, a mix proportion of concrete-based aluminium dross was used in the formulation of concrete. The control concrete mixture was made with zero addition of the aluminium dross. In this research, M40 concrete mixture was used as a standard concrete formulation. M40 concrete denotes a concrete cube that achieve minimal strength of 40 MPa after 28 days of curing period. In concrete mix design, M40 grade concrete is a designated grade where the ratio of cement, sand, and aggregate would be determined using concrete mix design calculation to achieve above objectives. Different percentage of aluminium dross was varied (5%, 10%, and 15%) in the standard concrete mixture. The workability based on the slump test and compressive strength of the concrete-aluminum dross mix were conducted to select the best replacement percentage of treated aluminum dross. The second phase was conducted to evaluate the performance of aluminum dross concrete based on the mechanical, durability, chemical and toxicity properties.

The limitation of the study is an essential element to preserve the validity and impartiality of the study by pointing out areas that require further investigation. A study's limits demonstrate that all relevant factors had been considered and that it was carried out in an exhaustive and methodical way. Furthermore, limitations in a study ensure that all areas of the research are evaluated and carried out thoroughly and methodically. Some of the limitations known are:

- Lack of material availability: The aluminum dross provided by Cenviro Sdn Bhd comes in different batches and different companies, hence, the composition and ammonia level were varied.
- Time constraints: The research has a timeline that affect the capacity to carry out thorough testing and commissioning, as well as to properly assess all design possibilities.
- Technological limitations: The availability of specific technology or equipment needed were limited in this study. The reagent and solution used for ammonia testing were limited. The concrete mould and construction material testing equipment at Construction Material Laboratory were limited in numbers. Therefore, the students were required to wait for a very long time for their turn.
- Data availability: This study may be limited due to the lack of previous resources regarding the pretreatment procedure of aluminum dross prior to be used in concrete mixture.

1.6 Significant of Study

The significant of this study is to participate in the new concrete technology that has shifted into utilizing waste in the concrete mixture to produce sustainable concrete. The industrial sectors are facing problems due to generation of wastes. Hence, the use of environmentally friendly resources from industrial wastes are the best solution to overcome initiation of wastes into the environment. In this work, aluminum dross was used as substitution in cement replacement with the aim to produce high quality concrete. The concrete produced was assessed for its strength and workability performance as well as toxicological effect. The utilization of industrial waste materials as an alternative building material is targeted to possibly reduce both environmental pollution and construction costs.

1.7 Structure of Thesis

The thesis consists of five chapters. In general, the first chapter states background of study, problem statement, research objectives, significant of study, as well as scope and limitation of the study. The second chapter describes a review of available and related literature on aluminum dross as a replacement material in concrete. The existing knowledge on constituent materials used to produce sustainable concrete are also reviewed. Chapter 3 describes the research methodology including the pretreatment of aluminum dross, materials used, design of mix proportions, mixing, casting, and curing of test specimens. The equipment and procedures used to evaluate the fresh and hardened properties of aluminum dross concrete are also explained in this chapter. Chapter 4 presents and discusses the experimental results and the analysis of the results. Chapter 5 presents the conclusions drawn from the investigation of this study and offers recommendations for future work. A list of References and Appendices containing the details of experimental data are given at the end of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, an extensive review of the relevant technical literature on aluminum dross as cement replacement material was carried out. The properties and characteristics of aluminum dross were discussed in detail. Furthermore, some comparison on the various waste as cement replacement material were elaborated including the properties, advantages, and limitation toward the environment. In addition, previous research findings on the treatment of aluminum dross were listed. Lastly, he critical research problem was identified based on the gaps that were established in the course of literature review.

2.2 Concrete: Cement

Concrete is a building material in construction for a long time ago. It has been extensively utilized in the construction of buildings and structures. According to Barbhuiya et al., (2024), around 23.2 million metric tonnes concretes are produced in 2023, and the demand may further surge to 23.2 million metric tonnes in 2027 due to the rapid development in construction sector. However, the concrete manufacturing industry uses cement, raising concerns about the environmental issue. Additionally, they mentioned that the construction sector that involved the building sector, was responsible for producing almost 40% of greenhouse gases by consuming the world's primary energy, mineral, and water resources as a result of the growing global population, particularly in metropolitan area.

2.2.1 Properties of cement

The main components that are present in cement is calcium oxide (50-60%), while the remaining components are silica (20-25%), alumina (5-10%), iron oxide (1-2%), and other minerals, as illustrated in Table 2.1 (Ali et al., 2018). Generally, Portland cement is the most common type of cement used around the world as the key ingredient in construction industry. As stated in previous chapter in Section 1.2, the production of Portland cement in 2023 was around 4.1 billion metric tonnes (Raabe et al., 2022).

Table 2.1: Chemical composition of Portland Cement.

Component	Composition (%wt)
CaO	52
SiO_2	20
MgO	2
Al_2O_3	6
Fe_2O_3	2.5
SO3	0.5
K_2O	0.67
Na_2O	0.34
Loss of Ignition (L.O.I)	34.8

(Source: Ali et al., 2018)

2.2.2 Environmental Impact of Cement

Cement is a key vital building component, yet it is also a pollutant. The production of cement generates a significant amount of greenhouse gas emissions, including carbon dioxide, nitrogen oxide, sulphur dioxide, volatile organic compounds (VOC) emissions and heavy metals that are harmful to the environment and public health. According to a study, cement manufacturing emits 8% of global carbon dioxide due to the usage of fossil fuel to generate the heat and also the chemical reaction during the calcination of limestone that release carbon dioxide (Khaiyum et al., 2023).

Mokhtar and Nasooti (2020) reported that about one tonne of cement requires 3.2 GJ of energy and generates emissions of 662.2 kg of carbon dioxide. The majority of energy contributors are due to the consumption of fuel oil, electricity, and limestone. The World Health Organization (WHO) states that the exposure to cement dust can lead to lung cancer, respiratory and cardiovascular disorders, as well as early mortality (Ahmad et al., 2021). National Institutes of Health stated that the current occupational exposure limit for total cement dust appears to be 10mg/m (Julius Mwaiselage, 2014).

Carbon emissions can be reduced by enhancing the energy efficiency of cement production by the usage of renewable energy sources, including solar, wind, or hydroelectric power. For instance, waste heat from kilns can be recovered or utilized to heat the water or to generate the electricity.

Another effective path to reduce carbon dioxide emission is by adopting the usage of sustainable alternatives as the cement replacement material, such as fly ash, rice husk ash, slag, aluminum dross or recycled materials (Ishak, Shapie, and Lai , 2020; Zareei et al., 2017; Gopalakrishnan and Chinnaraju, 2013; Benjamin 2018). Those waste materials contribute by reducing the global warming.

2.3 Cement Replacement in Concrete Mixture

British Standard, BS 8500:2023 offer up to 65% Portland cement replacement by two, or more, supplementary cementitious materials (SCM) which are called lower carbon additions in the standard (BS 8500-2, 2023). The term 'additions' refers to inorganic constituent material used in combination with cement to modify or improve concrete properties. British Standard, BS 8500 introduced the concept to cater the issue of carbon dioxide emissions from cement production.

Currently, as stated by Imbabi, Carrigan, and McKenna (2022), the experts in concrete technology over the world has worked hard to replace partially or fully cement content in concrete production due to its drawbacks (released CO_2 to the atmosphere; high manufacturing cost; climate change). Industrial waste is one of the products that can be added into concrete as cement replacement materials. Most of the wastes were pozzolanic materials as tabulated in Table 2.2.

As stated in Section 1.2, pozzolan or pozzolanic material contain siliceous or siliceous and aluminous material that chemically reacts with calcium hydroxide in the presence of moisture (Yingsamphancharoen and Rodchanarowan, 2019). The chemical reaction between the siliceous and/or siliceous-aluminous components present in the pozzolan (e.g., aluminum dross), calcium hydroxide and water at ambient temperature is called the pozzolanic reaction (Zheyang Ma, 2024). Calcium hydroxide is the most important hydration product of cement that provide strengthness to the concrete development. However, cement contain only 15% of calcium hydroxide by volume of the cement paste (Bache et al., 2016). Hence, due to the limited availability of calcium hydroxide in concrete, the substitution of pozzolanic material in the development of the concrete can enhance the concrete strengthness by producing hydration products such as calcium silicate hydrate (C-S-H) and/or calcium aluminum silicate hydrate (C-A-S-H) (Ahmed, 2019). Equation 2.1 illustrates the pozzolanic reaction between calcium hydroxide and silica oxide, producing calcium silicate hydrate. Equation 2.2 depicts the pozzolanic reaction between calcium hydroxide and alumino-silicate, producing calcium alumino silicate hydrate.

$$3\mathrm{Ca(OH)_2} + 2(\mathrm{SiO_2}) \rightarrow [3(\mathrm{CaO}).2(\mathrm{SiO_2}).3(\mathrm{H_2O})] \qquad [2.1]$$

$$3\mathrm{Ca(OH)_2} + [3(\mathrm{Al_2O_3}).2(\mathrm{SiO_2})] \rightarrow [3(\mathrm{CaO}).3(\mathrm{Al_2O_3}).2(\mathrm{SiO_2}).3(\mathrm{H_2O})] \qquad [2.2]$$

2.3.1 Fly ash

Ishak, Shapie, and Lai (2020) reported that in their study, fly ash replacement at 10% of the weight of cement was considered the best ratio of cement replacement as it achieved 7% higher compressive strength than control concrete (40.61 MPa) at 56 days. However, through X-Ray Fluorescence (XRF) test, the fly ash was classified as class F as it has less cementitious properties due to the less concentration of calcium oxide (CaO) in concrete matrix by 10%. The XRF data of class F fly ash was due to the lower amount of calcium content as mentioned by (Wardhono, 2018). Calcium oxide is an essential hydration product in concrete development. According to the findings of this study, the partial replacement of cement by fly ash is a more cost-effective alternative with potential applications in the building industry while decreasing environmental impact.

2.3.2 Rice husk ash

Rice husk ash is one of the wastes from the agriculture industry. As reported by Zareei et al., (2017), rice husk ash resulted as a potential cement replacement material. This was due to the replacement of 25% rice husk ash leading to the reduction of chloride ion permeation by 78% compared to control concrete. Furthermore, the compressive strength of rice husk ash at 25% also had been improved as it increased by 6.8% from control concrete at 83.36 MPa. The increase in strength may be due partially to the pozzolanic reaction of rice husk ash as it contained high specific surface area and the presence of reactive silica.

2.3.3 Slag

A research work by Gopalakrishnan and Chinnaraju (2018) where it focused on replacing cement with combining silica fume and Ground granulated blast-furnace slag (GGBS). Different ratio of GGBS and silica fume had been investigated on which replacement is the best combination of partial replacement of cement. Throughout the study, concrete mixes HPC3 where it

contained 30% of GGBS and addition of 10% silica fume worked as the ideal combination ratio to improve the compressive strength, flexural strength, and split tensile strength at 28 days. The targeted strength was 60 MPa, yet HPC3 attained the highest compressive strength among other mixes at 55.11 MPa, 11.3% higher than control mix at 48.88 MPa.

2.3.4 Aluminum dross

Adding aluminum dross in concrete contributes to a more economical and environment friendly technology. This study utilize aluminum dross as the cement replacement material. Benjamin (2018) stated that up to 5% replacement level of untreated aluminum dross by weight of cement shown a remarkable strength although it does not achieve the targeted mean strength. The control concrete obtained 69.33 MPa of compressive strength at 28 days, but 5% aluminum dross replacement ratio attained 56.6% less strength than control concrete. The compressive strength decreases with an addition of aluminum dross as aluminum dross release gases when it encounters water. To cater these problems, the aluminum dross needs to be pre-treated with water washing before substituted into concrete mixture.

Table 2.2: **Comparison of cement replacement material in concrete mixture.**

Waste	Application	Characteristic	Advantages	Limitation	References
Fly ash	Concrete	▪ 10% of fly ash achieved higher compressive strength than control concrete (40.61 MPa) at 56 days ▪ Class F – less cementitious properties (e.g., low concentration of CaO = <18%)	▪ Cost effective ▪ Reduce the construction cost	▪ Slower gain strength	▪ (Wardhano, 2018)
Rice husk ash	Concrete	▪ 25% of rice husk ash reduced the chloride ion permeation by 78%. ▪ Increase the compressive strength by 6.8% from desired strength at 83.36 MPa. ▪ Large surface area of 2326 m^3/kg. ▪ High pozzolanic activity due to high silica content (80-90%)	▪ Higher silica content ▪ Reduce ion permeation ▪ Increase compressive strength	▪ Slower gain strength	▪ (Safiuddin et al., 2010; Mohammed et al., 2012)
Slag silica fume and Ground granulated-furnace slag)	Concrete	▪ HPC3 (30% of GGBS and 10% silica fume) attained highest compressive strength at 55.11 MPa, higher than control mix at 48.88 MPa. ▪ Less reactive than OPC.	▪ Increase compressive strength	▪ Slower early age strength development	▪ (Gopalakrishnan and Chinnaraju, 2018)
Aluminum dross	Concrete	▪ 5% of untreated aluminum dross obtained less strength compared to normal concrete due to the formation of gases from the untreated aluminum dross.	▪ Reduce the usage of cement	▪ Untreated aluminum dross cause expansion to the concrete	▪ (Benjamin, 2018)

2.4 Aluminum Dross (AlD)

Aluminum dross is a by-product generated from aluminum production. This kind of waste emits noxious gases, has bad odor and dusty that affect the environment. Annually, the production of aluminum dross is increasing due to the high demand of aluminum. Li & Sobri (2022) reported that Malaysia's annual aluminum production averages 97 million tonnes, leading to the generation of aluminum dross at 31.9% giving around 31 million tonnes, as stated in Chapter 1 (Section 1.2). Dumping aluminum dross into landfill sites is the only way to address these issues. However, it is crucial to treat the waste before landfilling to reduce the adverse effect. The cost for the treatment process is very prominent.

Recycling or upcycling aluminum dross is one of the best techniques to cater to those problems. Among various recycling options of aluminum dross in literature, construction and building materials applications are one of the value-added options to reduce disposal activity. Several studies have proven that aluminum dross can be added to concrete production, filler in asphalt, concrete bricks, and tiles.

For this study, aluminum dross will be utilized in concrete production as cement replacement material. Aluminum Dross Concrete is referred to be a composite material made by Ordinary Portland cement, aggregates and incorporated with treated aluminum dross. The addition of aluminum dross to concrete is one of the ways of enhancing the strength of concrete. As reported by Mailar et al., (2016), the actual involvement of aluminum dross act as a filler material or pozzolan to fill in any gaps present in the mix which can assist in the strength development of concrete.

2.5 Aluminum Dross Generation

2.5.1 Aluminum Smelting Industry

Aluminum is the most common element in the Earth's crust other than oxygen and silicon. In terms of metallic elements, aluminum is considered the most abundant metal which makes up about 8% by weight of the Earth's solid surface.

As stated by Shinzato and Hypolito (2005), aluminum production starts by refining bauxite through the Bayer process. From this process, alumina in a white powder form will be produced. To produce metallic aluminum, the alumina will be smelted using the Hall-He´roult process as illustrated in Figure 2.1.

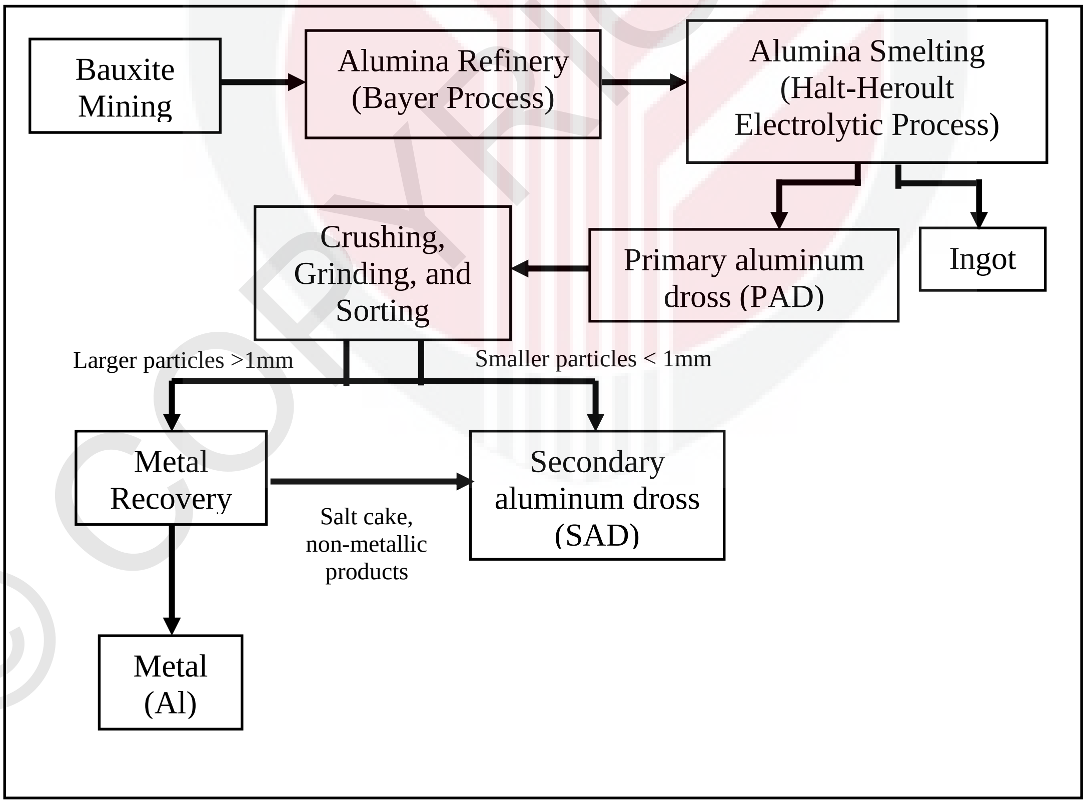

Figure 2.1: Process flow diagram of production of aluminum dross from the aluminum manufacturing industry
(Source: Shinzato and Hypolito (2005)

Aluminium is a well-known material in various applications due to its conductive properties, lightweight design, excellent corrosion resistance, and affinity for oxygen. Figure 2.2 depicted the increasing trend of the aluminum production in the year of 2013 until 2023. Meanwhile, Figure 2.3 demonstrates the worldwide aluminum production in 2023. From both figures, Figure 2.2 and 2.3, China became the biggest aluminum player by producing an amount of 41, 666 million tonnes of aluminum in 2023 (International Aluminium Institute, 2023).

According to data from International Aluminium Institute 2023, the total production of primary aluminum in 2023 was 70, 593 million tonnes, increased up to 10% than the previous year. Kudyba et al. (2021) estimated that 5 million tonnes of aluminum dross are generated globally every year, and it is expected that an average of 2% (15-25 kg) of dross is produced per metric tonne of molten aluminum. A large amount of dross is generated due to the metal capacity to become oxidized during fusion. Normally dross generation from this process contains about 80% (wt) of metallic aluminum, which can be recycled by secondary industries. Metal and non-metallic substances such as alumina, nitride, carbide, and salt metal oxide are found in waste aluminum dross.

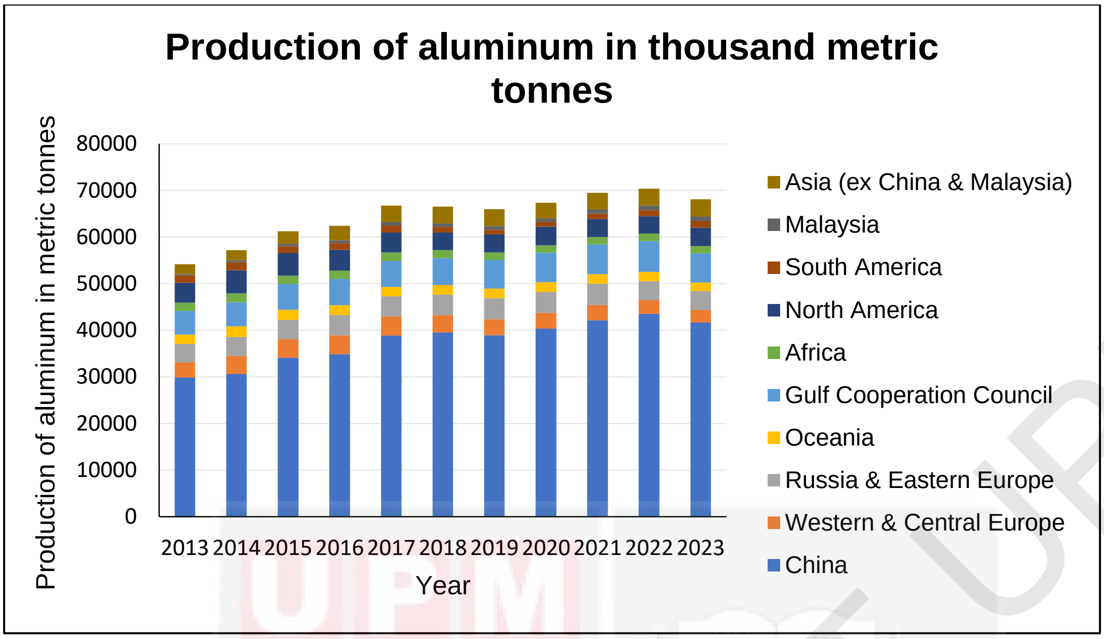

Figure 2.2: Production of aluminum in thousand metric tonnes from 2013-2023
(Source: International Aluminium Institute, 2024)

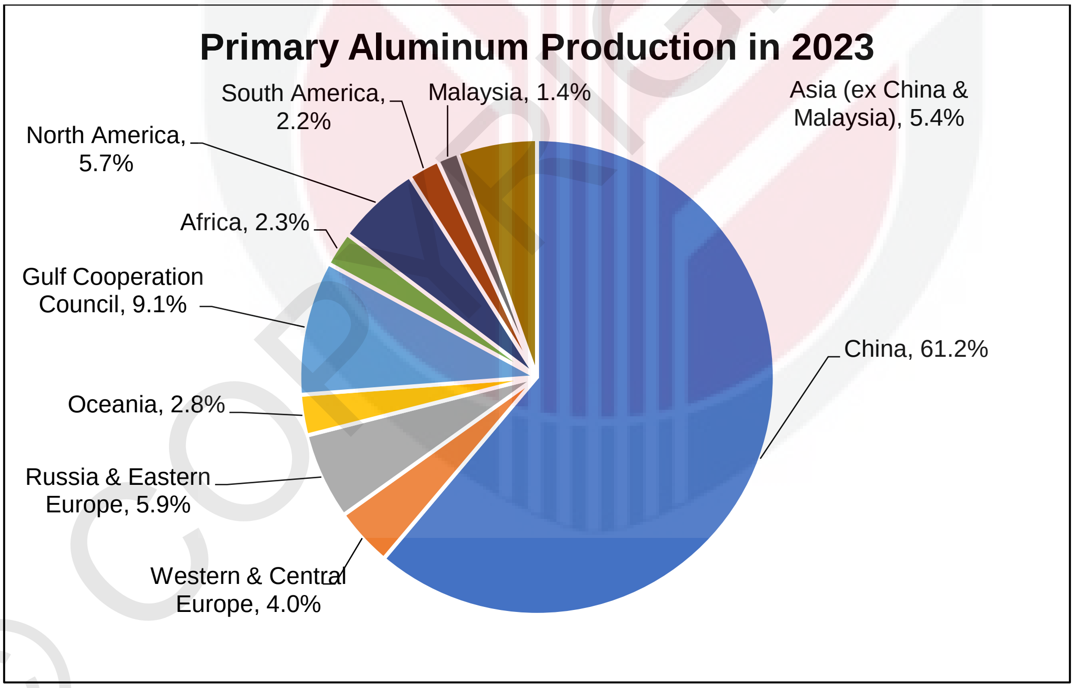

Figure 2.3: Primary Aluminum Production in 2023
(Source: International Aluminium Institute, 2023)

2.5.2 Type and Characteristics

Aluminum dross is one of the kinds of industrial wastes from the aluminum industry. Generally, there are two forms of aluminum dross which are white dross (primary aluminum dross) and black dross (secondary aluminum dross). White dross is produced in aluminum smelting industries whereas black dross is generated in the aluminum recycling industries. The quantity and formation of these substances are determined by several factors, including the type and quality of input materials, operating conditions, the type of technology, and the furnace used (Zauzi et al., 2016).

