DEVELOPMENT OF ECO-BRICK WITH INCORPORATION OF TREATED SLUDGE

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This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I declare that this thesis entitled “Development of Eco-Brick With Incorporation of Treated Sludge“ is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor Degree Of Manufacturing Engineering (Hons.)

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My beloved stepfather, Mohamad Bin Hadri

My beloved mother, Hayati Binti Ithnin

My adored brother, Muhammad Fitri Bin Samari

for giving me moral support, money, cooperation, encouragement, and understandings

Thank You So Much & Love You All Forever

ABSTRACT

For thousands of years, bricks have been an important part of building and construction. It is commonly recognised that the process of producing fired clay brick has always required a significant amount of energy and resources, even with its consistent workability and accessibility. Authorities seek sustainable and eco-friendly options as an urgent requirement to minimize the effect of these difficulties. This project focuses on the development of sustainable clay bricks using treated sludge. The focus of this study is to explore how to incorporate treated sludge into eco-bricks. The study's objective is to determine the specific components that are present in the sludge and to evaluate the viability of using it for brick manufacture. The sludge was analysed using XRF and EDX methods, which revealed the presence of heavy metals such as chromium (Cr), copper (Cu), vanadium (V), and zinc (Zn). All these heavy metals were found to be within the allowed limits established by the Department of Environment from the beginning of the investigation. This provides evidence that the sludge is safe concerning the presence of heavy metals. The EDX study provided additional confirmation of the chemical composition, which enhanced the possibility of the sludge being used for the manufacturing of eco-bricks. The study examined several combinations of materials and successfully produced bricks containing up to 20 weight percent of sludge. Nevertheless, an increased sludge concentration of 50 wt.% adversely affected the mechanical stability of the bricks. The EDX study of the eco-bricks verified that the materials do not contain any harmful compounds that are controlled by TTLC regulations, therefore assuring their environmental and health safety. The compressive strength tests revealed a significant decrease as the sludge concentration increased. Bricks that did not contain any sludge had a compressive strength of 7.87 N/mm^2, but those with 20% sludge had a compressive value of 0.18 N/mm^2. These findings establish an initial basis for enhancing the composition of eco-bricks, ensuring an optimal balance between environmental advantages and mechanical functionality.

ABSTRAK

Selama beribu-ribu tahun, batu bata telah menjadi bahagian penting dalam pembinaan dan pembinaan. Umumnya diakui bahawa proses menghasilkan bata tanah liat yang dibakar sentiasa memerlukan sejumlah besar tenaga dan sumber, walaupun dengan kebolehkerjaan dan kebolehcapaian yang konsisten. Pihak berkuasa mencari pilihan yang mampan dan mesra alam sebagai keperluan segera untuk meminimumkan kesan kesukaran ini. Penyelidikan ini memberi tumpuan kepada pembangunan bata tanah liat yang mampan menggunakan enap cemar yang dirawat. Fokus kajian ini adalah untuk meneroka cara menggabungkan enap cemar yang dirawat ke dalam batu bata eko. Objektif kajian adalah untuk menentukan komponen khusus yang terdapat dalam enap cemar dan menilai daya maju menggunakannya untuk pembuatan bata. Enapcemar dianalisis menggunakan kaedah XRF dan EDX, yang mendedahkan kehadiran logam berat seperti kromium (Cr), kuprum (Cu), vanadium (V), dan zink (Zn). Kesemua logam berat ini didapati berada dalam had dibenarkan yang ditetapkan oleh Jabatan Alam Sekitar sejak awal penyiasatan. Ini memberikan bukti bahawa enap cemar adalah selamat berkaitan dengan kehadiran logam berat. Kajian EDX memberikan pengesahan tambahan tentang komposisi kimia, yang meningkatkan kemungkinan enap cemar digunakan untuk pembuatan bata eko. Kajian itu meneliti beberapa kombinasi bahan dan berjaya menghasilkan batu bata yang mengandungi sehingga 20 peratus berat enap cemar. Namun begitu, peningkatan kepekatan enap cemar sebanyak 50 wt.% menjejaskan kestabilan mekanikal batu bata. Kajian EDX terhadap eko-bata mengesahkan bahawa bahan tersebut tidak mengandungi sebarang sebatian berbahaya yang dikawal oleh peraturan TTLC, oleh itu memastikan keselamatan alam sekitar dan kesihatannya. Ujian kekuatan mampatan menunjukkan penurunan yang ketara apabila kepekatan enap cemar meningkat. Bata yang tidak mengandungi sebarang enap cemar mempunyai kekuatan mampatan 7.87 N/mm², tetapi yang mempunyai 20% enap cemar mempunyai nilai mampatan 0.18 N/mm². Penemuan ini mewujudkan asas awal untuk meningkatkan komposisi bata eko, memastikan keseimbangan optimum antara kelebihan alam sekitar dan kefungsian mekanikal.