Table 2.3 depicts a comparison of white and black dross generates from the aluminum production. Based on the data given in Table 2.3, primary aluminum dross (PAD) requires more energy and water utilization compared to secondary aluminum dross (SAD) production. Moreover, primary dross releases some atmospheric emissions and solid wastes compared to secondary dross production. Nevertheless, as people become more aware of environmental issues, the need for maximum efficiency and the importance of recycling, the problem of dross removal is gaining attraction.

Table 2.3: Comparison of white and black dross generates from aluminum production

Parameter	Primary aluminum dross (PAD)	Secondary aluminum dross (SAD)
Consumption of energy (GJ/t Al produced)	174-186	10-20
Atmospheric emission (kg/t Al produced)	204	12
Solid waste (kg/t Al produced)	2100-3650	400
Investment cost	High	Low

Table 2.3: Continued

Consumption of water (kg/t Al produced)	57	1.6
Emission	High	Low

(Source: Mahinroosta and Allahverdi, 2018)

Figure 2.4 shows the physical appearance of PAD and SAD., whilst Table 2.4 tabulates the properties for both type of dross. As mentioned, white dross is classified as primary aluminum dross (PAD). White dross contains a high percentage of aluminum substance such as Al, Al_2O_3 and it is produced during the primary aluminum smelters. White dross contains a higher percentage of metallic aluminum substance, ranging from 15 to 75 %, and 5% salts (Kyung and Solem, 2022). It is made up of fine powder that has been separated from liquid aluminum.

Black dross consists of a small amount of metal substance and is created at the time of the secondary aluminum refining processes. Non-metallic components are absorbed in the liquid flux during the melting process, resulting in a by-product known as black dross. Black dross involves a mix of aluminum oxides and slag, with recoverable aluminum content in the range of 12%–18%. There is a large amount of the salt-flux mixture (e.g., NaCl, KCl, and fluorides), a small amount of fine metallic Al particles, and some minor contaminants (e.g., Al_4C_3 and AlN) in the black dross (Hu et al., 2021).

The composition of secondary aluminum dross varies significantly from batch to batch, which attracts researchers to identify potential applications for this material. Aluminum metal can be recovered using low-cost recovery processes, and aluminum oxides have applications in the metallurgical and construction industries.

Table 2.4: Characteristics of primary and secondary aluminum dross

Parameter	Primary aluminum dross (PAD)	Secondary aluminum dross (SAD)
Type of dross	White	Black
Metallic aluminum content	15-75%	12-18%
Reactivity	High	Low

(Source: Kyung and Solem, 2022)

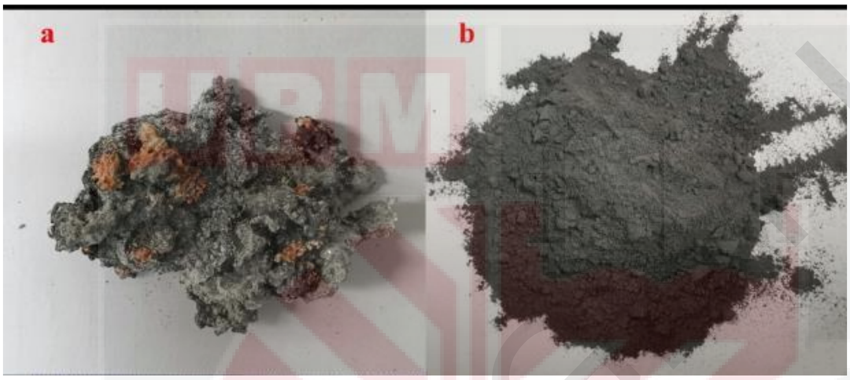

Figure 2.4: (a) Primary Aluminum Dross, (b) Secondary Aluminum Dross
(Source: Hashmi et al., 2022)

2.6 Typical Secondary Aluminum Dross Management

Aluminum dross is classified as toxic industrial waste, and it requires proper treatment before it can be discharged. Disposal and recycling of aluminum dross produced during aluminum production have become a global issue.

Most of the secondary aluminum dross is disposed of in landfill sites (Shen et al., 2021). This activity affects the environment due to the pollution caused by toxic ions that leached out from the disposed of aluminum dross into the groundwater. Each country has different method to manage the production of waste. In the United States (US), the government's priority is to reduce the waste to a minimum value. Since 1970, US has established an independent executive agency named the United States Environmental Protection Agency (US EPA) (Cooper, 2021) to conduct the environmental assessment to protects people and the environment from significant health risks caused by the waste.

In Malaysia, the Department of Environment (DOE) is a responsible authority in Malaysia for the regulation of industrial waste. The Environmental Quality (Scheduled Wastes) Regulations 2005 is a legislation governing scheduled waste in which is administered by the Department of Environment under the Ministry of Natural Resources (Malaysian Investment Development Authority (MIDA), 2023). The Act is a provision relating to the providing the disposal, treatment, management, storage and transport of scheduled wastes. In Malaysia, aluminium dross is categorized as scheduled wastes coded as SW104 according to Department of Environment (DOE Malaysia, 2019). According to the legislation, aluminium dross generators must send the waste to Kualiti Alam Sdn. Bhd. which is a scheduled Waste Management Center (WMC). Currently, WMC receives about 40,000 metric tonnes annually, resulted in a short life span of their secured landfill if the wastes are sent to the landfill (Li and Sobri, 2022).

Due to the high cost of treatment, a large amount of aluminum dross has never been properly treated before discharge (Raabe et al., 2022). According to Zauzi et al. (2016b), the expenses for secondary aluminum dross treatment can escalate to RM2000 per tonne. Therefore, in a year, RM80 million is needed by the WMC to treat 40,000 metric tonnes of aluminum dross. Recovering and recycling the aluminum dross is one of the practical ways to reduce the issue of dross disposal. Various studies have reported on the application of aluminum dross as an alternative material for construction industry.

Currently, more energy is required to recover aluminum from the dross. Energy could be conserved if dross can be used as an engineering material in some way. Furthermore, energy-saving components may produce a valuable material or could be applied for any specific applications. Dross is composed primarily of Al (42%), Al_2O_3 (62%), MgO (3.1%), and SiO_2 (5.2%) (Satish, Reddy and Neeraja, 2018).

2.7 Impact to Safety, Health, Economic and Environment due to Aluminum Dross Mismanagement

Aluminum dross, the primary focus of this study, has created significant health, economic, and environmental issues for the worldwide aluminum sector due to improper management of the waste. Presently, according to the European Waste Catalogue as shown in Table 2.5, aluminum dross is coded as 100309 where categorized as toxic and hazardous waste. In Malaysia, aluminum dross is classified as schedule waste coded as SW104 (Table 2.6) by the Department of Environmental Malaysia.

Tsakiridis, Oustadakis, and Agatzini-Leonardou (2013) mentioned that this waste is highly flammable (H3-A; materials emitting flammable gases in the dangerous levels in contact with moisture), irritant (H4; non-corrosive materials can cause inflammation through extended or replicated contact with skin or mucous membranes), leachable (H13), and harmful (H5; substances if inhaled or swallowed or penetrate the skin cause health problems).

Back in 2009, The Star Malaysia reported that almost 300 residents from Kampung Sungai Gatom, Johor, Malaysia, were affected from the 300 tonnes of aluminum dross disposal incident due to the ammonia emission (Yun, 2024). In 2019, 10 years after the occurrence, a researcher discovered the concentrations of few substances (phosphorus, copper, and manganese) in the water samples at the incident region. The concentration level of the substance was not critical, yet the community was advised against consuming the water for drinking purposes. Additionally, the aluminum content in the water samples were lower than the standard limit of 0.06mg/L. From the incident, there were a few impacts of aluminum dross disposal to safety, health, environment, and economic value.

- Safety

Equations 2.3 to 2.7 show the formation of aluminum compounds under melting process, while Equations 2.8 to 2.12 describe the production of hazardous gases when brought into contact with water (Kravchenko et al., 2005; Li et al., 2012; Gil and Korili, 2016; Ni et al., 2019).

Industrially, Altenpohl et al., (2008) discovered that the manufacturing of aluminum has undergone a high thermal process with a presence of oxygen to melt the aluminum from bauxite as shown in Equation 2.3. Bauxite contains iron oxides and silicate. Then, the nitrogen gas was used in the process acting as a shielding gas, causing a formation of aluminum nitride (AlN) due to the chemical reaction between liquid aluminum and nitrogen as illustrated in Equation 2.4. AlN is highly reactive in aluminum dross, and can emit toxic ammonia gas to the environment (Xie et al., 2023). The chemical reactions in Equations 2.5 to 2.7 illustrate the reactions of producing alumina, Al_2O_3. Equation 2.5 expresses the reaction of aluminum with water forms aluminum oxide and hydrogen at temperature above 480°C. After that, an electric arc furnace is used and heated to a temperature about 2000°C to melt the metallic aluminum, resulting in a formation of aluminum carbide, Al_4C_3 with alumina. Silicon oxide presence in bauxite also reacts with aluminum to yield aluminum oxide as presented in Equation 2.7.

Hydrolysis of aluminum nitride (AlN)

$$4\,Al + 3\,O_2 \rightarrow 2\,Al_2O_3 \quad [2.3]$$

$$2\,Al + N_2 \rightarrow 2\,AlN \quad [2.4]$$

$$2\,Al + 3\,H_2O \rightarrow Al_2O_3 + 3\,H_2 \quad [2.5]$$

$$2\,Al + 3\,H_2O \rightarrow Al_4C_3 + Al_2O_3 \quad [2.6]$$

$$4\,Al + 3\,SiO_2 \rightarrow 2\,Al_2O_3 + 3\,Si \quad [2.7]$$

$$2\,AlN + 3\,H_2O \Leftrightarrow Al_2O_3 + 2\,NH_{3\,(g)} \quad [2.8]$$

$$Al_4C_3 + 6\,H_2O \rightarrow 2\,Al_2O_3 + 3\,CH_{4\,(g)} \quad [2.9]$$

$$Al_4C_3 + 6\,N_2 + 9\,C + 6\,H_2O \rightarrow 3\,Al_2O_3 + 12\,HCN_{(g)} \quad [2.10]$$

$$2\,AlP + 3\,H_2O \rightarrow Al_2O_3 + 2\,PH_{3\,(g)} \quad [2.11]$$

$$Al_2S_3 + 3\,H_2O \rightarrow Al_2O_3 + 3\,H_2S_{(g)} \quad [2.12]$$

Equations 2.8 to 2.12 show the production of gaseous compounds from the reaction of dross with water, water vapour, or air moisture (Ni et al., 2019). The main concern is it leachability and high reactivity with water or any humidity in air which can lead to the formation of toxic, harmful, explosive, poisonous and bad odor gases, such as ammonia, methane, phosphine, hydrogen, hydrogen sulfide etc. (Li et al., 2012). It is predicted that each metric tonne of the dross generates twelve metric tons of gaseous pollutants, some of which are explosive, poisonous, and smelly (Mahinroosta and Allahverdi, 2018).

The exothermic steam-hydrolysis of aluminum nitride, AlN with the presence of water, producing ammonia gas, NH_3 is shown in Equation of 2.8. In addition, the aluminum carbide, Al_4C_3 in Equation 2.6 reacts with water producing methane gas, CH_4 as illustrated in Equation 2.9. Then, Equation 2.10 expresses the reaction of aluminum carbide with nitrogen gas, producing hydrogen cyanide, a highly poisonous gas (Saravanakumar et al., 2018). Aluminum phosphide, AlP is a solid residue in primary aluminum dross. This chemical reacts with water, producing an extremely toxic gas namely, phosphine gas, PH_3 as expressed in Equation 2.11 (Raabe et al., 2022). Lastly, during the electrolytic activity, an impurity of sulphur reacts with aluminum to produce aluminum sulfide, Al_2S_3. In Equation 2.12, aluminum sulfide chemically reacts with water, forming a flammable gas, hydrogen sulfide, H_2S (Q. Yang et al., 2019).

As a result, disposal of aluminum dross into landfills could lead to several safety issues.

- Human health

As mentioned above, the leachability of aluminum dross causes the creation of harmful gases. The production of highly combustible gases from the reaction of aluminum dross and water can affect human health if breath in, swallowed, or absorbed through the skin. Moreover, inflammation can be brought on by direct, prolonged, or recurrent contact with the skin or mucous membrane. Grande et al,. (2023) stated in their research that aluminum dross has a minimal particle size, it is easily dispersed in the air during manufacturing, transportation, and disposal, and when breathed in significant quantities, it can cause silicosis and bronchitis.

- Economic value

Notably, the disposal cost or to be more specific the operational cost for aluminum dross are very high, as controlled landfills are required for this type of waste (Samara et al., 2020). According to Yusoff, Muslim, and Paulus (2019), the disposal cost of this waste can be high; the approved local disposal waste company will charge RM 2000.00 per tonne for disposal in Malaysia. In UK, the average annual cost for waste disposal is 400 Euros per tonne (Xie et al., 2023).

Therefore, many countries shifted to find a prominent solution to reduce the waste. For instance, Europe and the United States are now obligated to investigate trash reduction methods through recycling due to the environmental restrictions. Issues related to the generation of waste and the depletion of natural resources affect the productivity of industry.

- Environment

Safety risks for the landfill sites are the most important concern as aluminum dross is a high flammability material. For instance, under different climate conditions such as rain can lead to penetration of toxic metal ions to the surface, pursuing water and air pollution. The highly combustible gases released from aluminum dross can ultimately damage entire ecosystems. One of the most significant impacts is eutrophication, which happens when excessive nutrients, such as ammonia, are delivered into a body of water. This causes an overgrowth of algae and other aquatic plants, which depletes oxygen and lowers water quality. As plants die and degrade, they deplete oxygen, making it harder for fish and other aquatic animals to thrive (Soler et al., 2021).

Hence, to reduce the possible effects of aluminum dross on human health, economy, and environment, it must be appropriately treated and disposed of to prevent higher discharge rate of gases into environment. Furthermore, by identifying effective recycling solutions, the volume of waste, associated disposal costs, and environmental impact could be reduced.

Table 2.5: European waste catalogue and hazardous waste list.

No	Code	Hazardous Waste Type
1.	100304	Slags from primary production
2.	100308	Secondary production salt slags
3.	100309	Secondary production black drossess
4.	100315	Dross that are flammable or emit flammable gases upon contact with water
5.	100319	Flue gas dust containing hazardous materials
6.	100323	Solid wastes from processing the gas comprising hazardous materials
7.	100325	Filter sludge and cake from processing gas containing hazardous materials

(Source: EPA, 2002)

Table 2.6: Scheduled waste list of metal and metal-bearing wastes.

No	Code	Hazardous Waste Type
1.	SW101	Waste containing arsenic or related compound
2.	SW102	Lead acid battery waste, either entire or crushed
3.	SW103	Battery waste that contains cadmium and nickel or mercury or lithium
4.	SW104	Dust, slag, dross, or ash containing arsenic, mercury, lead, cadmium, chromium, nickel, copper, vanadium, beryllium, antimony, tellurium, thallium, or selenium excluding slag form iron and steel factory
5.	SW105	Galvanic sludges
6.	SW106	Waste from the recovered acid pickling liquor
7.	SW107	Slag from copper production that contains arsenic, lead, or cadmium and has to be processed further or refined

(Source: Department of Environment Malaysia, 2019)

2.8 Reuse of Aluminum Dross

Globally, aluminum dross is quite well known due to its unique physical and chemical properties. Several scientists have driven to revolve into eco-friendly materials whilst investigating industrial waste as an alternative source in the manufacturing of products (Teara, Ing, & Tam, 2018). Although aluminum dross is a type of waste, it has several useful applications, including filler in composites, use in the refractories industry, and as an adsorbent. The current research work carried out focused on exploring the role of aluminum dross replacement in the construction industry.

A variety of products can be made from the residual aluminium dross after it is recycled into aluminium oxide as summarized in Table 2.7. Aluminium oxide is utilised in a wide range of industrial application such as, adsorbent, catalyst, and concrete.

2.8.1 Aluminum Dross as Adsorbent and Coagulant

In a study conducted by Zulfika et al., (2017), raw aluminum dross without any treatment were efficiently use for the adsorption of congo red in textile wastewater industry. Untreated aluminum dross contained 89.80% aluminum oxide (Al_2O_3). Findings shown that an amount of 0.4 g of adsorbent can remove between 20 and 40 ppm of dye concentration at pH 9 with a removal rate of about 100%.

Moreover, aluminum dross can be used as a coagulant in water treatment process. A study by Abdulkadir, Ajayi, and Hassan (2015) reported that an amount of 35% aluminum dross (42.5 g) were leached with copper chloride water solution to produce aluminum oxyhydrochloride. The product was then treated with aluminum hydroxide to obtain aluminum chloride for water treatment purpose.

2.8.2 Aluminum Dross as Catalyst and Catalyst Support

Aluminum dross was modified into a catalyst in pyrolysis of used cooking oil (Faten et al., 2017). An increase in surface area (68.24 m^2/g) and acidity (748 µmol/g) by using acid washing method enabled aluminum dross as potential catalyst candidate in catalytic reactions. The performance of the material in pyrolysis of waste cooking oil proved modified Al dross represent as a good candidate in the cracking reaction.

A study by Roslan et al., (2019) reported that γ-Al_2O_3 with a specific area of 156.5 $m^2 g^{-1}$ was successfully extracted from aluminum dross as a catalyst support in glycerol dry reforming reaction (GDR). The catalyst support contributes to the higher specific area of EGA, that enhanced the dispersion of Ni particles on the catalyst matrix.

2.8.3 Aluminum Dross in Construction Material

Galat, Dhawale, and Kitey (2017) stated in their report that the utilization of aluminum dross in concrete industry can help to reduce the need for raw materials. A percentage up to 10% of raw aluminum dross by weight of cement enhanced the strength of the concrete cubes by 9.69% than control concrete (33.11 MPa).

An investigation by Udvardi, Géber, and Kocserha (2019) described the behaviour of untreated aluminum dross as a filler in asphalt is almost like limestone powder. Mixture contain limestone has an average cracking temperature at T= -26.1 °C, while the mixture contains aluminum dross has an average cracking temperature at T= -28°C. It can be stated that the mixture with aluminum dross has a better cracking property.

Table 2.7: Various application of aluminum dross recycling

Application	Success rate	Reference
Adsorbent	0.4 g of dross removed all congo red dye by 100%.	(Zulfika et al., 2017)
Coagulant	35% aluminum dross (42.5 g) mixed with copper chloride to produce oxyhydrochloride to treat water.	(Abdulkadir, Ajayi, and Hassan, 2015)
Catalyst	Acid washing method increased the surface area and acidity of aluminum dross by 68.24 m^2/g and 748 µmol/g, respectively. This enable aluminum dross to be a potential catalyst.	(Faten et al., 2017)

Table 2.7: Continued.

Catalyst support	γ-Al_2O_3 with a specific area of 156.5 m^2 g^{-1} was successfully extracted from aluminum dross as a catalyst support in glycerol dry reforming reaction (GDR)	(Roslan et al., 2019)
Concrete	10% of raw aluminum dross increased the strength of concrete 9.69% higher than control concrete at 33.11 MPa.	(Galat, Dhawale, and Kitey, 2017)
Asphalt	Aluminum dross able to withstand low temperature as it has an average cracking temperature at T= -26.1°C.	(Udvardi, Géber, and Kocserha, 2019)

2.9 Pretreatment of Aluminum Dross Prior to Use

Generally, aluminum dross is classified as hazardous solid waste. In most countries, secondary aluminum dross (SAD) is classified as hazardous solid waste. As stated by Lv et al. (2022), one tonne of SAD can emit around 109 m^3 of ammonia (NH_3). This phenomenon can cause skin burns and potentially serious pulmonary diseases. To minimize the effect on the environment and human health, aluminum dross must undergo pretreatment prior to use.

Calcination is the most conventional method to extract remaining aluminum when the dross is processed in rotary kilns (Saravanakumar et al., 2018). The process involves heating the solid at high temperature, T= >982°C to remove volatile compounds and oxidize a portion of the bulk. Although calcination is the most effective purifying technique, it has drawbacks. The calcination procedure affects the thermal stability, particle size of the materials and not eco-friendly. As reported by Saikumari, Dev, and Dev (2021), there is a reduction in catalytic activity with increasing temperature of calcination.

Nowadays, there are a few methods that are introduced to treat aluminum dross such as pyrometallurgical and hydrometallurgical methods. Most of the techniques involves filtration and grinding of the dross to recover the metal value.

- Pyrometallurgical Method

Industrial sector treated aluminum dross by both pyrometallurgical and hydrometallurgical processes. Back in the days, scientists used Rotary Salt Furnaces (RSF) to refine the metallic aluminum from dross. This method used a high thermal process approximately 758 °C as the ideal temperature for fluxing. This action will emit maximum number of hazardous gasses to the environment. Another concern is large energy consumption of pyrometallurgical processes as it requires some reducing agents and operate at relatively high temperatures, T= 758°C. To address this issue, industries has shifted to plasma technology as it ensure salt-free operation to extract metallic aluminum with minimum harm to the environment (Meshram and Singh, 2018).

It is reported by Carmona and Cortés (2014) as they designed a plasma arc furnace to treat aluminum dross. This equipment employed plasma torch to provide the heat for melting the aluminum dross, and increased the temperature ranging from 700°C to 800°C. The oxygen gas was supplied in an adequate amount to maintain the temperature. This method contributed to a minimum or no use of salt fluxes with high energy efficiency.

In other experimental work performed by Boulos (2016), the Alcan plasma dross treatment adopted a gradual rotation of furnace which resulting in rupture of oxide layer, giving a maximum value of aluminum recover. The optimized rotation speed was 4 rpm, where an amount of 75% metal were recovered. Argon gas was purged to the system to minimize the oxidation of dross.

- Hydrometallurgical Method

Salts and soluble chloride are abundant in aluminium dross. Leaching is an excellent method for removing soluble salts from. The hydrometallurgical processes provided an economically viable alternative for aluminum dross treatment. Mostly, hydrometallurgical route is the common technique applied in industry. The medium used in hydrometallurgical is leaching method, where it involves the usage of aqueous solutions. It can be done via water or alkaline or acidic leaching. Through this process, 88.5% of aluminum and nitrogen can be recovered giving less harm to the environment (Tsakiridis, Oustadakis, and Agatzini-Leonardou, 2013).

Acidic leaching is suitable for aluminum recovery and ammonia treatment in aluminum dross as it neutralises the ammonia. The most frequent acid use to extract aluminum from the aluminum dross is hydrochloric acid. Through this process, ammonium chloride is produced from the reaction between aluminum nitride and hydrochloride acid. Ammonium chloride is a soluble salt in aqueous solution (Yang et al., 2022). Additionally, a study by Sepperer et al., (2020) reported the presence of 1% organic tannic acid sourced from chestnut and mimosa industrial tannin extracts decreased the emission of ammonia in manure from 0.27ppm/sec to 0.12ppm/sec at 200 s. According to Mahinroosta and Allahverdi (2018), acid treatment is technically and financially viable route for aluminum dross. However, the hazardous nature of acid increases the environmental risk as the process will generate acidic waste.

Sodium hydroxide (NaOH) is the most common alkaline solution that involve in the alkaline leaching of aluminum dross. A study by Hamdan et al., (2016b), the minimum concentration of sodium hydroxide used in the leaching process is 1%, at temperature 25°C. In addition, according to Miskufova et al., (2019), higher concentration of sodium hydroxide at 10% leached 98% of aluminum compound from dross at temperature 96°C. Higher concentration of NaOH (> 10%) reduced the surface area of aluminum dross due to saturation of aluminum dross at higher NaOH concentration. The reduction in the surface area of aluminum dross contributed to the less workability of the concrete. Nevertheless, its proven that alkaline leaching is workable method for treating aluminum dross. However, a significant of waste effluent is produced from this process and can harm the environment.

Present study developed a new method to treat aluminum dross by using water as it is low cost and can achieve sustainable treatment (H. Lv et al., 2022).Water is the most available material in the world. Water washing is a crucial stage in aluminum dross treatment as it segregates the water- soluble phases, such as nitrides and salts, from the insoluble residues where sodium and potassium are included in the non-water-soluble compounds. Panditharadhya et al. (2018) mentioned that it is not practical to use aluminum dross without pre-treating it with water as in a research study conducted by Pereira et al. (2000), a remarkable volumetric expansion was detected in the mortar developed from raw aluminum dross. This action is due to the presence of substantial amount of chloride content, and toxic gas (e.g., ammonia gas) were emitted in high concentrations. Similarly, a research conducted by Elseknidy et al., (2020), there was an expansion volume of concrete incorporated with 5% untreated aluminum dross. This expansion led to a reduction of the compressive strength of the concrete at 28 days of curing age by 0.7% from the desired strength at 30 MPa. Meanwhile, there was no visible increase in volume in the concrete mixture that included water-washed aluminium dross. The expansive nature of untreated aluminum dross was due to the formation of gases entrapped in the concrete matrix. Therefore, it can be concluded that, the application of aluminum dross without water washing process is impractical. Table 2.8 summarizes the pretreatment process of aluminum dross.

In conclusion, the pyrometallurgical process requires high energy consumption (often 1000°C) which is associated to the production of toxic gasses to the environment and loss of materials. Therefore, hydrometallurgical process (water washing) is selected to be in this research work, as it is more environmentally friendly and has lower energy consumption.

Table 2.8: Pretreatment methods of aluminum dross.

Method	Type	Process	Advantages	Disadvantages	References
Conventional	Calcination	Extraction of remaining aluminum from the dross in rotary kilns High temperature, T = > 982 °C	▪ Higher removal rate of volatile substances	▪ Affects the thermal stability and the particle size of the materials. ▪ The catalytic activity is reduced with the increasing temperature of calcination. ▪ Not environmentally friendly.	(Saikumari, Dev, and Dev 2021)
Pyrometallurgical	Rotary Salt Furnaces (RSF)	High thermal process, T = 758 °C Required some reducing agents.	▪ High efficiency ▪ No salt cake disposal	▪ Emission of maximum no. of hazardous gases. ▪ Large energy consumption. ▪ Not environmentally friendly.	(Meshram and Singh, 2018)
	Plasma Arc Furnace (PAF)	Less harm compared to RSF Used O2 gas to maintain the heating temperature (T=700 °C to 800 °C)	▪ Increased efficiency ▪ Increased productivity ▪ Improved safety		(Carmona and Cortes, 2014).

Table 2.8: Continued.

Method	Type	Process	Advantages	Disadvantages	References
Hydrometallurgical	Acidic Leaching	Hydrochloric acid is the most frequent acid to extract aluminum.	• Less energy • High conductivity and selectivity	• Lower efficiency • Production of acidic waste	(Sepperer et al., 2020)
	Alkaline Leaching	Utilization of sodium hydroxide, NaOH as the common alkaline solution.	• Lower corrosivity than acid leaching	• Low recovery of metallic aluminum • Environmentally friendly • Low energy consumption	(Yousef Ghorbani, 2016)
	Water	Water-washing segregates the water-soluble phases, such as nitrides and salts, from the insoluble residues.	• Toxic effluent • Required excess water • Emission of toxic gases	• Low cost	(Panditharadhya et al., 2018)

2.10 Concrete Mix Design

Concrete mix design is a process where the determination of precise proportions of cement, aggregates, and water must be found for concrete to achieve targeted desired minimum strength in the hardened stage. The basic component of mix design is cement, aggregate and water. Concrete production can be formulated as Concrete Mix = Cement: Fine Aggregate: Coarse Aggregate. The water-to-cement ratio is a critical factor in determining the strength, workability, and durability of concrete. The hydration process, which takes place when the concrete sets and hardens, is greatly influenced by the ratio of water to cement in the mixes.

In this study, the main aim in designing an aluminum dross concrete mix is to produce reasonable workability, easy of placing and effective utilization of aluminum dross as a cement replacement material. The term 'workability' in concrete refers to how readily fresh mixed concrete can be placed, consolidated, compacted, and finished without segregation (Nagaraj and Shamanna, 2019).

Preliminary trial mixes are crucial in formulating aluminum dross concrete mix as it indicates which percentage value of aluminum dross is fit for a well-constructed concrete mix. Slump tests usually will be used in this stage to assess the level of workability of a concrete. The amount of added aluminum dross in concrete depends on the following factors:

a) Amount of cement paste.

b) Shape and surface characteristics of the aluminum dross.

The proportion of control concrete mix or known as standard concrete mix can be used as a guideline in designing aluminum dross concrete mixes. The amount of aluminum dross can be adjusted based on the workability of trial mixes.

Concrete Grade: M40

Concrete grades are determined by the material's strength, composition, and minimum strength required after 28 days of initial construction (Ambroziak and Ziolkowski, 2020). Concrete grades are expressed in MPa units, where MPa represents total strength and M stands for mix. Concrete mixes are described in ascending numbers of 5, starting with 10, and indicate the compressive strength of the concrete after 28 days. For example, M10 has a strength of 10 MPa. There are three grades of concrete, nominal (M5 to M20), standard (M25 to M45), and high strength concrete grades (M50 to M70). Each grades have its own applications in construction sector.

Different mixes (M) contain varying concentrations of cement, sand, and coarse particles (Base Concrete, 2023). For example, M20 has a ratio of 1:1.5:3. Additional instances are tabulated in Table 2.3. However, for concrete grade above M25 grade, it is known as 'Design Mix' concrete where it is frequently utilized in the construction of large structures with demanding strength needs (BS 8500-1, 2023). Therefore, they 'Design Mix' in mix ratio part, it defines a specific mixture of cement, sand, aggregates, and water that is calculated and designed to meet the precise engineering requirements of a particular construction project.

For this research work, M40 would be the targeted concrete grade as stated in the Table 2.9 where it is applied in the commercial construction sites and create a foundation an beams. An experimental work conducted by Yingsamphancharoen and Rodchanarowan (2019) proved the chemical resistance of M40. The acid attack procedure was performed onto M20, M30, and M40 concrete. 5% of sulphuric acid was employed into the curing water for 28 days and the compressive strength was observed after 28 days. Based on the trials, the physical appearance of M40 concrete did not deteriorate like M20 and M30, whereas the strength slightly reduced to 35 MPa from the desired minimum compressive strength, 40 MPa.

Table 2.9: Concrete mix design and application of various concrete grades.

Concrete Grade	Mix Ratio (Cement: Sand: Aggregate)	Compressive Strength (MPa)	Type of Usage	Application
Nominal Grade of Concrete				
M10	1: 3: 6	10 MPa	Domestic & Commercial	Patio slabs, pathways, and non-structural work
M15	1: 2: 4	15 MPa	Domestic & Commercial	Pavement kerbs and floor blinding
M20	1: 15 :3	20 MPa	Domestic	Domestic floors and foundations
Standard Grade of Concrete				
M25	1: 1: 2	25 MPa	Domestic	All type of construction and foundations
M30	Design Mix	30 MPa	Domestic & Commercial	Pathways and roadways
M35	Design Mix	35 MPa	Commercial	Commercial structures and external walls and slabs.
M40	Design Mix	40 MPa	Commercial	Commercial constructions sites, foundations, and beams. M40 can withstand chemical corrosion.
M45	Design Mix	45 MPa	Commercial	Critical load-bearing structures (bridges)
High Strength Grade of Concrete				
M50	Design Mix	50 MPa	Commercial	Construction of tall buildings, bridges, and other critical structures.
M55	Design Mix	55 MPa	Commercial	
M60	Design Mix	60 MPa	Commercial	Superior chemical resistance
M65	Design Mix	65 MPa	Commercial	
M70	Design Mix	70 MPa	Commercial	

(Source: Base Concrete, 2023)

2.11 Aluminum Dross in Concrete Mixture

According to Panditharadhya et al., (2018), aluminum dross is one of the pozzolanic materials that contribute to the more stronger bond in concrete matrix. Aluminum dross contains a direct amount of siliceous and aluminous materials that can influence the pozzolanic reaction with calcium hydroxide in the presence of water to form concrete. Table 2.10 shown the potential advantages of adding aluminum dross into the concrete.

Table 2.10: Advantages of aluminum dross in concrete

Properties	Advantages	Reference
Pozzolanic material	Promote the pozzolanic reactivity Seal the voids in concrete matrix Enhance the concrete strength	(Panditharadhya et al., 2018; Ishak et al., 2020) (Manikanta et al., 2021;
High alumina content	Facilitate early strength development Accelerate setting time of concrete	(Nduka et al., 2019; Zauzi et al., 2016)
Environmentally friendly material	Reduce the cement requirement for concreting The heavy metals content was within the limit	(Razak et al., 2020; Javali et al., 2017)
Sustainability	The utilization of aluminum dross corresponds with the sustainability goals and promotes the circular economy by recycling industrial waste.	(Ishak et al., 2020)

Experimental research on the physical, mechanical, and durability characteristics of concrete with cement replacement with aluminum dross has been debated in academic publications. For instance, Nduka et al., (2019) reported that up to 10% substitution of aluminum dross attained engineering properties of concrete blocks. Their findings indicate that the blocks blended with aluminum dross present less workability. This is due to the higher specific surface area and expansive nature of aluminum dross. However, their results revealed that the replacement of cement by 10% aluminum dross accelerated the strength development of concrete blocks. As the percentages of aluminum dross increased from 20% to 40%, the void formation also increased, resulting in lower compressive strength.

Additionally, Gozde Ozerkan et al., (2007) evaluated that high volume of aluminum dross replacement is not appropriate because of its high water absorption capacity. For instance, based on their finding, at 15% aluminum dross replacement, the water absorption was 26.2% higher than normal concrete. High water absorption capacity leads to a decline in compressive strength, as more entrapped air occurs. Furthermore, it can be observed that as aluminum dross increased from 0% to 10%, the corrosion rate decreased due to the presence of calcium and aluminum hydroxides as well as alkali metal ions (Na^+ and K^+) which maintained the pore solution at the pH value of 11.

Nandram and Prajakta (2018) reported that 10% replacement level can be used to achieve a good quality concrete as the strength increased by 6.25% from the normal concrete at 28 days of curing age. Similarly, from the above studies, the increase in dross content exhibits a decrease in strength.

2.11.1 Physical Properties

Durability of concrete is the physical ability of concrete to resist weathering action, chemical attack and abrasion while maintaining the desired engineering properties. Water absorption test is one of the durability tests that measure the amount of water absorbed in a certain time.

In addition, an acid resistance test is performed to investigate the degradation of elements, such as calcium hydroxide, from the hardened concrete cement paste. This activity will contribute to the loss of strength and mass of the concrete.

2.11.2 Mechanical Properties

The most widely used test to assess the workability of fresh concrete consistency is by slump test accordance to BS EN 12350-2 (BS EN 12350-2, 2019).

BS EN 12390 provides instructions for developing a strategy to examine and obtain samples of hardened concrete from a structure (BS EN 12390, 2000). For this study, there are four properties of hardened concrete that have been investigated. Following are the hardened concrete test for this research work:

The mechanical properties of concrete determine the range of practicality of a material and identify the lifespan that can be expected. The compressive strength test is the key parameter that denotes the concrete in the structural design to guarantee the overall quality of the finished product. Usually, compressive test is conducted on the 7th, 21st, and 28th days of curing age.

Meanwhile, flexural strength test plays a substantial role in the modern designs of concrete. Flexural test measured the amount of force needed to bend a beam of a material at the end of curing age (28 days). As a result, the more strength a material offers, the more units a restoration can include.

Modulus of Elasticity reflects the capacity of concrete to deflect elastically. This property is essential in assessing a material's ability to support loads while maintaining its shape. Concrete with a greater elastic modulus can tolerate more stress.

2.11.3 Chemical Properties

Chemical property is to identify an unidentified substance in the compound. The composition of heavy metals in raw aluminum dross can be observed using X-Ray Fluorescence (XRF). Table 2.10 shows the chemical composition of raw aluminum dross based on a work by Zauzi et al., (2016). It showed that Al_2O_3 makes up about 90% of the raw material, with the remaining 10% containing SiO_2, Fe_2O_3, MgO, SO_3, CaO, TiO_2, and Na_2O.

Table 2.11: Chemical composition of raw aluminum dross

Composition	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	CaO	TiO_2	Na_2O
wt%	1.2	89.8	0.54	0.84	0.15	0.41	0.022	0.31

(Source: Zauzi et al., 2016)

X-Ray Diffraction (XRD) works to characterize cementitious materials. In a study by Reddy & Naqash (2019a), at 2θ angle of 29.46, the peak intensity of calcium aluminum silicate hydrate is higher in aluminum dross concrete than in normal concrete, indicating a rapid hydration process.

The morphological study of aluminum dross concrete is performed by Scanning Electron Microscopy (SEM). An experimental work by Saikumari et al. (2021), with the addition of aluminum dross in concrete, there were formation of ettringite in voids which compacted the concrete matrix, thus providing higher strength to aluminum dross concrete.

Brunauer-Emmett-Teller (BET) analysis is used to analyze the fineness of cement and aluminum dross. Razak et al. (2020) reported that aluminum dross has a greater average pore size (10.23 nm) than Ordinary Portland cement (5.25 nm). This indicates that aluminum dross is a mesoporous material where the porosity is greater than OPC.

Thermogravimetric analysis (TGA) helps in identifying various phases of hydrated cementitious materials present in the concrete. Aluminum dross concrete was found to have less calcium hydroxide compared to normal concrete due to the pozzolanic reaction (Ukrainczyk et al., 2016).

Toxicity analysis is conducted to examine the ammonia gas or leachate in concrete. The ammonia level test is conducted as aluminum dross may emit ammonia gas in contact with water. The diffusion of ammonia gas from the concrete will make the concrete structure more porous (Abd El-Aziz and Sufe, 2013).

Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES) determines the amount of heavy metals in a concrete specimen. It measures the contaminants for environmental safety assessment. The heavy metals such as arsenic, copper, boron, chromium, barium and aluminum were found to be minimum in aluminum dross concrete and within the limits by US ESHO (Javali et al., 2017).

2.12 Research Gap

Based on the literature review, there are many potentials uses for aluminum dross in Malaysia, including the application in building and construction material. To make it commercially viable, continued innovation and collaboration with relevant authorities to ensure the usage of aluminum dross meets safety and building codes. Malaysia aims to reduce the intensity of carbon emissions, approximately at 40% by 2030. Substituting aluminum dross in construction materials can significantly lower cement consumption, as cement production is a major source of CO_2 emissions. To ensure the safety and effectiveness of aluminum dross as the construction material requires a pre-treatment process, which involves washing it with water. Water is commonly used for this purpose because it is cheap and widely available. Previous research on the usage of dross in construction has not adequately addressed the issue of ammonia gas during the mixing process. This can lead to environmental concerns, damage the equipment and infrastructure, and even risks to human when not handled properly. Therefore, in this research work, the pretreatment process of aluminum dross should be properly performed prior to use it in concrete development.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

The first stage of this study was material preparation. Aluminum dross was treated with water prior to use in concrete manufacturing. Drying process was involved to remove water content followed by grinding to obtain powdered aluminum dross. pH test and ammonia test were conducted on powdered aluminum dross.

The samples for cube, cylinder and beam mould were prepared for different types of concrete testing analysis. The designated ratio of 1:1.9:2.3 of cement, fine aggregate, and coarse aggregate were used to prepare the M40 grade concrete after several mix trials. The ratio was calculated using concrete mix design table as depicted in Appendix A. The concrete samples were produced with different percentages of aluminum dross at 5%, 10% and 15%. The curing processes were taking place after all the concrete were casted into the moulds. For concrete cubes, there was a test after 7th, 21st, and 28th days of curing age. The strength of the concrete increases with curing age due to the chemical reaction during the curing process that evolve over time (Seyam & Nemes, 2023). Compressive test was done to the cubes while flexural test was done to the concrete beam after 28th days of curing age. For cylinder mould, Modulus of Elasticity test was measured to observe the concrete stiffness. The chemical and toxicity analysis of the concrete were also performed to evaluate the performance of concrete with the substitution of aluminum dross.

3.2 Materials

The materials used in this study are aluminum dross, Ordinary Portland Cement (OPC), river sand as fine aggregate, and crushed granite as coarse aggregate. The specific characteristic and properties of each material are as follows:

3.2.1 Aluminum Dross

The aluminum dross utilized in this study was supplied by Waste Management Centre, Cenviro Sdn Bhd., Port Dickson, Negeri Sembilan. Six samples of aluminum dross were provided by different company and used in this study. The sources cannot be disclosed.

3.2.2 Cement

The cement used in this study was Ordinary Portland Cement (OPC) supplied by the Construction Material Laboratory, Universiti Putra Malaysia. Ordinary Portland Cement is the most common cement type that has been used widely in construction sector due to its excellent strength and durability (Avnstorp, 2012; Chattopadhyay, 2019; Yadav et al., 2020). The grade of the cement, CEM–I–42.5N was used according to ASTM C 150-00 (ASTM C150/C150M, 2019). This grade of cement corresponds to ASTM Type 1 that comply with British Standard (BS EN 197-1) and Malaysia Standard MS EN 197-1 (BS EN 197-1, 2011; MS EN197-1, 2014). The cement with a specific gravity of 3.15 and had a bulk density of 1440 kg/m^3 was used.