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LIST OF ABBREVIATIONS

$UTeM$	-	Universiti Teknikal Malaysia Melaka
TCLP	-	Toxicity Characterization Leaching Procedure
TTLC	-	Total Threshold Concetration
SEM	-	Scanning Electron Microscopy
EDX	-	Energy Dispersive X-Ray
XRF	-	X-ray Fluorescence
TS	-	Treated Sludge
FA	-	Fly Ash
BA	-	Bottom Ash
PMS	-	Paper Mill Sludge
SWTP	-	Sewage Water Treatment Plants
RSA	-	Rice Straw Ash
SBA	-	Sugarcane Bagasse Ash
SOI	-	Sludge from the Oil refining Industry
SPOEI	-	Sludge from Pomace Oil Extraction Industry
DOE	-	Department Of Environment
EPA	-	Environmental Protection Agency
	-	

LIST OF SYMBOLS

wt. %	-	Weight Percentage
°C	-	Degree Celcious
MPa	-	Megapascal
Kpa	-	Kilopascal
kV	-	Kilovolt

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CHAPTER 1

INTRODUCTION

1.1 Background

Due to its reliance on conventional building methods and materials, the construction sector significantly contributes to environmental damage. Environmentally friendly and sustainable solutions have been more important in construction operations in recent years. Currently, 1391 billion bricks are produced year worldwide, and demand for bricks is predicted to continue growing (Zhang, 2013). An alternate method of developing building materials from other sources is required due to the rise in demand for these resources in recent years brought on by development (Johnson et al., 2014). One such area of exploration is the transformation of conventional clay bricks into sustainable bricks, integrating industrial by-products to enhance performance while mitigating the environmental impact. Traditional clay bricks have long been the staple building material, appreciated for their durability and ease of manufacturing. However, the production of clay bricks involves extensive excavation of natural resources, energy-intensive firing processes, and the emission of greenhouse gases, contributing to environmental concerns. As the building and merchandising seeks more sustainable solutions, the development of sustainable bricks emerges as a promising avenue for reducing the environmental footprint associated with traditional brick production.

Sustainable bricks incorporate a variety of industrial by-products and waste materials, offering a potential alternative to conventional clay bricks. Not only do these materials provide an opportunity to mitigate the environmental impact of brick manufacturing, but they also offer cost advantages by repurposing waste products that would otherwise require disposal. As shown in Figure 1.1, it shows that the cost for development of bricks using clay is increasing from 2010 until 2022. The need to reduce environmental impact and reduce the rising prices of traditional building materials has fuelled the search for alternative solutions. Treated sludge, a by-product of metal refining scheduled wastes are common and, if properly characterized, offer potential as sustainable elements in the building sector. However, before incorporating these elements into sustainable bricks, it is critical to thoroughly examine their hazardous properties, guaranteeing regulatory compliance and eliminating any environmental and health hazards. Addressing the challenge of waste disposal and concurrently seeking sustainable alternatives, this study embarks on a hazardous characterization exploration of treated sludge scheduled wastes for their integration into composite bricks.

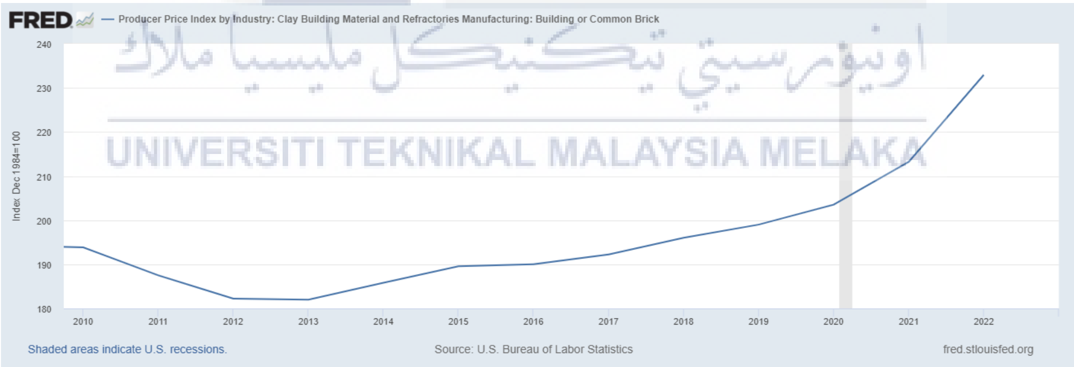


Figure 1.1 Cost development Brick using Clay **(U.S. Bureau of Labor Statistics, 2024)**

Treated sludge (TS), originating from wastewater treatment processes is deemed as challenging waste streams due to their complex compositions and potential environmental impact. To transform these liabilities into valuable resources, there is a growing interest in repurposing them as constituents in composite construction materials, particularly bricks. Eco-bricks have gained attention for their potential to enhance structural performance, thermal properties, and sustainability in construction practices. The hazardous characterization study seeks to comprehensively assess the chemical, physical, and thermal characterization of treated sludge scheduled wastes. Understanding the inherent properties of these materials is crucial not only for identifying potential environmental and health risks but also for determining their suitability for incorporation into composite bricks.

1.2 Problem Statement

Mixing, moulding, and curing are all examples of water-intensive brick production processes. To relieve pressure on local water supplies, Eco-brick development should attempt to reduce water use and integrate water recycling technologies. Another difficulty is the energy consumption connected with brick manufacturing. Traditional brick kilns can be energy-intensive, causing greenhouse gas emissions. Eco-brick development should look at energy-saving technology, such as low-energy fire processes or alternative materials that use less energy throughout the manufacturing process.

A significant concern is the diversity in material qualities that come with using unusual or recycled materials, such as treated sludge. This diversity might result in conflicting compressive strength values. The composition of sludge can vary greatly depending on its source, and the presence of hazardous substances or different particle sizes in the sludge might affect the homogeneity of the brick mixture. Furthermore, the absence of standardized processes for introducing sludge into brick manufacture might cause issues. Achieving the necessary mix of sustainability and compressive strength sometimes requires significant testing with various sludge-to-traditional brick ratios. This trial-and-error technique may provide unexpected results, with some combinations resulting in inappropriate strength. Concerns about toxicity play an important part in the creation of sustainable bricks. The presence of heavy metals or other toxic chemicals in sludge poses environmental and health problems. In addition to investigating the compressive strength of the created bricks, extensive testing for hazardous element leaching is required. To avoid any negative influence on the environment or human health, it is critical to ensure that the finished product follows safety criteria.

1.3 Objective

The objective of this project is as follow:

1. To identify the specific components that present in the treated sludge including any hazardous substances.
2. To develop sustainable bricks using up to 50 wt.% of treated sludge.
3. To analyze the toxicity level of the developed sustainable brick as referred to Total Threshold Concentration (TTLC).
4. To investigate compressive strength of the developed sustainable brick.

1.4 Scopes

To achieve the objective of the project, the scope of this project is:

1. The material of treated sludge is the sludge from firing treatment process up to 400˚C that have been given by the industry.
2. Identification and quantification of hazardous components, such as heavy metal, organic pollutants, and other toxic substance by using Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray (EDX) and X-ray Fluorescence (XRF).
3. Investigation of leaching behaviour to understand the potential for contaminants to migrate from the waste materials. Compliance with regulatory guidelines on leaching limits.
4. Total Threshold Concentration (TTLC) has been referred to by DOE guidelines.
5. Mechanical testing of sustainable bricks to assess strength.

1.5 Thesis Outline

This thesis is divided into five chapter. For chapter 1, it describes about the project research background, problem statement, objective, scope of work, and thesis outline. Next, chapter 2 will provide a detailed review of the recent study on development of brick using various type of sludge through firing and some method that they use for the analysis. Chapter 3 discuss the flow how to develop the eco-brick from collect raw material until last analysis of the eco-brick. From this chapter, it will describe in detail on the specification that use for the experiment. Furthermore, chapter 4 will show the result that already get from the analysis and discuss about the results. From here it will explain more detailed about the failure that had happen during the process of development the eco-brick. Lastly, chapter 5 summaries all the research findings and make some recommendation for future research on this topic. Appendix A and B show the Gantt chart of activities for this project in 1st and 2nd semester, respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Most of this chapter explains the theory and research that were established and conducted many years ago by many researchers. Based on their study on composite brick development utilising different types of sludge, related material from earlier studies is retrieved as references and discussion. Furthermore, this chapter provides further information from a study report regarding scheduled waste and residue classification and toxicity levels in sludge. Finally, this chapter discusses environmental impact assessment using current papers.