Table 3.1 illustrates the compositional analysis of cement as indicated by the manufacturer. XRF spectroscopy was used to determine the quantitative measurement of compound and element in cement. Cement used in this study was Ordinary Portland Cement (OPC). Calcium oxide, silica, aluminum oxide and iron oxide are the main compounds in OPC. Each of them has their own role in the concrete manufacturing. Calcium oxide (CaO) provides strength to the cement. Silica (SiO_2) make the concrete became more denser by reducing the porosity. Aluminum oxide (Al_2O_3) accelerates the cement hydration reaction, while iron oxide (Fe_2O_3) contributes colour to the concrete specimen. According to the compositional analysis of OPC as tabulated in Table 3.1, it shows that CaO (62.5%), SiO_2 (22.5%), Al_2O_3 (6.0%), Na_2O (3.8), Fe_2O_3 (3.9) and SO_3 (1.1) constituted the major elemental species. Other compounds detected in trace amount (≤1%) are MnO, MgO, and K_2O.

Table 3.1: Compound and Elemental Analysis of OPC

Compound/Element (w/w%)	Ordinary Portland Cement (OPC)
Al_2O_3	6
SiO_2	22.5
CaO	62.5
Fe_2O_3	3.9
SO3	1.1
Na_2O	3.8
Others	0.2

3.2.3 Aggregates

In this study, the Construction Material Laboratory, Universiti Putra Malaysia supplied both fine and coarse aggregates that were used to produce concrete and complied with British Standard, BS EN 12620 (BS EN 12620, 2002). Both of the aggregates are very important to each other because fine aggregate fills the voids between the coarse aggregate, promote an overall compactness to the concrete (Ueno & Ogawa, 2020).

Natural river sand was used as fine aggregate. Fine aggregate help to make the concrete mixes more compact. Furthermore, the presence of fine aggregate lubricates the concrete mixture and facilitates proper placement (Ranatunga et al., 2023). The specific gravity of sand is 2.64 with a fineness modulus of 2.32.

For coarse aggregate, crushed granite was used with a size of 20 mm. Coarse aggregate makes the concrete become more denser and strengthening the concrete structure (Yaseen Ali Salih, 2018). The specific gravity and fineness modulus of coarse aggregate is 2.77 and 8.47 respectively.

3.3 Experimental Setup

The experimental work of this study is illustrated in Figure 3.1.

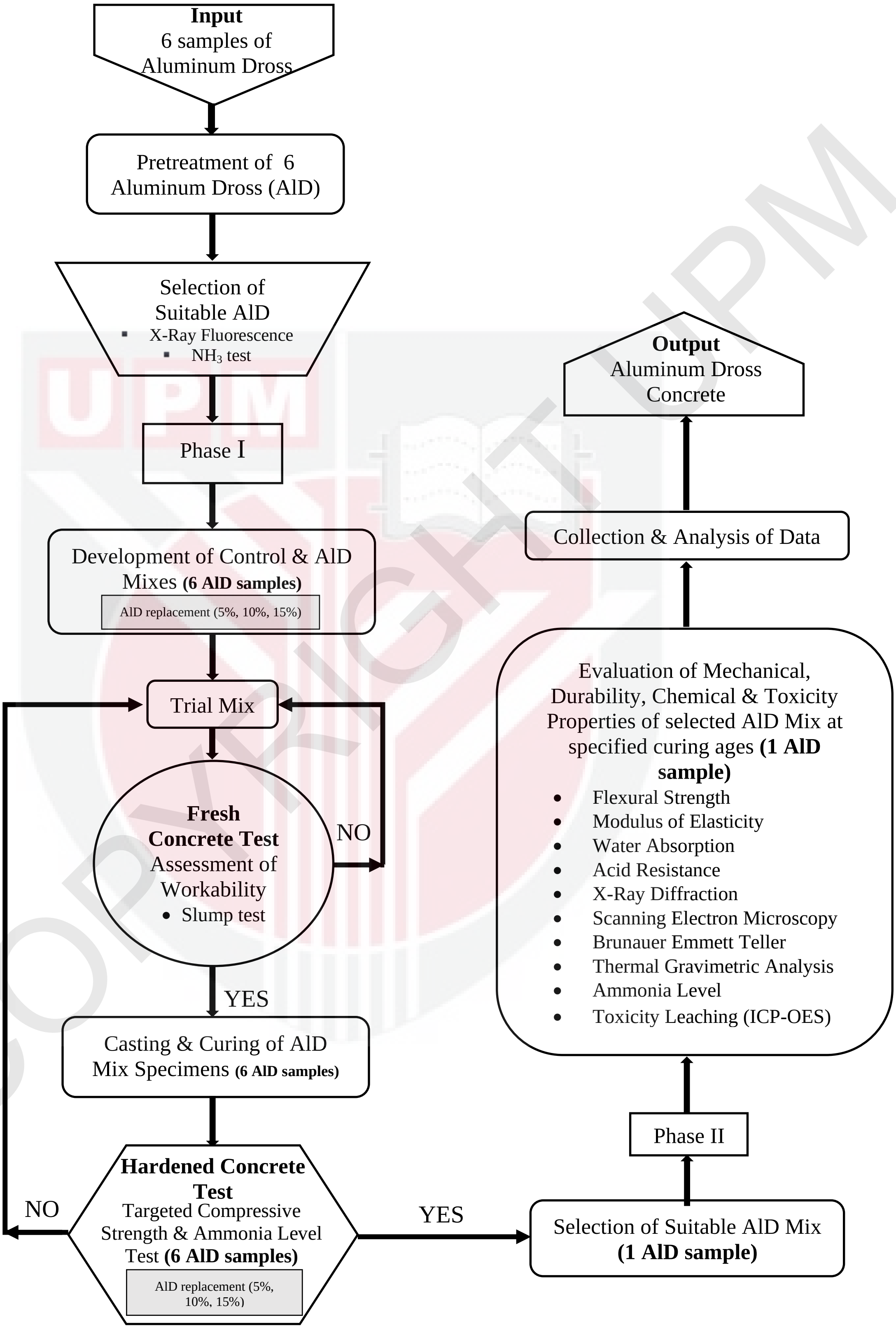

Figure 3.1: Schematic Diagram of Experimental Work

3.4 Pretreatment of Aluminum Dross

The aluminum dross was treated prior to use in concrete production. In chapter 2, Section 2.6, there were three typical methods that were used to treat aluminum dross. However, for this study, water-washing method was chosen as it is more environmentally friendly, low cost and also has a lower energy consumption. The most effective method to remove any potential oxide generation and toxic gas formation from aluminum dross sample is to wash it with water (Panditharadhya et al., 2018). According to Pereira et al., (2000), a mortar made by utilizing raw aluminum dross had a significant volumetric expansion. This is due to the high concentrations of toxic gases released when aluminum dross comes in contact with moisture. Therefore, the usage of aluminum dross without a water-washing pretreatment method is not practical.

All six types of aluminum dross samples were were washed and dried to remove foreign matter and reduced ammonia concentration, hence maximizing the yield of aluminum dross. Initially, aluminum dross underwent water washing with a constant 1:6 dross-to-water ratio for 30 minutes at room temperature (Javali et al., 2017). The mixture was continuously stirred for about 30 minutes at room temperature to dissolve the inorganic and alkaline salt present in the aluminum dross. The washing process helped in removing odor from the aluminum dross. The mixing process during water washing was done manually by hand. As stated by Hassan Basri et al., (2019), 30 minutes is the optimal mixing time to get a homogeneous mixture. Feng et al., (2020) reported that the pretreatment process that was conducted at a standard room temperature (25°C) was essential for water-soluble salt removal as 80% of the sodium and 85% of the potassium were leached. At the same time, chloride was dissolved during the water-washing procedure (Tsakiridis et al., 2013). However, during the water-washing process, a pungent smell was produced. As mentioned in previous chapters, when aluminum dross comes in contact with water, ammonia gas was emitted. Thus, optimization methods were employed to minimize the ammonia concentration in the aluminum dross. Two techniques were incorporated in the process, utilization of mechanical mixer and also two times water washing. The capacity of high-speed mixer provided a homogenous mixture to the solutions. Moreover, to decrease the water demand and increased the yield of treated aluminum dross, two times water washing were used. Ammonia concentration were conducted for all six samples before and after the optimization method to analyze the reduction of ammonia level.

Then, the undissolved dross residues were then separated from the alkaline solution by filtration, using filter paper grade QT43 with a pore size of 14-18 μm. After that, the aluminum dross would be dried under the sun to remove water for 2 to 3 hours. The drying method could be optimized by oven-dried at 100°C for 24 hours. Before oven dried, the samples were ground using an industrial blender to reduce the sample size and increase the surface area for high moisture removal. After 24 hours, the bad odour from aluminum dross was reduced. Finally, the treated aluminum dross was sieved since it became lumpy after the drying process as stated in Appendix B.1. The aluminum dross that can pass through a sieve of 100 µm would be added to the concrete mixture.

3.5 Aluminum Dross Selection Process

Composition analysis by X-Ray Fluorescence

The quantitative measurement of chemical compositions in cement and aluminum dross was determined by X-Ray Fluorescence (XRF), Wavelength Dispersive XXRF. Initially, there were six samples of aluminum dross to be selected. For phase I of the study, based on quantitative analysis by XRF, only the best aluminum dross sample was pre-selected to be in concrete development. The criteria of selection were based on the amount of aluminum oxide, silica oxide, calcium oxide and iron oxide. All these compounds were the major constituents needed in the development of concrete. XRF was conducted onto all six treated aluminum dross and Ordinary Portland Cement.

The fused-bead technique was used to prepare the cement all treated aluminum dross samples. Mixed 0.5 g of each sample with 0.5 g Spectra-flux LT-110 ($Li2B4O7$; 66.5% & $LiBO2$; 33.5%) were stacked up in a platinum dish; subsequently, it was fused at 900 and 1250°C. Then the sample was cooled to avoid crystallization and placed in an XRF instrument for analysis. The chemical compound and composition of the cement and treated aluminum dross were presented in Chapter 4 of the thesis.

3.6 Concrete Mix Design

In the present study, the concrete mixes were constructed for M40 grade concrete to achieve a minimum compressive strength of 40 MPa based on British Standard, BS EN 206-1 at the end of curing age of 28 days (BS EN 206-1, 2001). The water-to-cement ratio (w/c) of 0.4 was implemented. Each trial mix had different proportion of cement and aluminum dross. All concrete mixtures were added with the same amount of aggregates. The control concrete mixture (COM1) was made without substituting any aluminum dross.

This research work was conducted in two phases as illustrated in Figure 3.1. In the first phase, a mix proportion for aluminum dross concrete from all types of aluminum dross were developed to select the best workable aluminum dross in concrete. The aim for this phase was also to choose the best replacement percentage of selected aluminum dross. The experimental work was executed with the replacement values of aluminum dross at 5,10, and 15% by weight of cement. These specimens were tested by using compressive strength after 28th days of water curing age. The criteria of selection were to have a good slump value at 100 mm with minimum compressive strength of 40 MPa at 28 days of curing age. For this, a total of 25 mixtures were performed using a standard Hobart model N50 Mixer at Construction Material Laboratory, Universiti Putra Malaysia using various formulations of aluminum dross content. The control concrete mixture was made based on standard commercial concrete without any cement replacement for comparison. The size of 20 mm coarse aggregate was used in this work with a 0.4 water to cement ratio based on the calculated concrete mix design depicted in Appendix A.

During the washing and curing process, the pH reading was observed using pH meter (pH 700 Meter Eutech Instrument). The pH of the water indicates the alkalinity of the aluminum dross due. This is due to the emission of ammonia gas when aluminum dross comes in contact with water, increasing the alkalinity of the solution (Zauzi et al., 2016b). In concrete production, the pH of the concrete plays a significant role in preventing corrosion.

The second phase was conducted to assess and study the performance of the selected aluminum dross with the best percentage of aluminum dross based on the chemical, physical, and mechanical properties of fresh and hardened concrete analysis. Toxicity properties were also determined as the concrete produce must have the acceptable value of heavy metal as prescribed by the Waste Acceptance Criteria (WAC) and the US Environmental Protection Agency (US EPA). The concrete specimens were tested at 7^{th}, 21^{st}, 28^{th} days of curing age. The description of different trial mixes based on the mixing of 1 m^3 concrete proportion was tabulated in Table 3.2.

Table 3.2: The mix proportions for 1m^3 concrete

Type	Phase	First Phase																								Second Phase
	Sample	Sample 1 (S1)				Sample 2 (S2)				Sample 3 (S3)				Sample 4 (S4)				Sample 5 (S5)				Sample 6 (S6)				Sample 3 (S3)
	Mix	COM1	COM2	COM3	COM4	COM1	COM2	COM3	COM4	COM1	COM2	COM3	COM4	COM1	COM2	COM3	COM4	COM1	COM2	COM3	COM4	COM1	COM2	COM3	COM4	COM5
Cementitious Materials	% of OPC	100	95.0	90.0	85.0	100	95.0	90.0	85.0	100	95.0	90.0	85.0	100	95.0	90.0	85.0	100	95.0	90.0	85.0	100	95.0	90.0	85.0	90.0
	OPC (kg/m^3)	25	23.7	22.4	21.2	25	23.7	22.4	21.2	25	23.7	22.4	21.2	25	23.7	22.4	21.2	25	23.7	22.4	21.2	25	23.7	22.4	21.2	311.4
	AlD (%)	0	5.0	10.0	15.0	0	5.0	10.0	15.0	0	5.0	10.0	15.0	0	5.0	10.0	15.0	0	5.0	10.0	15.0	0	5.0	10.0	15.0	10.0
	AlD(kg/m^3)	0	1.2	2.5	3.7	0	1.2	2.5	3.7	0	1.2	2.5	3.7	0	1.2	2.5	3.7	0	1.2	2.5	3.7	0	1.2	2.5	3.7	34.6
Fine Aggregate	% of sand	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Sand (kg/m^3)	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	646
Coarse Aggregate	% of gravel	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Gravel (kg/m^3)	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	790
Water (liters)		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	138

Note: Ratio remained same

3.7 Fresh Concrete Analysis

Consistency of Fresh Concrete-Slump Test

The concrete slump test is an on-site test to measure the consistency and workability of fresh concrete mixture. A slump test was conducted for fresh concrete from all six aluminum dross samples in accordance with the BS EN 12350-2 (BS EN 12350-2, 2019). A change in slump height would indicate an undesirable change in the concrete material ratio. Slump test was done prior to casting the concrete into the moulds. The slump cone used had a 300 mm height, 200 mm base diameter, and 100 mm upper diameter. The process of conducting a slump test involved cleaning and coating the internal surface of a slump cone with oil to prevent sticking. Next, the mould was placed on a smooth, horizontal non-porous base plate for stability. The prepared concrete mixture was poured into the mould in layers, with each layer being compacted using a tamping rod. Excess concrete was removed, and water was cleaned. It is important to clean any mixture or water that may have leaked between the mould and base plate to avoid interference with the test results. Finally, the mould was lifted vertically and slowly from the concrete, allowing it to settle naturally. The difference between the initial height of the cone and the height of the slumped concrete provides an indication of its workability, known as the slump value.

3.8 Hardened Concrete Analysis

3.8.1 Physical Properties

3.8.1.1 Surface area and pore analysis by Brunauer-Emmett-Teller

Brunauer-Emmett-Teller (BET) analysis was used to examined the surface area and pore structure of cement and selected aluminum dross through nitrogen adsorption.

The technique encompasses evaluations of both external area and pore area to determine the total specific surface area. Selected treated aluminum dross and cement were used in this test. Approximately 1 g of samples from each concrete mix was ground. The samples were then degassed for eight hours at a temperature ranging from 150 to 200°C in a vacuum environment. The total surface area, average pore size (in nm), and total pore volume (in cm^3/g) of the samples were derived from adsorption-desorption isotherms using the Brunauer-Emmett-Teller (BET) technique. The BET surface area was estimated based on a nitrogen uptake value of 101. Each sample was cooled to cryogenic temperatures using liquid nitrogen. A gradual dosage of nitrogen gas (the adsorbate) was applied to the sample (the adsorbent). The weight of nitrogen adsorbed was calculated after the relative pressure had been allowed to equilibrate following each dosage of nitrogen gas. The analysis was performed at the temperature of liquid nitrogen (approximately at 77 K) using a TriStar II Plus, Micromeritics.3.6 Concrete Mix Design Formulation.

3.8.2 Mechanical Properties

3.8.2.1 Compressive Strength Test

Compressive strength is known as the ability of a material or structure to support loads on its surface without cracking or deflecting. In this work, the compressive strength was tested using cubical moulds of size 100 mm x 100 mm x 100 mm as per the guidelines of BS EN 12390-3 (BS EN 12390-3, 2001). In this research work, compressive strength was tested at 7^{th}, 21^{st}, and 28^{th} days of curing age using Compression Test Machine 5000 kN, Unit Test Scientific.

The method of performing compressive strength began with cleaning and applying oil to the cubical moulds. The concrete mixture was then poured into the mould and the vibrating table was switched on to ensure a homogenous mixture. After 24 hours, the moulds were removed, and test specimens were put in water for curing at room temperature. These specimens were tested by compression testing machine after the 7^{th}, 21^{st}, and 28^{th} days of curing. The specimen was placed at the center and was loaded uniformly till the failure of the cube with a capacity of 6.0 kN/s.

3.8.2.2 Flexural Strength Test

The flexural strength test assesses the ability of an unreinforced concrete beam or slab to withstand bending failure. It was conducted using a Flexural Test Machine 3000 kN, Unit Test Scientific at 28th days of curing age on concrete beams with a size of 100 mm x 100 mm x 500 mm based on BS EN 12390-5 (BS EN 12390-5, 2019).

The flexural strength test was carried out by cleaning and glazing oil to the beams. The concrete mixture was poured into the beams. The beams were positioned on the vibrating table to eliminate surface voids. The hardened concrete was removed from the beams after 24 hours of casting and immersed for curing in water tank under room temperature. These specimens were tested by flexural testing machine after 28th days curing. Then, the specimen was placed centered on the loading points. The specimen was loaded continuously till the point of failure at three-point load with a capacity of 0.1kN/s was applied to the concrete beam.

3.8.2.3 Modulus of Elasticity Test

Modulus of Elasticity test describes the stiffness of the concrete as it is important properties of solid materials. It was conducted at 28th days of curing age on concrete cylinder moulds with a size of 100 mm x 200 mm based on ASTM C469 (Anonim, 2006). The test was performed using a Concrete Compression Machine 3540 kN, Unit Test Scientific along with Data Logger TML TDS-530.

The method that has been used to measure modulus of elasticity started with cleaning and coating oil to the cylinder moulds. Then, the prepared concrete mixture was poured into the mould and let it vibrate on the vibrating table for homogenous mixture. The specimens were removed after 24 hours and immersed in water tank for curing process. After 28th days of curing age, the samples were tested by compression testing machine. Before that, the molten sulphurs were used to cover and smoothen the top layer of concrete as the surface was rough. Next, the center of the concrete was marked vertically to attach the soldered strain gauge. Then, the specimen was placed on the loading points and centered the loading system in relation to the applied force. The wiring of strain gauge would be attached to the wiring of Data Logger TML TDS-530. The specimen was loaded continuously till the point of failure at a constant rate with a capacity of 10.0kN/s.

3.8.3 Durability Properties

3.8.3.1 Water Absorption Test

Water absorption tests were conducted to observe the percentage of water absorption of the concrete samples. The concrete specimens of each mix design of size 100 mm x 100 mm x 100 mm were tested as the provisions of ASTM C 642-06 (ASTM C 642-06, 1997). The samples that had been curing for 7th and 28th days were oven-dried for 24 hours before being weighed (W1). The samples were then submerged in water for 24 hours. The samples were removed from the water tank after 24 hours and dried it with a clean dry towel before being weighed (W2). The percentage of water absorption was calculated using Equation 3.1.

$$\textbf{Water absorption}\ (\%) = \frac{\mathbf{W_2 - W_1}}{\mathbf{W_1}} \times \mathbf{100} \qquad [3.1]$$

3.8.3.2 Acid Resistance Test

Acid resistance tests were performed to observe the effect of acid attack on the concrete samples. The method of acid resistance test were conducted following the method by Raja, College, and Nadu (2021). The test specimens were casted in cubical moulds with a size of 100 mm x 100 mm x 100 mm and water cured for 28th days. After 28 days, the samples were removed from the curing tank and allowed to dry for a day. The weights of specimens were measured (M1). The specimens would be immersed in acid water for another 28 days containing Sulphuric acid (H_2SO_4) with pH 2 at 5% weight of water. The volume of solution was 60 L. The pH was maintained throughout 28 days. The concrete cubes were taken out from the acidic water and cleaned before being weighed (M2). Compressive strength test was also conducted to investigate the effect acid water to the concrete strength. The average weight loss due to the effect of acid water was estimated using Equation 3.2.

$$\textbf{Weight Loss}\ (\%) = \frac{\mathbf{M_2 - M_1}}{\mathbf{M_1}} \times \mathbf{100} \qquad [3.2]$$

3.8.4 Chemical Properties

3.8.4.1 X-Ray Diffraction

X-Ray diffraction (XRD) analysis is the most frequent method to study and analyze crystals in powder samples. Crystalline mineral phase and crystallization orientation in the interface transition zone between the aluminum dross powder particles and cement are commonly used to investigate the mineral phase of aluminum dross particles. The XRD analysis was conducted on the 28th day samples. The samples were prepared by manually grounded the concrete using an agate mortar and pestle and sieved through 75 mm. Approximately 1 g of sample was stored in a closed plastic bottle from each concrete mix. The diffractometer with CuKu source having a wavelength of $\chi = 1.54$À at the scanning speed of 2s step and the diffraction angle of 2θ between 20° and 80° was employed for the test. XRD analysis was performed on PHILIPS (PW 3040/60 MPD X'PERT High Pro Panalytical).

3.8.4.2 Surface Morphology Analysis

In this study, the microstructure analysis was determined using Scanning Electron Microscope (SEM: JSM -5610V, JOEL) at the Material Characterization Laboratory (MCL), Universiti Putra Malaysia. The SEM images of control mix and aluminum dross concrete were analyzed.

The morphology analysis was conducted at different magnifications from x 200 to x 40000. The concrete specimens were collected in a small size of 5 mm at the age of 28^{th} day. The samples were crushed by a grinder. An amount of 10 g of the powdered concrete was attached to a metal stub. The stub was mounted in the SEM to observe the microstructure of the concrete.

3.8.4.3 Thermal Gravimetric Analysis

Thermogravimetric analysis (TGA) was carried out to determine the decomposition of the hydration compound in the concrete. The samples were prepared by manually grounded the concrete using an agate mortar and pestle and sieved through 75 mm. At the end of the 28^{th} day of curing age, approximately 1 g of sample was stored in a closed plastic bottle from each concrete mix. The analysis was performed using Thermogravimetric Analyzer 2 (Small Furnace), Mettler Toledo at Thermal Analyzer

Laboratory, Faculty of Science, Universiti Putra Malaysia. The experimental setup included a platinum top-opened crucible, a dynamic N_2 gas atmosphere (40 ml/min), and a heating rate of 10°C/min. The samples were heated at a constant rate at the temperature range of 50°C to 1000°C.

3.8.5 Toxicity Properties

3.8.5.1 Ammonia Level Test

The toxicity of ammonia level in aluminum dross was determined during the washing process and curing of concrete by using the salicylate method on DR 900 colorimeter, Hach. Blank sample was prepared by adding 0.1 mL of ammonia-free water to one AmVer Diluent Reagent Test. Then, an amount of 0.1 mL of sample was added to one AmVer Diluent Reagent Test. After that, each vial was added with one Ammonia Salicylate Reagent Powder Pillow for 5 mL samples, followed by one Ammonia Cyanurate Reagent Powder Pillow. The vial was shaken properly to dissolve the powder. The solution was let to 20 minutes for a thorough mixed. After 20 minutes, the vial was cleaned and inserted into Dr 900 Colorimeter. For a sample that resulted in dark green colour with a reading of more than 50 mg/L of ammonia, dilution of the sample was conducted.

3.8.5.2 Heavy Metal Analysis

The Toxicity Characteristic Leaching Procedure (TCLP) was employed to examine the toxic and heavy metals in the aluminum dross-based concrete and to ensure the 28th

days of concrete was ecologically suitable to be used. Initially, the coarse aggregates were removed from the concrete specimen, which was then ground to obtain a finely powdered sample that could pass through a 1.00 mm sieve. The concrete sample's leachate was produced in accordance with the US Environmental Protection Agency (US.EPA). Then, the toxicity analysis of the leachate produced by the treated aluminum dross was performed. Inductively coupled plasma optical emission spectroscopy (ICP OES, Optima 2000DV, Perkin Elmer) at Material Characterization Laboratory (MCL), Universiti Putra Malaysia was used to examine the leaching of toxic and heavy elements from the finely powdered 28th days concrete samples. An acid digestion method was performed on the concrete mixture to observe the elements such as Al, Ar, Cd, Cr, Cu, Ni, and Zn in the concrete. Studies conducted by Uddin et al., (2016) and Awotedu et al., (2018) suggested that nitric acid is often used as an oxidant reagent for this purpose, either alone or in combination with other digesting reagents, including acid or hydrogen peroxide. Therefore, nitric acid digestion was done using 5 mL of 65% HNO_3 added into 1 g of concrete sample. The mixture was heated for 10 minutes on the hot plate before cooling it down for 10 minutes. Later, 5 mL of 65% HNO_3 was added into the mixture and heated again for 30 minutes. If brown gas was observed, another 5 mL HNO_3 should be poured until reaction completed or until total digestion. Then, the sample was filtered, and serial dilution was conducted.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results of treated aluminum dross, assessment and performance of concrete were discussed. The samples were provided by Cenviro Sdn. Bhd. undergone a pretreatment process to remove foreign matter, salts, and oxide. However, ammonia gas was emitted during the water-washing process, hence, the optimization methods were applied into the process to reduce the ammonia concentration. The selection of aluminum dross was based on the quantitative measurement by XRF analysis and ammonia test. The best aluminum dross was selected for cement replacement in the concrete development. The hardened tests were performed onto controlled concrete block and aluminum dross concrete block using chemical, physical, and mechanical characterization analyses.

4.2 Pretreatment of Aluminum Dross

All the samples were in fine powder form, blackish in colour, with small aluminum pieces. The aluminum dross had a specific gravity of 3.39 and a bulk density of 774 kg/m^3. Figure 4.1 depicts the raw and treated aluminum dross. Figure 4.1(a) shows one raw aluminum dross sample. All six samples have similar appearance as displayed in Figure 4.1(a).

Based on the observation, the pretreatment process did not change the appearance of the aluminum dross in terms of colour. The treated aluminum dross did not have any lump or block as it already underwent filter process. The odour of aluminium dross was also significantly reduced, possibly due to the increase release of hazardous gases during the mixing process.

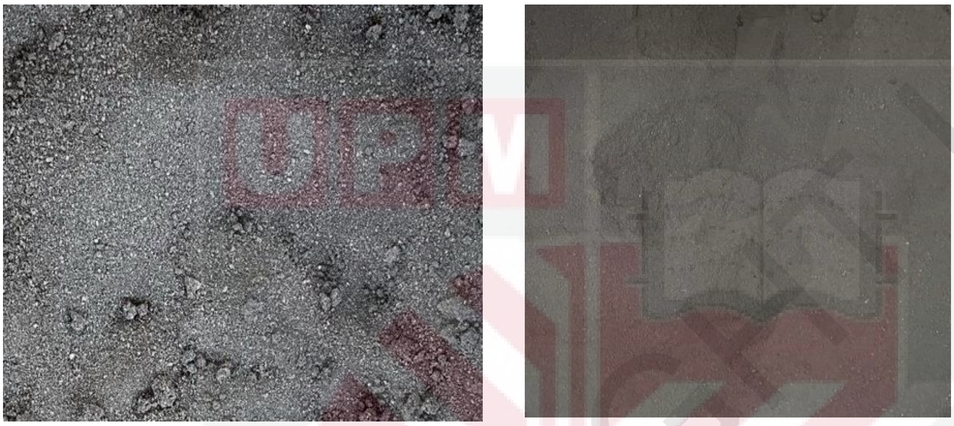

Figure 4.1: (a) Raw aluminum dross, (b) Treated aluminum dross

During the mixing process, a foul-smelling ammonia escaped due to the reaction involved as described in Section 2.7 and expressed by Equation 2.8. The reaction occurred during the mixing process represented the hydrolysis process of AlN in aluminum dross, releasing toxic ammonia gas. The aluminium dross also comprised trace levels of soluble salts like NaCl and KCl, in addition to insoluble materials like Al and Al_2O_3 (Ni et al., 2019). Equation 4.1 shows the presence of ammonia gas that led to the formation of ammonium hydroxide, NH_4OH. This ammonium compound could chemically react with both aluminum dross and concrete materials, potentially affecting their quality and properties.

$$NH_3 + H_2O \leftrightarrow NH_4OH \qquad [4.1]$$

$$2NH_4OH + Al_2O_3 + 3H_2O \rightarrow 2[Al(OH)_4]^- + 2NH_4^+ \qquad [4.2]$$

$$NH_4OH + Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^- + NH_4^+ \qquad [4.3]$$

The quality of aluminum dross might be affected by the presence of ammonia. Aluminum oxide, Al_2O_3 present in aluminum dross chemically reacted with hydroxide and water, producing aluminum hydroxide complexes as demonstrated in Equation 4.2. This reaction influenced the pH of the solution. The presence of NH_4OH increased the hydroxide ion concentration, which could further promote the dissolution of aluminum oxide. As reported by Li et al., (2019), due to the nature of ammonia, which is easily soluble in water, the pH of the water immediately rose to 7. This result might reveal that a moisture layer that had been presented on the salt cake's surface which possibly contained some ammonia had been broken down during the mixing process with water. Another experimental work conducted by Lv et al., (2022), the pH of aluminum dross can rose up to 9.8 when the ammonia concentration reached 300 ppm.

According to a study by Babu et al., (2020), concrete may experience progressive deterioration when ammonium ions react with cement hydrates. The mechanism of concrete deterioration is caused by the leaching process that leads to decalcification and the dissolution of hydration products so that the distribution of calcium ion distribution and pH value in leaching area reduces.

The deterioration of concrete when exposed to ammonia gases involved several mechanisms, as demonstrated in Equations 4.1 and 4.3. Firstly, Equation 4.1 illustrates the formation of NH_4OH. The generation of this ammonium compounds can create pressure within the concrete matrix, potentially leading to cracking and spalling, resulting in strength loss.

Secondly, ammonium hydroxide can react with calcium hydroxide, $Ca(OH)_2$, a major component of cement hydrates, to form soluble ammonium compounds as illustrated in Equation 4.2. This reaction results in the leaching of calcium ions, which reduces the availability of calcium for the formation of calcium silicate hydrates (C-S-H), the primary binding phase in concrete.

The findings reported by Schneider and Chen (2019) highlighted the deterioration in concrete strength due to prolonged exposure to a 10% ammonium nitrate solution, NH_4OH. Initially, after 3 months of direct immersion in the solution, the concrete strength was reduced to 50% of its initial strength of 38.2 MPa. Additionally, after 112 days of exposure, the strength dropped intensely to 7.64 MPa, indicating an 80% loss of strength. These results indicated that the long-term harm that chemical exposure causes to the performance of concrete.

4.3 Selection of Aluminum Dross Samples

As stated in Chapter 3, the samples of aluminum dross were generated by different industrial sectors. The selection of aluminum dross samples was conducted by characterizing X-Ray Fluorescence (XRF) and ammonia level tests.

4.3.1 Composition Analysis-X-Ray Fluorescence (XRF)

The compositional analysis using XRF were used to select the best aluminum dross as the replacement material of cement in concrete production. The composition of the compounds and elements contained in the raw or untreated aluminum dross is shown in Table 4.1. Based on Table 3.1 in Section 3.2.2, the weight percentage of the major elements in OPC such as calcium oxide, aluminum oxide, silicon oxide, and iron oxide impact the selection of aluminum dross samples. Each of the oxides play a significant role in concrete manufacturing as mentioned in Section 3.2.2. Thus, the weight percentages of CaO, SiO_2, Al_2O_3, and Fe_2O_3 are critical in evaluating the suitability of aluminum dross as a cement replacement in concrete.

Table 4.1: Compound and Elemental Analysis of Raw Aluminum Dross

Test Item	Sample 1 (S1)	Sample 2 (S2)	Sample 3 (S3)	Sample 4 (S4)	Sample 5 (S5)	Sample 6 (S6)
Compound/Element (w/w%)						
Al_2O_3	Trace	54.2	53.1	29.0	43.0	50
SiO_2	Trace	Trace	3.2	Trace	Trace	Trace
CaO	11.8	3.6	5.7	2.1	2.5	6.3
Fe_2O_3	24.0	23.8	14.3	23.3	22.5	5.3
CuO	26.9	Trace	8.8	24.2	7.1	8.0
ZnO	19.7	Trace	3.9	7.7	5.3	18.1
MgO	4.0	4.9	1.3	1.7	8.0	2.0
NaO	5.8	Trace	1.8	5.5	2.5	0.9
Cl	Trace	1.6	1.3	Trace	2.9	Trace
K	2.0	8.0	4.2	1.2	1.6	6.2
Ti	1.9	1.0	2.9	3.2	2.7	0.8
Cr	1.0	Trace	0.7	2.1	0.7	0.4
Others	3.9	2.9	0.0	0.0	1.2	2.0

Note: Others is for element such as barium, arsenic, and selenium.

Based on Table 4.1, the composition data of aluminum dross indicates that the samples contain metal oxide, heavy metals, and other elements. Hu et al., (2021) stated that aluminum and oxygen in the form of aluminum oxide, Al_2O_3 are the major elements in aluminum dross, whereas the content of ferum, sodium, chloride and magnesium can exceed 1% due to the fluxing during the melting process of secondary aluminum dross.

In this experimental work, among all the six samples, only sample 1 (S1) detected aluminum in the alumina form in trace amount (≤1%), thus, it was rejected to be in the concrete development. Sample 2 (S2) has the highest alumina (54.2%), yet there were trace contents of silicon, copper, zinc, and sodium oxides, therefore S2 also been removed from the list of ingredients in concrete development. Silica is important in concrete as it increased the strength by reducing the porosity (Grieb, 2014). Of all the samples, only sample 3 (S3) had the present of silica (3.2%) with abundance of alumina (53.1%). Even though only traces of silica content were found in S4, S5, and S6, further investigations were conducted by examining the ammonia test after pretreatment process of aluminum dross.

In addition, there were small amounts of hazardous heavy metals in aluminum dross as illustrated in Table 4.2 such as chromium, barium, arsenic, and selenium. The amount of Cr present in the sample was at an average of 0.82% for all six samples. This amount of Cr present can cause toxicity issues as a significant amount of waste is produced and disposed of each year. Meanwhile, only 4 samples (S1; S2; S5; S6) had the other heavy metals (barium; arsenic; selenium). This might be due to the thermal process involved during secondary treatment of extracting aluminum dross.

Even though only traces of silica were found in samples S4, S5, and S6, a high percentage of alumina were presented. Further investigation to select the best aluminum dross sample was conducted by examining the ammonia test after pretreatment process of aluminum dross.

4.3.2 Ammonia Level Test

In construction industries, the reaction between ammonia and cement based materials caused leaching, and/or expansion, along with a strength loss (Babu et al., 2020), in addition to a pungent odor formed from the mixing process of dross with water. The emission of ammonia gas impacts human health and the environment. Therefore, ammonia level tests were performed on the treated aluminum dross as illustrated in Appendix C.1 to maximize the ammonia removal for better selection of aluminum dross sample being substituted into concrete mixture and the results are shown in Table 4.2 and Figure 4.2. There were two stages of ammonia level tests. From the first stage, the results of ammonia level tests on all six samples were analyzed to select the best samples.

In this section, the ammonia test results in Table 4.2, depicted two different data. The first data denoted as initial was where manual mixing was involved. The final ammonia concentration was the improved version of the pretreatment process where the utilization of a mechanical mixer and two times water washing were employed.

Based on the findings tabulated in Table 4.2, the concentration of ammonia in all aluminum dross samples was reduced by about 50% due to the optimization of water-washing method by using a mechanical mixer and two times water washing. The stirring speed and 2 times water washing help in removal of ammonia. As reported by Ata et al., (2017), stirring speed allowed the uniform dispersion of gas bubbles in liquid phase. Lv et al., (2022) mentioned that high-speed stirring up to 600 r/min enhanced the diffusion of NH_3. Based on the analysis, two times water washing using the recycled water helped in removing bad odor generated from ammonia gas from the mixtures.

Table 4.2: Concentration of ammonia in treated aluminum dross during the washing process

Sample	Ammonia level (ppm)		Percentage of Ammonia Reduction
	Initial (Manual mixer)	Final (Mechanical mixer)	
S1	328	164	50
S2	298	149	50
S3	150	75	50
S4	200	100	50
S5	278	139	50
S6	175	88	50

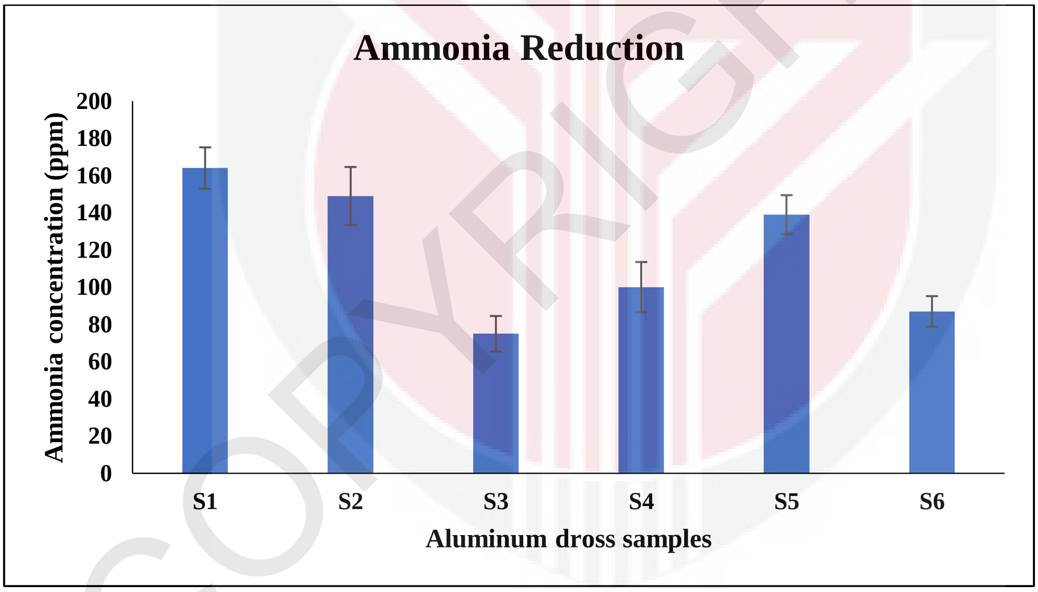

Figure 4.2: Ammonia reduction for each aluminum dross samples

In conclusion, based on the characterization results from XRF and ammonia level tests, aluminum dross Sample 3 (S3) was selected as the cement partial replacement material for concrete development. The XRF findings indicated that aluminum dross S3 has a significant percentage of aluminum oxide and silica at 53.1% and 3.2%, respectively. Although Sample 6 (S6) exhibited almost similar compound content to S3, it was not chosen due to its limited availability. Moreover, among all aluminum dross samples, S3 recorded the lowest ammonia concentration at 75 ppm. This study confirms that the water washing process effectively removed both salt and ammonia content from the aluminum dross.

4.4 Concrete Mixes

In this experimental work, aluminium dross-based concrete was produced to investigate the potential of the aluminium dross sample to be incorporated in concrete mixture for commercial application of M40 grade concrete. Table 4.3 shown the properties of Ordinary Portland Cement that was used in this study based on both Malaysia and British Standard (MS EN197-1, 2014; BS EN British Standard, 2000).

Table 4.3: Properties of Ordinary Portland Cement

Description	Unit	OPC CEM-I-42.5N Grade	Limits as per BS EN 197-1 12-1996
Chemical composition	-	-	-
Chloride content (Cl)	%	≤ 0.10	0.10
Loss in ignition (LOI)	%	1.5	max 4.0
Insoluble residue	%	0.4	max 1.5
Sulphate content (SO_3)	%	1.75	> max 3.0
Setting time	-	-	
Initial	minutes	160	min 45
Final	minutes	250	max 600
Physical properties	-	-	
Soundness	mm	1.0	max 10

Table 4.3: Continued.

Compressive strength	-	-	
3 days	MPa	23.1	min 23.1
28 days	MPa	44.8	min 41.0

Note: OPC is Ordinary Portland Cement; min is minimum; max is maximum; mm is millimeter
(Source: MS EN197-1, 2014; BS EN British Standard, 2000)

There are two phases of the research work. In the first phase of experimental work, all six aluminium dross samples were incorporated into the concrete mixture, replacing the cement content for better identification on the best sample and the ideal dosage of aluminium dross using experimentation trial. Each sample was added into the concrete mixture with a replacement value of 5% (COM2), 10% (COM3), and 15% (COM4) by the weight of the cement. The control concrete mixture (COM1) contained aluminium dross-free mixture. The control concrete was designed to ensure desirable quality of concrete at all stages and batches of production. The workability of all mixtures was tested using slump test and compressive strength, as depicted in Table 4.4. The selection criteria should have a satisfactory slump value at 100 mm and a minimum compressive strength of 40 MPa after 28 days of curing (Olawale et al., 2021).

In the second phase of experimental work, based on the slump test and compressive strength test conducted during the first phase, the optimal percentage of aluminium dross to be added to the concrete mixture was 10% (COM3). Chemical, mechanical, and physical analysis were conducted to assess the performance of aluminium dross in the concrete mixture at different curing age at 7th, 21st, and 28th days.

4.5 First Phase Results

The first stage of the study was conducted to compare the workability of fresh concrete using a slump test and test the compressive strength of the concrete aluminum dross mixes.

4.5.1 Consistency of Fresh Concrete-Slump Test

The fresh properties of all concrete mixtures from all six samples are depicted in Table 4.4. Slump value falls within 100 mm and 125 mm are acceptable (Singh, 2020). From the obtained results, among all the mixtures, the mixes COM1 had the highest slump flow at 120 mm. For the slump flow test, higher result indicates that a particular sample at specific percentage has high flowability. For the mix COM1, it showed that the sample with no additional aluminum dross gave the highest slump test result of 120 mm.

From Table 4.4, it could be observed that the slump test analysis started to decrease with increased aluminum dross percentage except for the mix COM3 for all samples. The highest slump flow test for mixtures with 10% cement replacement with aluminum dross was found in mix COM3-S3, showing an increase from 100 mm in 5% cement replacement to 113 mm, followed by a decrease to 91 mm in 15% cement replacement concrete mix. This might happen due to the fact that the addition of aluminum dross sped up the setting time of the concrete. In the research work by Gozde Ozerkan et al., (2007) and Busari et al., (2022), the addition or reduction of setting time with replacement of aluminum dross caused by the existence of nanoparticles that have a greater surface area, which would absorb a remarkably substantial volume of liquid.

Thus, more cement replacement with the aluminum dross of up to 15% might affect the behavior of the fresh concrete.

Table 4.4: Slump flow data for all concrete mixes for aluminum dross samples S1 to S6

Sample	Slump flow (mm)			
	COM1	COM2	COM3	COM4
Sample 1	120	98	98	83
Sample 2	120	100	102	96
Sample 3	120	100	113	91
Sample 4	120	99	110	105
Sample 5	120	100	102	98
Sample 6	120	100	89	79

4.5.2 Compressive Strength Test

The compressive strength for all the six samples were performed at 28^{th} days of curing age to identify optimum dosage of aluminium dross substituted into concrete mixture. Compressive strength is one of the utmost properties for the concrete to surpass desired grade. For the experimentation work, M40 grade concrete was set to be the benchmark. As stated in Chapter 2, M40 grade required 40 MPa as the minimum compressive strength, therefore, the concrete specimens with an addition of aluminium dross must achieve at least 40 MPa of compressive strength. The result was depicted in Figure 4.3.

According to Figure 4.3, the control concrete, COM1 achieved the minimum compressive strength of M40 grade concrete. The compressive strength of all 5%

cement replacement concrete samples (COM2) slightly decreased from control concrete, COM1 with an average of 8.25% reduction. However, for all 10% cement replacement mixtures (COM3), the compressive strength increased for all 6 mixes, achieving an average improvement of 4.5 MPa compared to COM2. The mixture, COM3-S3 had the highest compressive strength than control concrete, COM1 at 41.3 MPa. This was because of the calcium oxide and silica content in aluminum dross S3 that provide strength to the concrete as mentioned in Section 4.2.1. From the XRF data in Table 4.1, the aluminum dross S3 was the only sample that had silica content of 3.2 wt% with an amount of 5.7 wt% of calcium oxide. The strength of the concrete was impacted by both elements (calcium oxide and silica), even though the respective weight percentages were less than that of in OPC. Besides, the compressive strength for 15% cement replacement mixes (COM4) reduced significantly with an average of 17.25% as compared to control concrete, COM1. This possibly due to high formation of air voids as a result of aggressive reactions between aluminium dross and Portland and high ammonia content leading to weaker strength of the concrete mix.

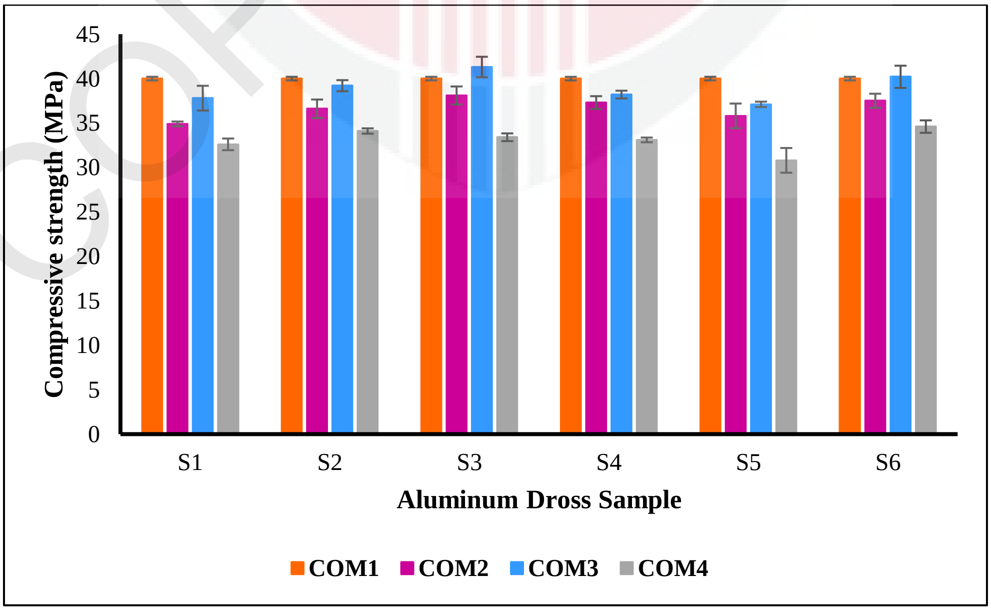

Figure 4.3: Compressive strength for all samples at 28th days of curing age

Based on the comparison of slump test and compressive strength test results for all aluminum dross samples, it can be concluded that COM3-S3 was the most suitable mixture for producing M40 grade concrete. This mixture demonstrated the highest slump flow value of 113 mm, indicating excellent workability. Additionally, it achieved a compressive strength of 41.3 MPa, which surpasses that of the control concrete sample, COM1. COM3-S3 has a lower standard deviation of 1.15, suggesting that the compressive strength values are clustered closely around the average of 41.2 MPa. This indicates good consistency and reliability in the performance of this mix.

4.6 Second Phase Results

Further studies explored the evaluation of physical, mechanical, chemical, durability and toxicity properties of aluminum dross in concrete mixtures. Generally, these properties examined the impact of aluminum dross as cement replacement material in concrete production.

4.6.1 Physical properties

4.6.1.1 Outer Surface of Concrete

The physical appearance of the control concrete (COM1) and aluminium dross concrete based on sample 3, S3 (COM2; COM3; COM4) can be observed as shown in Figure 4.4. Based on the observation, Figure 442a shows the outer layer surface of the control concrete mix, COM1, was quite smooth suggesting better interaction within the matrix. However, in Figure 4.4b, 4.4c, and 4.4d, the formation of voids was increased with the higher percentage of aluminium dross incorporated in the concrete mixture. The voids were highlighted in red circle in the Figure 4.4, 4.4c. and 4.4d. More voids could be observed in concrete mix COM4 (Figure 4.4d) as compared to other concrete mixes.

The cause of voids creation in concrete containing aluminium dross was due to the migration of entrapped air between the mould surface and concrete. Leftover ammonia content in aluminium dross samples reacted with the solid phases of Portlandite, causing an increase in void formation (Słomka-Słupik and Labus, 2022). The formation of voids could cause a decline in the concrete strength as the proportion of aluminium dross increased. This reaction caused the loss of calcium ions that contributed to the decalcification process.

(a)

(b)

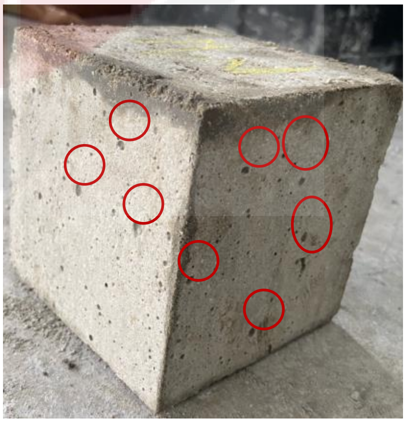

Figure 4.4: (a) Concrete mix COM1 (0% aluminum dross), (b) Concrete mix COM2 (5% aluminum dross), (c) Concrete mix COM3 (10% aluminum dross), (d) Concrete mix COM 4 (15% aluminum dross)

4.6.1.2 Surface Area and Pore Analysis-Brunauer-Emmett-Teller (BET)

BET method was used to determine the pore structure of the OPC and aluminum dross S3 as it is the most suitable aluminum dross to be substituted in the concrete development. Table 4.5 shows the nitrogen absorption analysis on the samples.

Based on Table 4.5, the OPC had lower surface area, pore volume, and median pore size than aluminum dross S3. The pore size obtained for the OPC is 5.84 nm means that the cement is mainly a microporous material. Meanwhile, the pore size of aluminum dross S3 is 10.313 nm, much bigger than OPC, indicating that the aluminum dross S3 is mostly composed of mesopores. According to Zauzi et al., (2016), the increases of BET surface area of aluminum dross due to the amount of aluminum and silica components that increased the surface pores. The larger pores volume and surface area for the aluminum dross S3 indicated that the aluminum dross was less dense, leading to low permeability and potentially decreased the durability properties as it increased the water demand. The creation of mesoporosity in aluminum dross increased the surface area resulted in a reduction in the strength of concrete. Besides that, the pore size could also affect the capacity of the water absorption for concrete structure. However, with the ideal ratio of OPC and aluminum dross S3, the properties of concrete might be improved. Further investigations were conducted to evaluate the performance of S3 in the concrete mixture.

Table 4.5: BET analysis on OPC and Aluminum Dross S3

Parameter	OPC	Aluminum Dross S3
Surface Area (m^2/g)	3.3080	7.4453
Pore Volume (cm^3/g)	0.2897	0.4583
Median Pore Size (nm)	5.8420	10.313

4.6.2 Mechanical properties

4.6.2.1 Compressive Strength Test

The second stage of the experimental work was performed to assess the performance of aluminium dross concrete. Figure 4.5 displays the compressive strength results of concrete mixes of COM1 and COM3-S3 at different curing age of 7th, 21st, and 28th days. Over the curing periods, the concrete mix COM3-S3 with 10% aluminium dross as cement replacement yielded higher compressive strength compared to COM1 (control concrete). It was observed that the compressive strength of the concrete increased with age which attributed to the continuous formation of hydration products (Odeyemi et al., 2021).

Hasan and Kabir (2013) reported that concrete gained strength for about 65% in 7 days, 94% in 21 days, and 99% in 28 days. Based on the results depicted in Figure 4.5, both mixtures, COM1 and COM3-S3 achieved the desired strength at specific curing ages. The compressive strength of mix COM3-S3 is 41.3 MPa, indicating a slightly higher strength compared to control mix COM1 at 40MPa. This suggests that a 10% dosage of aluminum dross as a cement replacement is effective. The pozzolanic action and filler effects of aluminium dross could contribute to the improvement of compressive strength in concrete (Zareei et al., 2017). In contrast, the study by Teara et al. (2018), a 50% replacement of fly ash into the concrete decreased the compressive strength about 60% from the initial strength at 31.9 MPa at 28 days. This is due to the slower pozzolanic reaction of fly ash at the early strength age.

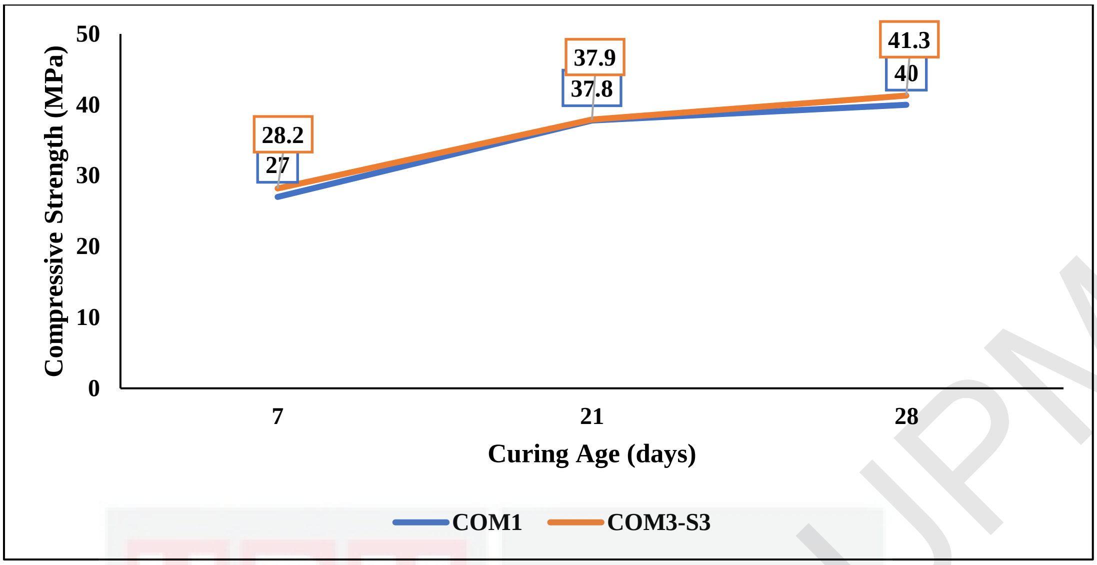

Figure 4.5: Compressive Strength of COM1 and COM3-S3 at 7th, 21st, and 28th of curing age

4.6.2.2 Flexural Strength Test

The flexural strength tests were conducted at 28 days of curing age onto control concrete, COM1 and 10% cement replacement concrete mixes at different curing aging (COM2-S3; COM3-S3; COM4-S3).

Typically, flexural strength of concrete is 10% to 20% of its compressive strength. Thus, for this study, the minimum flexural strength is 4 MPa. However, in the research work, the flexural tests were conducted onto the concrete beams until the specimens broke to investigate the maximum force the material could withstand.

Based on the data shown in Figure 4.6, all concrete mixes yielded higher flexural strength with an average of 9.1 MPa, exceeding the minimum flexural strength. Flexural test of control mixture, COM1, gave 9.87 MPa at the end of 28 days of curing age. It was observed that the concrete mixtures COM2-S3 (5% aluminium dross) and COM4-S3 (15% aluminium dross) had flexural strength approximately 6.4 and 11.3% lower than the control mixture COM1. The maximum flexural strength of 10.03 MPa was achieved with 10% cement replacement with aluminium dross in the mix COM3-S3 at the age of 28 days due to the presence of the nano sized particles of aluminium dross in concrete that could compact the gap and strengthen the bond between the concrete component. In addition, the research by Reddy and Naqash (2019b) proved that the concrete with an addition of 25% alccofine improved the flexural strength by 3.57% (4.2 MPa) at 28th days of curing age.

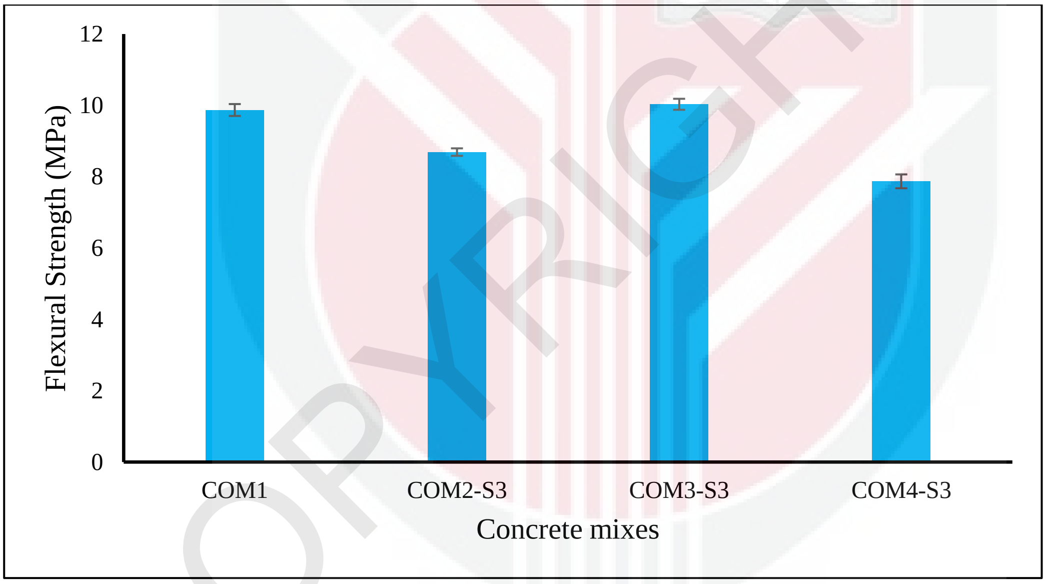

Figure 4.6: Flexural Strength of Concrete Mixes at 28th days of Curing Age

Figure 4.7 displays the results of beams for all concrete mixtures that were tested. It can be noted that all the concrete mixtures started from COM1, COM2-S3, COM3-S3, and COM4-S3 had a high flexural strength exceeding the minimum flexural strength which is 4 MPa. The higher the value, the higher the ductility (Gao et al., 2021).

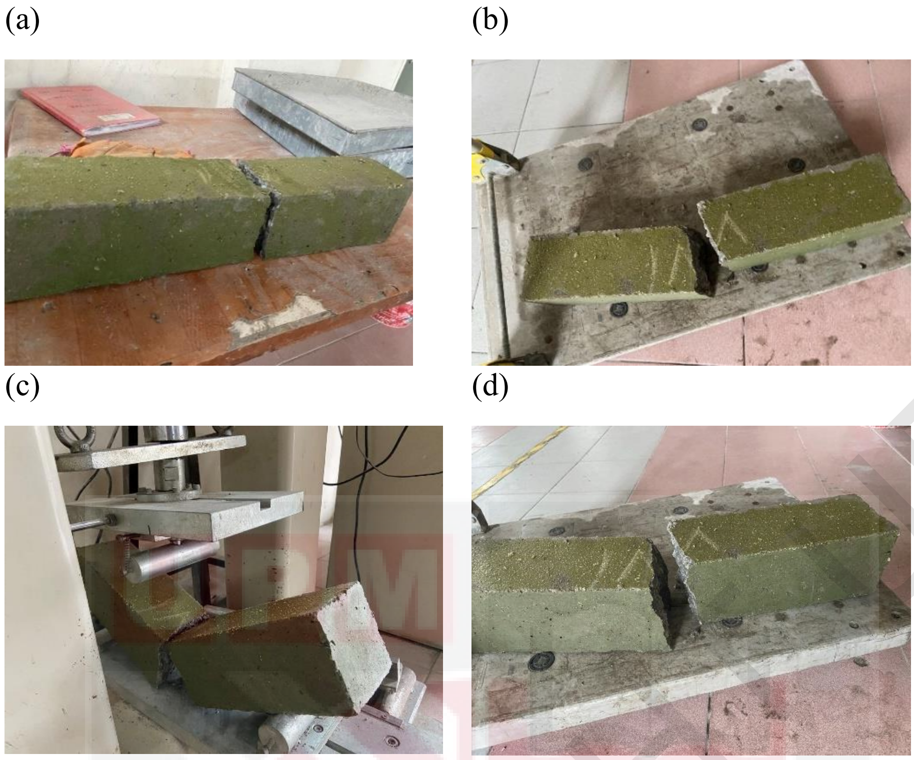

Figure 4.7: Concrete beams for flexural strength test at 28th days of curing age (a) COM1 (0% aluminum dross) (b) COM2-S3 (5% aluminum dross sample 3) (c) COM3-S3 (10% aluminum dross sample 3) (d) COM4-S3 (15% aluminum dross sample 3)

4.6.2.3 Measurement of Concrete Stiffness-Modulus of Elasticity Test

Modulus of Elasticity (MOE) determine the material's ability to support loads and maintain its shape. MOE has a relationship with compressive strength. According to the British Standard, the value of Elastic modulus at 28 days of concrete age is given by Equation 4.1 in accordance to BS 8110: Part II 1985 (BS 1880-2, 1985). The British Standard, BS 8110: Part II also tabulated the mean value of the MOE based on the concrete compressive strength at 28 days.

$$E_{c,28} = k_o + 0.2 f_{cu,28} \quad [4.4]$$

Where:

k_o : constant closely related to the MOE of the natural aggregate (20 kN/mm^2 for normal weight concrete)

$f_{cu,28}$: concrete compressive strength at 28 days

In this study, M40 grade concrete is the aim concrete. Thus, based on the Equation 4.4, the predicted Elastic Modulus, E_c ranges from 22 GPa to 34 GPa with a mean value of 28 GPa as tabulated in Table 4.6. The value of E_c in Table 4.6 is based on the static modulus of elasticity, k_o. Based on the typical range of static modulus of elasticity, for compressive strength of 40 MPa, the modulus of elasticity (E_c) at 28th days ranged from 22 to 34 kN/mm^2.

Table 4.6: Typical range for the static modulus of elasticity, k_o at 28 days

$F_{cu,28}$ (N/mm^2)	**$E_{c,28}$** Mean value (kN/mm^2)	Typical range (kN/mm^2)
20	24	18 to 30
25	25	19 to 31
30	26	20 to 32
40	28	22 to 34
50	30	24 to 36
60	32	26 to 38

Note. Reprinted from British Standard, BS 8110: Part II 1985 page 46
(Source: BS 1880-2, 1985)

In this work, the test for Elastic Modulus was conducted on the concrete mixes of COM1 and COM3-S3 at 28 days to compare whether the addition of aluminum dross influenced the elasticity of the concrete. The concrete mixtures COM2-S3 and COM4-S3 were not tested for the Modulus of Elasticity (MOE) due to limitations in the availability and high cost of strain gauges.

Table 4.7 tabulated the theoretical and experimental E_c where the theoretical E_c was determined based on Equation 4.4 using the compressive strength test obtained from the concrete mixes on 28 days curing. Meanwhile, the experimental E_c results were obtained from the analysis conducted in the laboratory using a Concrete Compression Machine 3540 kN, Unit Test Scientific along with Data Logger TML TDS-530.

Based on Table 4.7, the experimental E_c values for both concrete mixes of COM1 and COM3-S3 indicated a reduction compared to the calculated E_c. COM1 has a reduction of 2.7 GPa (9.6% reduction) while COM3-S3 reduced by 6.5% (1.81 GPa) from the theoretical E_c. This might be due to the presence of voids highlighted in red colour as portrayed in Figure 4.7. The presence of voids in concrete allowed the loss of water within the concrete capillary during the curing process. This action reduced the elasticity of concrete (Wang et al., 2022). Thus, the experimental Ec for both mixtures were slightly lower than calculated Ec.

Based on the experimental E_c, the modulus of elasticity at 28th day of the control concrete, COM1 and aluminum dross concrete COM3-S3 for M40 grade concrete were found to be varying from 25.3 GPa to 26.2 GPa for the maximum value corresponding to 10% cement replacement with aluminum dross. An investigation by Bahoria et al., (2020), M30 grade concrete with 6% waste plastic as the natural sand replacement contributed to a highest E_c for about 29.94 GPa from the normal concrete at 25.79 GPa. This is similar to this study, where the E_c for COM3-S3 was higher than COM1 since there was an addition of aluminum dross that enhanced the strength of the concrete.

Table 4.7: The Elastic Modulus of COM1 and COM3-S3 at 28 days

Mixtures	Theoretical Ec (GPa)	Experimental Ec (GPa)
COM1	28	25.3
COM3-S3	28.01	26.2

Figure 4.8 displays the cylinder moulds for COM1 and COM3-S3 to test the Elastic Modulus. Both specimens had cracks appeared on the surface due to the uneven surface of the concrete during the test. Figure 4.8a with no addition of aluminum dross had more cracks compared to Figure 4.8b. The experimental E_c for COM1 was 0.9 GPa lower than COM3-S3. This result revealed that the filler effect of aluminum dross incorporated as cement replacement contributed to the enhancement of concrete strength. A study by Udvardi et al., (2019) reported that the addition of aluminum dross in the asphalt production improved the strength, as aluminum dross act as a pozzolanic material where it sealed the voids presence in the mixtures. Furthermore, at 28 days of curing age, replacing 10% of the cement with periwinkle shell ash (PSA) increased the modulus of elasticity by 6.4%, achieving a value of 27.03 GPa compared to the control concrete (Olusola, 2018).

(a) (b)

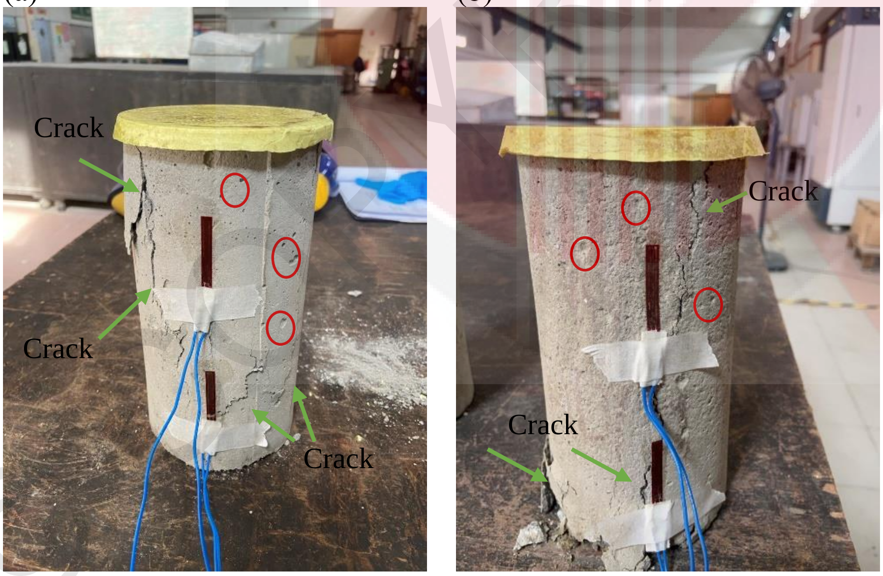

Figure 4.8: Concrete cylinder moulds for Modulus of Elasticity Test at 28th days (a) COM1 (0% aluminum dross) (b) COM3-S3 (10% aluminum dross sample 3)

4.6.3 Durability Properties

4.6.3.1 Rate of Water Absorption-Water Absorption Test

In the concrete manufacturing, curing is the most vital procedure as it prevents early evaporation of moisture from concrete mixes. This action might weaken the strength of the final concrete product. Specifically, the reduction of absorption results in higher strength as there are fewer voids in the concrete specimen. Hence, the hardened concrete should be submerged in water to cure.

For durability test, the concrete mixes of COM1, COM2-S3, COM3-S3 and COM4-S3 were cured for 7^{th} and 28^{th} days. Figure 4.9 shows the water absorption rates calculated using Equation 3.1 on day 7 and 28 of the concrete mixes. As shown in Figure 4.9, COM2-S3 with 5% cement replacement with aluminium dross had the lowest water absorption. On the other hand, concrete mix COM3-S3 with 10% cement replacement with aluminium dross had approximately the same water absorption as control concrete mix COM1. The higher aluminium dross incorporated in the concrete mix, the higher water absorption as shown in the concrete mix, COM4-S3 (15% aluminium dross). This is due to the effect of aluminium dross that could result in internal micro-blisters in the concrete samples that increased the number of micropores (Javali et al., 2017).

Varunkumar et al., (2023) reported that the substitution of aluminum powder up to 3.5 kg/m^3 increased the amorphousness of Al_2O_3 , facilitating water infusion into the matrix. The higher Al_2O_3 content may absorb higher moisture and hence deteriorate bonding to the polymer matrix. Therefore, higher aluminum dross addition in the concrete mix, contributed to a higher water absorption.

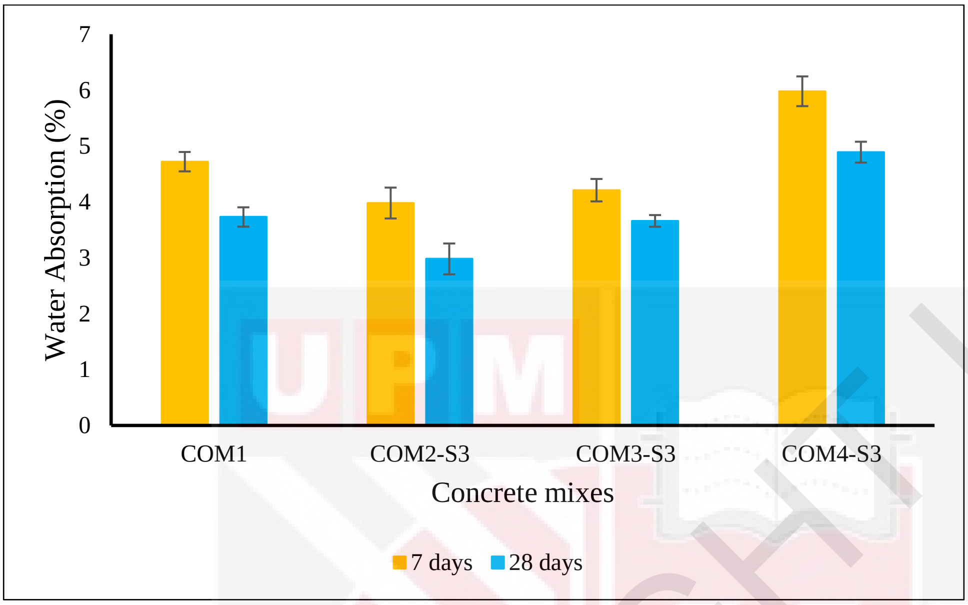

Figure 4.9: Water Absorption of Concrete Mixes at 7 and 28 days

4.6.3.2 Acid Resistance Test

The acid resistance was assessed by the differences in weight of dry specimens before and after acid attack using 5% of 1.0 M sulphuric acid by weight of the water. The control concrete mixture, COM1 and aluminium dross concrete, COM2-S3, COM3-S3, and COM4-S3 were immersed in the acid water for another 28 days. Compressive strength was evaluated after 28 days of acid water immersion to investigate the effect of acid attack.

Table 4.8 presents the results of acid resistance test and compressive strength onto the concrete mixtures after being immersed in the sulphuric acid-water for 28 days. The percentage of acid resistance was based on the weight loss of the concrete. The average weight loss of concrete mixtures was 2.7% from the initial weight of 2259 kg/m^3. Among the mixtures, COM4-S3 experienced the highest weight loss at 2.76%, accompanied by a decline in compressive strength of 9.6%.

The reduction of weight loss and compressive strength in all tested concrete mixtures were caused by the formation of calcium sulphate salt produced from the reaction of the sulphuric acid and calcium hydroxide as in Equation 4.5 and 4.6 below.

$$H_2SO_4 + Ca\,(OH)_2 \rightarrow CaSO_4.\,2H_2O \qquad [4.5]$$

$$H_2SO_4 + 3CaO.\,SiO_2 \rightarrow CaSO_4.\,2H_2O + \; Si(OH)_4 \qquad [4.6]$$

As mentioned by Jayakumar and Bhandari (2005) and Raja et al., (2021), the leaching of calcium hydroxide was caused by acid attack in two phases, as demonstrated in Equation 4.5 and Equation 4.6. This chemical reaction altered both physical and chemical characterization in terms of concrete’s weight, strength and microstructure properties. During the first phase as illustrated in Equation 4.5, the reaction of calcium hydroxide and sulphuric acid occurred in the cement paste of the hardened concrete. This action led to an increase in porosity which contributed to the strength loss. Second phase arisen when all calcium hydroxides were consumed by the sulphuric acid to produce calcium silicate hydrate as in Equation 4.6. Most of the cases, the expansion and/or cracking happened during the second phase causing a severe damage to the concrete.

Table 4.8: Acid Resistance Percentage and Compressive Strength at 28 days

Mixtures	Weight (kg/m^3)		Weight Loss %	Compressive Strength (MPa)		Reduction of Compressive Strength (%)
	Before	After		Before	After	
COM1	2276.3	2217.4	2.66	40	38.2	4.5
COM2-S3	2252.1	2192.9	2.70	38.1	35.8	6.0
COM3-S3	2254.4	2194.5	2.73	41.3	38.4	7.0
COM4-S3	2256.8	2196.2	2.76	33.4	30.2	9.6

Figure 4.10 illustrates the image of the concrete after the acid attack (acid resistance test) by immersion into sulphuric acid-water for 28 days. It can be observed that the second phase of acid attack did not occur to the concrete specimens as there was no appearance of expansion and/or cracking. In spite of that, the outer layer surface of the concrete became brittle and creating an uneven structure of the concrete, thereby supported the reduction in compressive strength of the concrete as tabulated in Table 4.8.

Naseeruddin et al., (2019) reported in their study that almost a linear relationship between weight loss and strength were observed with an addition of 2% H_2SO_4 in the curing water. The authors suggested that the structure of the concrete must be provided with a resin that can protect the cement matrix against different types of chemicals and acids.

(a)

(b)

(c)

(d)

Figure 4.10: Concrete for acid resistance test at 28th days (a) COM1 (0% aluminum dross) (b) COM2-S3 (5% aluminum dross sample 3) (c) COM3-S3 (10% aluminum dross sample 3) (d) COM4-S3 (15% aluminum dross sample 3)

4.6.4 Chemical properties

4.6.4.1 Structural Analysis-X-Ray Diffraction (XRD)

XRD technique was applied to concrete mixtures of COM1 and COM3-S3 at 28 days of curing period as shown in Figure 4.11. The main aim was to investigate the mineral composition of cement hydrate products presented in the concrete. Generally, aluminium dross is the aluminosilicate source in which its oxide composition mainly from the aluminium oxide (alumina), silicon oxide (silica), iron oxide, and calcium oxide (Mayhoub et al., 2021). These oxides are found in four main crystalline mineral phases: quartz, mullite, calcite, hematite and magnetite. It was shown in the XRD patterns that, quartz and calcite peaks could be found with mainly high peaks in aluminium dross concrete.

From the XRD analysis, the average intensity of calcium hydroxide ($Ca(OH)_2$) in the presence of aluminium dross at $2\theta = 22.64$ increased compared to the control concrete, COM1. The peak intensities of calcium hydroxide were found to be more in concrete mix, COM3-S3. Furthermore, the intensity of ettringite or calcium aluminium silicate hydrate (C-A-S-H) increased more in normal concrete compared to aluminium dross concrete. The formation of ettringite indicates rapid hydration process. Moreover, the appearance of CSH was more with high dosage of aluminium dross, COM3-S3 due to the chemical reaction of calcium hydroxide converted to secondary CSH. This reaction enhanced the strength of the concrete as it can be observed in Figure 4.4 where the compressive strength of COM3-S3 was 41.3MPa, 1.3% higher than control concrete, COM1.

Calcite or calcium carbonate, $CaCO_3$ also could be seen in the XRD pattern. The average intensity peak of calcite was found to be in at 2θ = 40.98. The calcite aids in curing process of the concrete (Reddy and Naqash, 2019a). As reaching 28 days of curing age, the calcite undergone the decarbonation process as stated in TGA analysis.

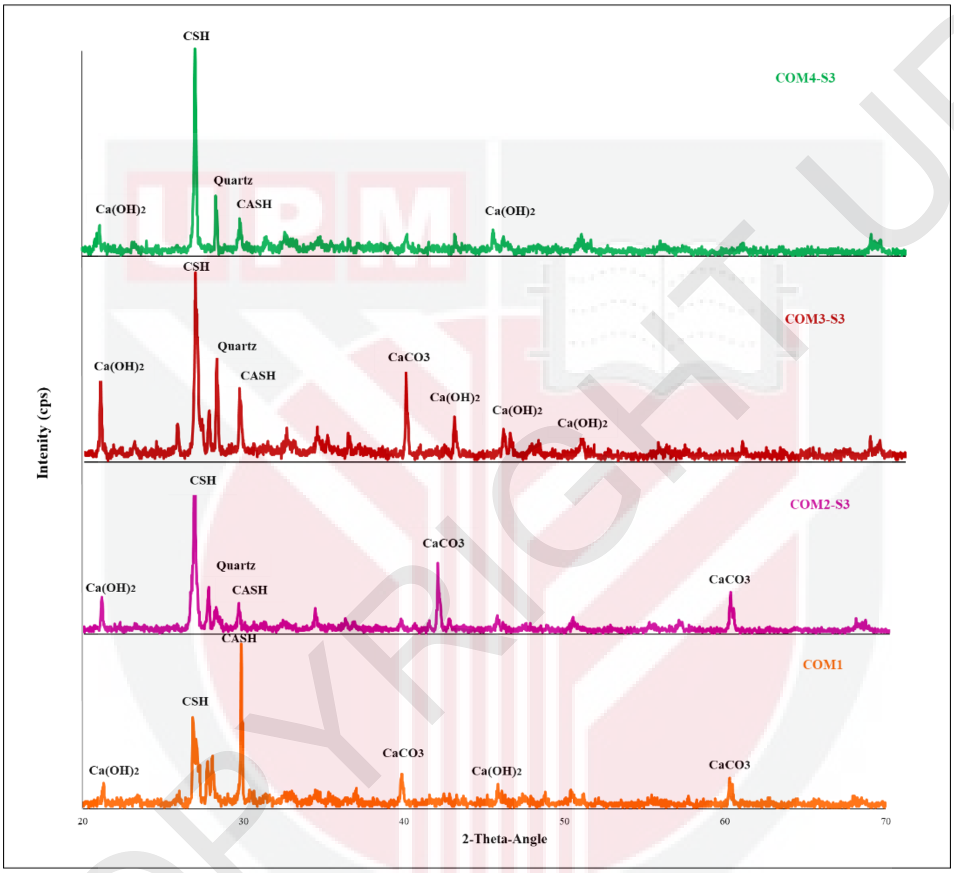

Figure 4.11: XRD analysis for concrete mixes at 28 days

4.6.4.2 Surface Morphology Analysis-Scanning Electron Microscopy (SEM)

SEM analysis provides high definition and detailed images that can examine the distribution, interactions, and bonding between the cement matrixes. The microstructure of concrete develops throughout time because of the concrete formulation and processes which includes mixing, placement, and curing.

The SEM images of concrete mixture at 28 days for control concrete, COM1, and concrete containing aluminum dross from sample 3 (COM2-S3; COM3-S3; COM4-S3) are illustrated in Figure 4.12. As seen in Figure 4.12a, the SEM images of control concrete mix, COM1, contains the main hydration product, calcium silicate hydrate. Besides, the asymmetrical form of unreacted dross was depicted in SEM images of COM2-S3 (Figure 4.12b). It can be observed that the formation of calcium hydroxide or also known as portlandite resulted in during the curing process, when calcium reacts with water as displayed in Figure 4.12c, showing the surface morphology of concrete mix with 10% cement replacement with aluminum dross.

Mailar et al., (2016) reported in their investigation that aluminum oxide in aluminum dross was chemically reacted with calcium hydroxide to produce hydration compounds. The calcium monosulpho-aluminate (ettringite) also appeared in the form of smaller hexagonal hydrated crystals due to the presence of aluminum dross. It was discovered that concrete containing aluminum dross had a less permeable surface due to the presence of needles (ettringite) in voids compared to control concrete. The concrete with aluminum dross provided slightly higher strength compared to conventional concrete due to the filling activities of aluminum dross in voids. The presence of micro-pores within the matrix as well as formation of micro-cracks caused by internal blisters can be observed for COM4-S3 mix (Figure 4.12d). The matrix becomes less compact as a result from these cracks.

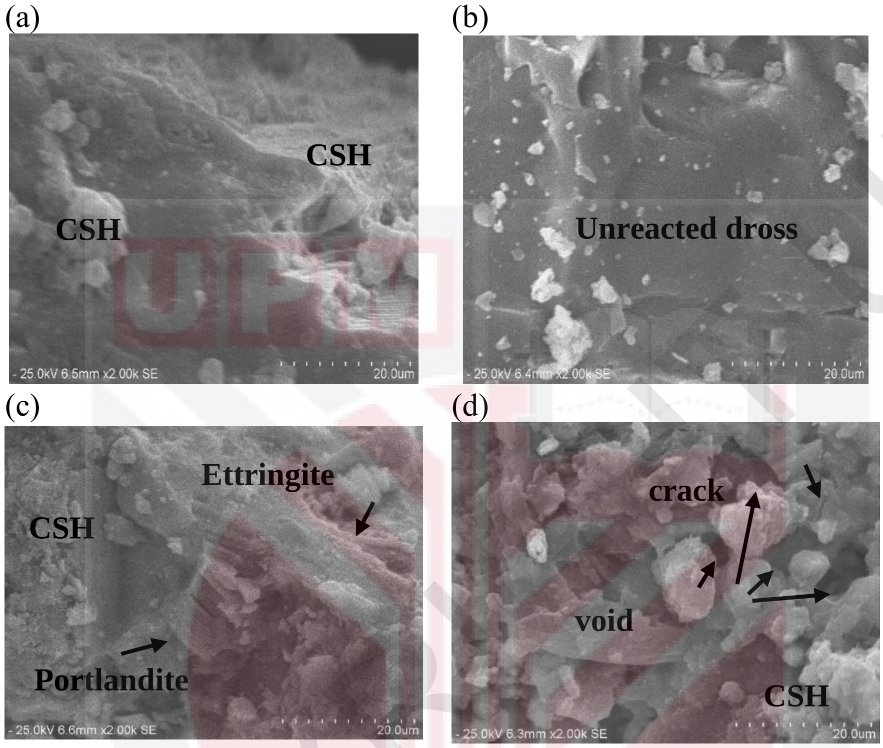

Figure 4.12: SEM images of concrete mixtures at 28 days (a) COM1 (0% aluminum dross) (b) COM2-S3 (5% aluminum dross sample 3) (c) COM3-S3 (10% aluminum dross sample 3) (d) COM4-S3 (15% aluminum dross sample 3)

4.6.4.3 Thermal Decomposition Analysis-Thermal Gravimetric Analysis (TGA)

The TGA results presented in Figure 4.13 shows the decomposition of hydration compounds in the temperature ranging from 50°C to 1000°C and Figure 4.14 illustrates the weight loss of concrete mixes with respect to temperature. From Figure 4.12, the TC curves portrays four characteristic endothermic effects. The first effect, which occurs in temperature range from 50°C to 100°C had to do with the evaporation of pore water from capillary pores (Ukrainczyk et al., 2006). The second endothermic effect, with temperature range from 100°C to 450°C had to do with the dehydration of calcium silicate hydrates and ettringite. The third effect, with peak temperature between 400°C to 500°C, was attributed to the decomposition of calcium hydroxide formed during hydration as shown in Equation 4.7.

$$\mathrm{Ca\,(OH)_2} \rightarrow \mathrm{CaO} + \mathrm{H_2O} \qquad [4.7]$$

Finally, an endothermic effect around 800°C indicated the decarbonation of calcium carbonate in the hydrate compound as shown in Equation 4.8.

$$\mathrm{CaCO_3} \rightarrow \mathrm{CaO} + \mathrm{CO_2}\ \text{(Decarbonation)} \qquad [4.8]$$

The difference in weight between 100°C and 600°C was used to calculate the total weight loss, which included water loss from other hydrates (Vedalakshmi et al., 2003). The amount of calcium hydroxide was calculated using Equation 4.9 as a percentage of the weight at 580°C (Reddy and Naqash, 2019b). Calcium hydroxide has a molecular weight of 74 and water has a molecular weight of 18.

$$\text{Calcium hydroxide} = \frac{W_{400} - W_{580}}{W_{580}} \times \frac{74}{18} \times 100 \quad [4.9]$$

As shown in Figure 4.15, the percentage of calcium hydroxide was more in control mix, COM1 compared to aluminium dross concrete mixes, COM2-S3, COM3-S3 and COM4-S3. The percentage of calcium hydroxide was less in concrete mixes containing aluminium dross were due to the pozzolanic reaction in which calcium hydroxide was consumed by silicates and aluminates presented in aluminium dross (Reddy and Naqash, 2019a).

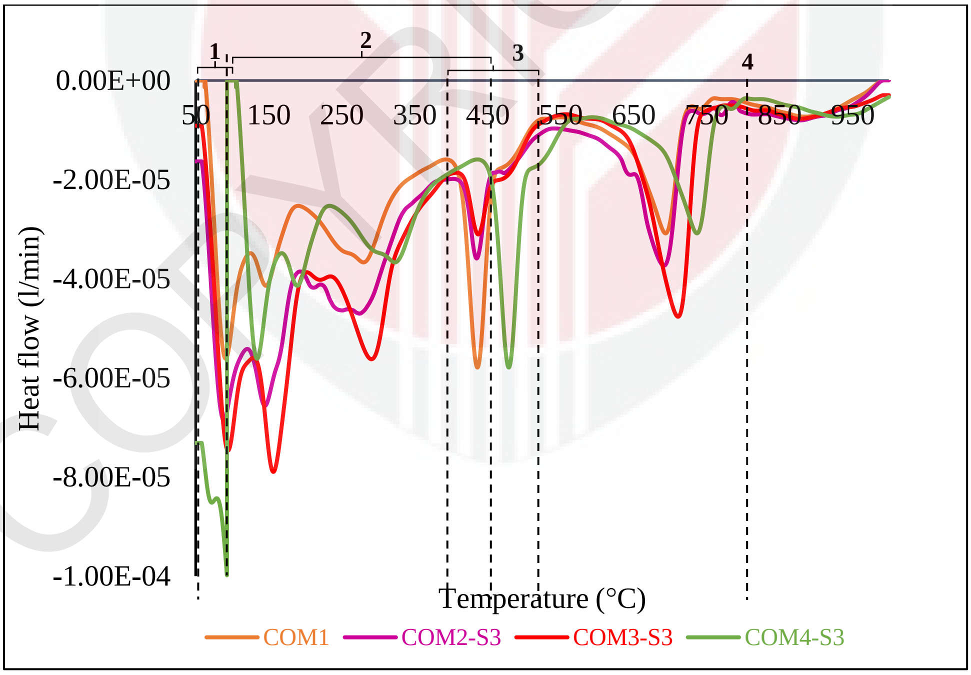

Figure 4.13: TG curve of concrete mixes

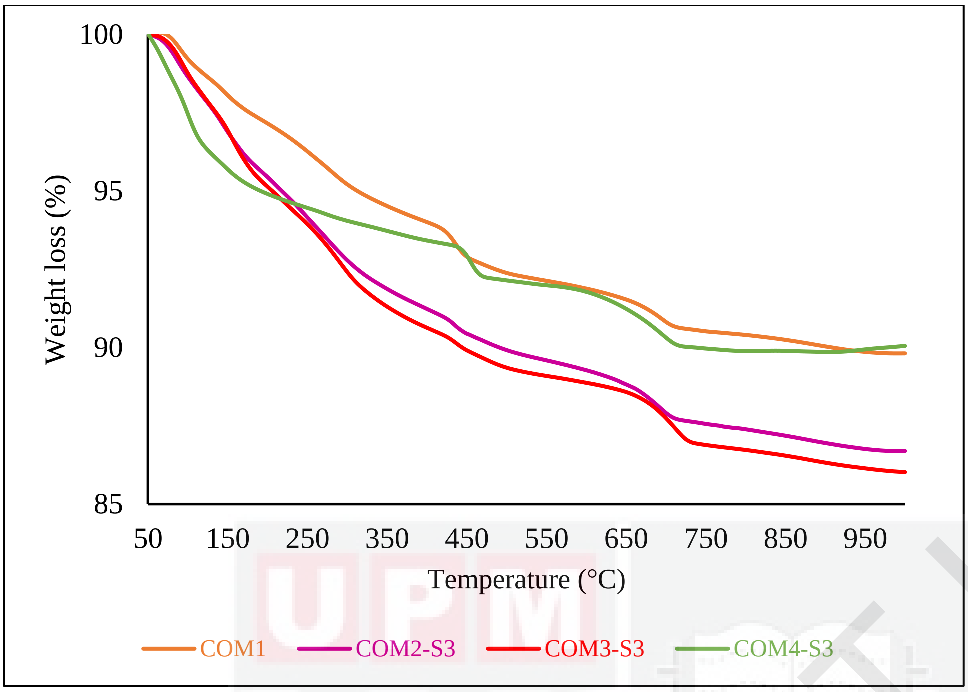

Figure 4.14: Percentage of weight loss of concrete mixes

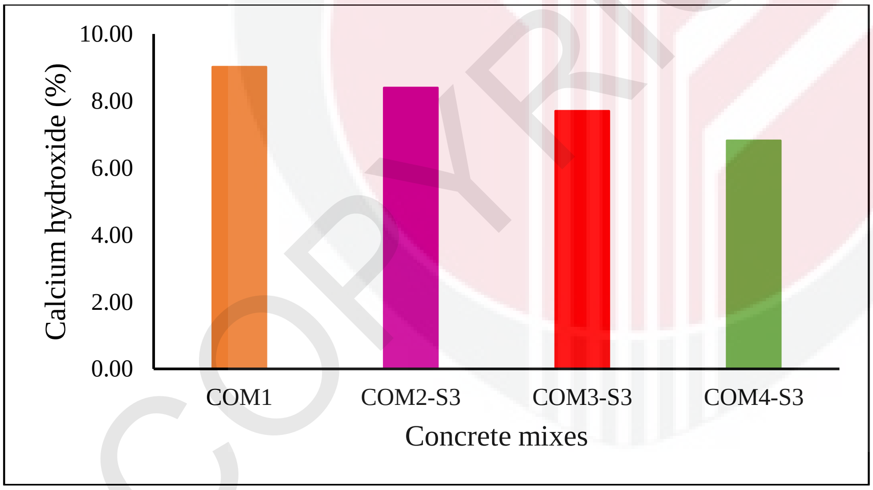

Figure 4.15: Percentage of calcium hydroxide of concrete mixes

4.6.5 Toxicity properties

4.6.5.1 Ammonia Level Test

The ammonia level tests for the second stage of the experimental work were conducted on control concrete, COM1 and aluminium dross concrete mixes (COM2-S3; COM3-S3; COM4-S3). The tests were performed during the curing process of 7th and 28th days to examine the concentration of ammonia emit from the aluminium dross. Table 4.9 shows the ammonia level in the concrete specimens.

From the observation, air bubbles appeared in the water tank where aluminium dross-concretes were placed. The air bubbles were reduced over curing time, and ammonia gas was expected to escape from the hardened concrete. As tabled in Table 4.9, the ammonia concentration in the control concrete mixture, COM1 was absent, meanwhile, as for concrete mixtures, COM2-S3, COM3-S3 and COM4-S3, the ammonia content reduced over the curing period from 7 days to 28 days and within the limits annotated by the Occupational Safety and Health Administration Permissible Exposure Limits (OSHA PEL).

Higher aluminium dross incorporated in the concrete mixes depicted higher ammonia concentration release. This correlation could be related to the morphological study of the concrete. As can be seen from Figure 4.13d namely the concrete mixture COM4-S3, formation of microcracks and gap between the concrete matrixes could be observed. The diffusion of ammonia gas from the concrete would render the concrete more porous which possibly affect the strength of the concrete (Abd El-Aziz and Sufe, 2013).

Table 4.9: Concentration of ammonia in concrete mixes

Mixtures	**Concentration of ammonia (ppm)**		**Regulated limit value (ppm)**
	7 days	28 days	
COM1	0	0	50
COM2-S3	30	10	50
COM3-S3	35	13	50
COM4-S3	40	19	50

Note: Regulated level refers to the limit stipulated by OSHA PEL

4.6.5.2 Metal Analysis

The amount of trace to major elements presented in the leachate samples of aluminium dross and concrete mixes at the end of 28 days of curing age were determined using Inductively coupled plasma optical emission spectroscopy (ICP-OES).

Table 4.10 tabulated various elements found using the ICP-OES analysis at the wavelength of 90 ppm. In the leachate samples of aluminium dross and concrete mixes that were obtained using a procedure stated in Section 3.7.4.1, the heavy metals such as aluminium, arsenic, chromium, copper, nickel, and zinc were detected. It was noticed that the concentration of heavy metal in almost all concrete mixes including control mix COM1 was found to be very minimum and within the limits. For all concrete mixes containing aluminum dross, the concentration of cadmium exceeded the WAC limit. However, the concrete mix, COM4-S3 was the only aluminum dross concrete mix in which the concentration of arsenic and chromium were slightly higher than the regulated limit.

Ordinary Portland Cement (OPC) usually has a pH of 12 which indicates high alkaline. When OPC comes in contact with water, the $Ca(OH)_2$ contributes to a higher alkalinity of concrete. Conversely, within the curing period, the pH of concrete would decrease due to the consumption of $Ca(OH)_2$ in the formation of hydration products such as CSH and ettringite. Through this process, the non-volatile metals such as chromium and arsenic were released (Sumra et al., 2020; Eckbo et al., 2022). In addition, Estokova et al., (2018) reported that the substitution of higher waste materials in concrete mixture also contributed to the increase of leachate in cement matrix. Thus, the higher concentration of chromium and arsenic in concrete sample COM4-S3 was due to the higher percentage of aluminium dross that reacted aggressively with OPC which led to the vigorous leaching of chromium and arsenic. Table 4.10 shows that the concentration of elements increased as the dosage of aluminium dross increased. Based on the toxicity test, the increment of the metal values such as arsenic, cadmium, chromium, copper, and nickel were below the leaching limit value by the US EPA, indicating that the concrete should be safe to be used as construction materials. Among all concrete mixes containing aluminum dross, COM3-S3 was selected as the best mix as most of the leachate except cadmium were below regulated limit value by both US EPA and WAC.

Table 4.10: Toxicity Analysis of Concrete Mixes at 28 days

Element	Leachate of Concrete (ppm)				Leachate of aluminum dross S3 (ppm)	Regulated limit level (ppm)	
						US Environmental Protection Agency	Waste Acceptance Criteria
	COM1	COM2-S3	COM3-S3	COM4-S3			
Aluminum	na	0.30	0.40	0.60	0.60	0.05-0.20	
Arsenic	0.20	0.32	0.43	0.56	0.62	5.00	0.50
Cadmium	0.01	0.02	0.02	0.03	bdl	1.00	0.01
Chromium	0.09	0.13	0.49	0.67	0.19	5.00	0.50
Copper	0.33	0.44	0.45	0.39	0.87	1.30	2.00
Nickel	0.09	0.11	0.12	0.10	0.13	1.00	0.40
Zinc	0.92	2.68	3.85	2.33	1.15	1.50	4.00

Note: na: not available; bdl: below detected level
Regulated limit level imposed by US EPA and WAC

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

The current study was performed to develop eco-friendly concrete by adding aluminum dross into the mixture. A simple aluminum dross treatment process consisting of washing, drying, and sieving was effective in obtaining a material suitable for concrete. The chemical, mechanical, and physical analysis of aluminum dross concrete type was investigated. Within the scope of the project, many tests were performed to evaluate the properties of aluminum dross as well as concrete containing aluminum dross as cement replacement.

According to the characterization of all treated aluminum dross samples, aluminum dross sample 3 (S3) was selected as the potential cement replacement material. The XRF analysis indicated that S3 contains significant percentages of aluminum oxide (53.1%) and silica (3.2%). Additionally, S3 also recorded the lowest ammonia concentration among all samples at 75 ppm, demonstrating its suitability for use in concrete.

In addition, an amount of 10% aluminum dross was found to be the best replacement value in producing M40 concrete. Based on the findings, the mixture with 10% aluminum dross sample 3 (S3) achieved high workability and compressive strength. Specifically, it achieved a slump flow value of 113 mm, indicating excellent workability. Furthermore, this mixture attained a compressive strength of 41.3 MPa, surpassing the control concrete sample, COM1. These results highlight the effectiveness of aluminum dross as a cement replacement material in enhancing the performance of concrete.

Based on the findings, it was determined that 10% is the best replacement value of aluminum dross in the concrete mixture. At this substitution level, the properties of the concrete are not adversely affected, and the compressive strength, along with other properties, remains close to that of normal concrete. The concrete mix COM3-S3 (10% aluminum dross, sample 3) recorded the highest compressive strength at 41.3 MPa. Furthermore, thermogravimetric analysis revealed that COM3-S3 was more stable, exhibiting a 7.9% lower calcium hydroxide content than the control mix (COM1), due to the pozzolanic reaction. Scanning electron microscope (SEM) analysis showed that the formation of calcium silicate hydrate and ettringite needles in the voids contributed to the increased density of the concrete. Additionally, toxicity tests demonstrated that the ammonia content and the leaching of heavy and trace elements were minimal, remaining within acceptable limits. Hence, it can be concluded that aluminum dross, as an industrial waste, can be a potential candidate for cement replacement in concrete production. The replacement is feasible considering enhancing properties as well as conserving environmental sustainability.

5.2 Recommendation

Based on this study, further research can focus on incorporating the effect of various curing method on the mechanical and chemical properties of aluminium dross concrete. Other efficient ammonia removal method can also be employed, such as acid treatment. The method was proven to be efficient.

There are some suggestions on how this experiment may be improved in the future based on the study that has been done.

- The filtration method to recover the aluminum dross should be improved by employing a mechanical press to remove water efficiently, thus, minimizing the time use. This kind of machine provide pressure that can increase productivity.
- The grinding procedure during the pretreatment process also should be improved by utilizing a powder grinder to maximize the amount of treated aluminum dross. This equipment is suitable for crushing substances in large amounts.
- Furthermore, other efficient methods to remove ammonia gas in aluminum dross in the pretreatment process can also be employed, such as acid treatment. The method was proven to be efficient in some studies. However, there are no available sources that can prove the effectiveness of the aluminum dross using this treatment.
- Last but not least, another curing technique other than water curing can be studied on the aluminum dross concrete to evaluate the effectiveness of replacing cement with aluminum dross.

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APPENDICES

Appendix A

Concrete Mix Design Calculation

Stage		Item	Reference	Values		
	1.1	Characteristic strength	Specified	40 N/mm2 at; Proportion defective 6 %		28 days
	1.2	Standard deviation	Fig 3	4.6 N/mm2 or no data	-	N/mm2
	1.3	Margin	C1 or specified	(k = 1.64) - x - :	-	N/mm2; 0 N/mm2
1	1.4	Target mean strength	C2	40	0	40 N/mm2
	1.5	Cement strength class	Specified	42.5 / 52.5		
	1.6	Aggregate type: course Aggregate type: fine		crushed / uncrushed crushed / uncrushed		
	1.7	Free water/cement ratio	Table 2 Fig	0.4	use the lower value	
	1.8	cement ratio	Specified	0.45	to obtain higher strength	0.4
2	2.1	Slump or Vebe time	Specified	Slump	100 +- 25 mm or Vebe time (s)	-
	2.2	Maximum aggregate size	Specified			20 mm
	2.3	Free water content	Table 3			173 kg/m3
3	3.1	Cement content	C3	173	0.4	433 kg/m3
	3.2	Maximum cement content	Specified	- kg/m3		
	3.3	Minumum cement content	Specified	- kg/m3		
				use 3.1 if <- 3.2 use 3.3 if <- 3.1		- kg/m3
	3.4	cement ratio				433
4	4.1	aggregate (SSD)		2.54 known/assumed		
	4.2	Concrete density	Fig 5			2400 kg/m3
	4.3	Total aggregate content	C4	2400	433	173 1795 kg/m3
5	5.1	Grading of fine aggregate	600 micrometer sieve			68.3 %
	5.2	Proportion of fine aggregate	Fig 5			0.45 %
	5.3	Fine aggregate content	C5	1795	0.45	808 kg/m3
	5.4	Coarse aggregate content		1795	808	987 kg/m3

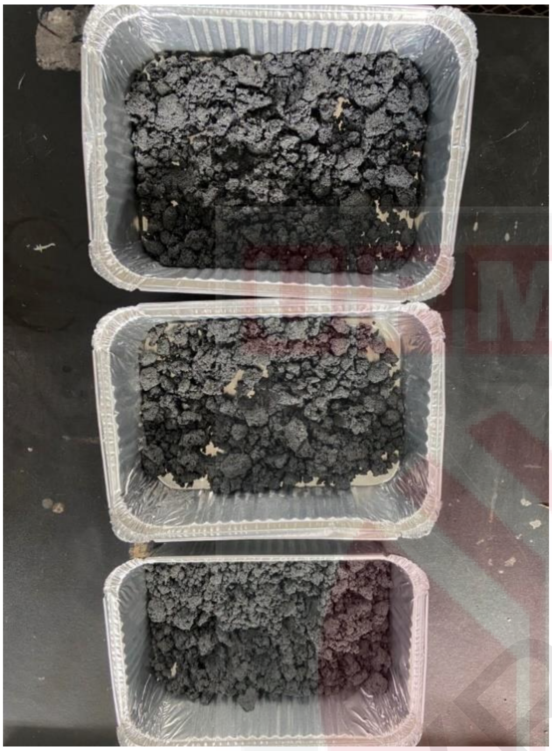
	Quantities	Cement (kg)	Water (kg or l)	Fine aggregate (kg)	Coarse aggregate (kg) @20mm
	per m3 (to nearest 5kg)	433	173	808	987
	per trial mix (m3)				
TOTAL	0.23	99.6	39.9	186.1	227.4

Appendix B

Part B.1 Pretreatment of aluminum dross provided by Cenviro Sdn. Bhd.

The images of aluminum dross

Note: From left – After washing process, after oven-dried process before sieving



Part B.2 Production of concrete

The images of some of the concrete produced.

Note: From left – Concrete in cube mould; Water-curing process

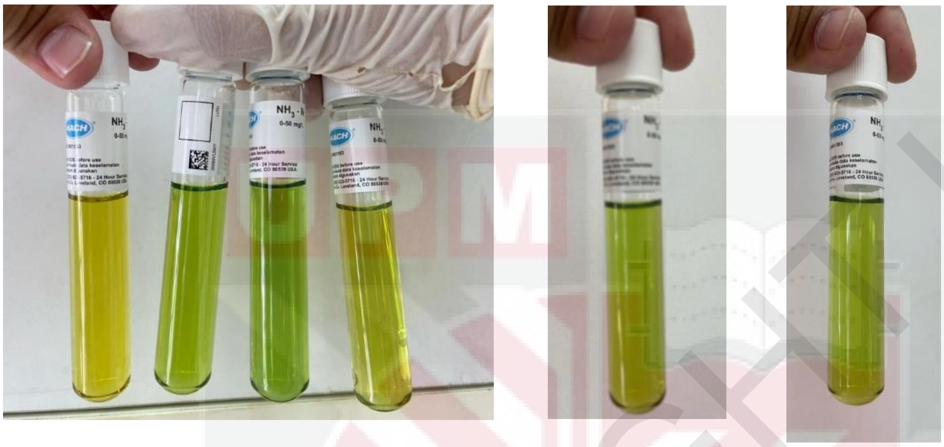
 

Appendix C

Ammonia Level Test

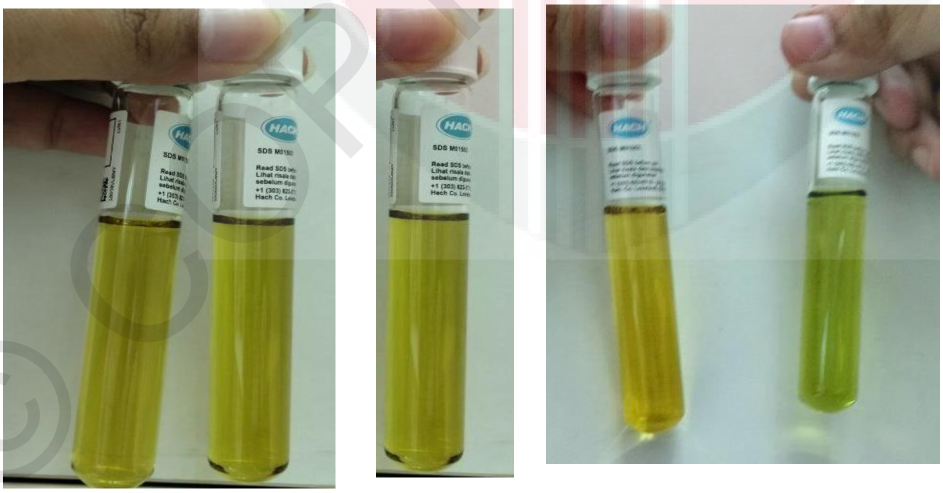
Part C.1 The images of ammonia test for all six samples of aluminum dross during the pretreatment process

Note: From left – Blank, S1, S2, S3, S4, S5, S6



Part C.2 The images of ammonia test for concrete mixes

Note: From left – Blank, COM1, COM2-S3, COM3-S3, COM4-S3



Appendix D

Part D.1 Compressive strength for all samples at 28th days of curing age

Sample	Compressive strength (MPa)			
	COM1	COM2	COM3	COM4
Sample 1	40	34.9	37.8	32.6
Sample 2	40	36.6	39.2	34.1
Sample 3	40	38.1	41.3	33.4
Sample 4	40	37.3	38.2	33.1
Sample 5	40	35.8	37.1	30.8
Sample 6	40	37.5	40.2	34.6

Part D.2 Compressive Strength of COM1 and COM3-S3 at 7th, 21st, and 28th of curing age

Curing Age (Day)	Compressive Strength (MPa)	
	COM1	COM3-S3
7	27	28.2
21	37.8	37.9
28	40	41.3

Part D.3 Flexural Strength of Concrete Mixes at 28th days of Curing Age

Mixtures	Flexural Strength (MPa)
COM1	9.87
COM2-S3	8.69
COM3-S3	10.03
COM4-S3	7.87

Part D.4 Water Absorption of Concrete Mixes at 7 and 28 days

Mixture	Water Absorption (%)	
	7 days	28 days
COM1	4.72	3.73
COM2-S3	3.98	2.98
COM3-S3	4.21	3.66
COM4-S3	5.98	4.89

BIODATA OF STUDENT

My name is Nur Hidayah binti Mohd Zahari. I was born on 28^{th} March 1997 in Kota Bharu, Kelantan. I'm currently 27 years old. I finished my primary education in 2009 at Sekolah Kebangsaan Pasir Hor, and my secondary education in 2014 at Sekolah Menengah Kebangsaan Agama Melor, Kota Bharu, Kelantan. Then, I further my study in Foundation of Agriculture Science at Universiti Putra Malaysia for one year from 2015-2016. I continued my bachelor's degree at Universiti Putra Malaysia for Bachelor of Chemical and Environmental Engineering with Honours. I graduated in 2020 and further my current study at the same university as a postgraduate student in MSc of Chemical Engineering under the supervision of Associate Professor Dr Salmiaton Ali with another three co-supervisors which are Dr. Shafreeza binti Sobri, Dr. Noor Azline binti Mohd Nasie, and Dr. Shafizah Ishak.

LIST OF PUBLICATIONS

Published Journal

Zahari, N. H., Salmiaton, A., Sobri, S., Nasir, N. A. M., & Ishak, N. S. (2024). Utilization of Aluminum Dross as a Cement Replacement Material for Sustainable Concrete Development. *Pertanika Journal of Science and Technology*, 32(2), 761–779.

Under Publication

Zahari, N. H., Salmiaton, A., Sobri, S., Nasir, N. A. M., & Ishak, N. S. (2023). Microstructure Properties on Concrete Incorporated with Rubber Sludge as Filler. Scientific Net, *International Conference on Innovation in Chemical Engineering & Technology 2023 (ICICET 2023).*