2.2 Composite Brick Development

This section analysed brick production processes that used multiple materials such as sludge, agrowaste, plastic waste, industrial trash-solid waste from various industrial operations, and building and waste from demolitions. The review covers material selection, mix and waste replacement ratios, and the effect of waste addition on the physico-mechanical properties of made bricks. Many academics have investigated the firing-based manufacture of bricks from waste materials.

Sewage sludge is a semisolid residual substance formed during wastewater treatment from the sedimentation of suspended solids. There are two forms of sewage sludge: primary sludge, which is generated by gravity sedimentation of suspended particles and organics, and secondary sludge, which is created by microbes that devour organic waste (Lamastra et al., 2018). The increased number of wastewater treatment facilities and resulting sludge formation as the urban population grows puts pressure on the constant development of sludge disposal solutions. Such ways include employing sludge as a clay brick making.

(Sutcu et al., 2019) The study investigates the possibility of utilising fly ash (FA), bottom ash (BA), and clay to make ecologically acceptable building materials in clay-based bricks. A variety of brick parameters, including porosity, water absorption, bulk density, compressive strength, and thermal conductivity, were assessed during testing at firing temperatures of 950 and 1050°C. According to the findings, bricks burnt at 1050°C exhibited marginally higher bulk density and thermal conductivity but somewhat reduced porosity and water absorption. FA was added, which resulted in a drop in bulk density and thermal conductivity but an increase in porosity and water absorption. The characteristics of the bricks were not considerably affected by the BA content. The study also discovered that replacing garbage with ashes up to 30% of the original amount might lessen waste products' negative environmental effects and save non-renewable natural resources. Porosity, water absorption, bulk density, and thermal conductivity were among the qualities that changed when FA and BA were added to the brick-making process. All burnt bricks had immobilised heavy metals in their ceramic structures, according to the leaching investigation. In addition to supporting sustainable building practices and providing important information for upcoming advancements in environmentally friendly building materials, the study offers insightful information on the possibilities of waste-based materials in brick manufacturing.

(Limami et al., 2021) The utilisation of recycled wastewater treatment plant sludge as an ingredient in the manufacturing of environmentally friendly, lightweight earth bricks is investigated in this study. According to the study, the sludge concentration of the bricks increases their thermal efficiency, porosity, and capillary water absorption coefficient. This leads to a production technique that is cleaner, uses less energy, and has better thermal insulation qualities. It also complies with Moroccan building material testing criteria. The study also emphasises how sewage additives might be used to create building materials that are both environmentally and energy efficient. The earth material and sludge had a high clayey content, with quartz predominating in both, according to the X-ray Diffraction and Fluorescence examination. Brick samples with greater sludge contents were more porous, which raised the capillary water absorption coefficient and lowered compressive strength. The results of the study highlight the possibility of creating more sustainable and cleaner production techniques in the building industry. The study's findings contribute to the creation of environmentally and energy-conscious construction materials by providing important insights into the application of sludge additives to improve earth brick qualities.

(Devant et al., 2011) describe the unique formulation of red ceramics using a blend of clay, sewage sludge, and forest debris in their investigation into the production of alternative bricks. Finding a means to recycle sewage sludge and turn it into structural ceramics like clay bricks is the goal in place of the conventional disposal techniques. The binary combination is a superior option for waste vaporisation since the addition of forest waste enables a large proportion of sewage sludge to be absorbed into an extrudable mix. 10% sludge, 10% forest debris, and 80% clay produced an ideal ternary combination that met the technological constraints for extrudability, compressive strength, thermal conductivity, and porosity, making the ceramic material appropriate for ceramic construction. Through leaching and outgassing studies, the environmental implications of the manufacture of these ceramics were also examined. There are no environmental dangers for end users, as indicated by the leaching tests, which found quantities well below the permitted limits for construction materials.

(Eliche-Quesada et al., 2015) The study looked at the use of sludge from the pomace oil extraction industry (SPOEI) and oil refining industry (SOI) as raw materials for the manufacturing of lightweight bricks for building. Characterising the wastes and clay, adding the sludges to the bricks in varying amounts (0–30 wt%), and evaluating the bricks' mechanical, chemical, thermal, and physical qualities were all part of the research. The kind and quantity of garbage had a big impact on the bricks' quality; more waste content resulted in poorer compressive strength and higher porosity. Brick characteristics were not significantly affected by adding 5 weight percent of SOI or 10 weight percent of SPOEI; however, adding more resulted in increased porosity and decreased compressive strength.

According to leaching studies, the amounts of heavy metals that leached from the broken bricks were within permissible bounds, meaning that the bricks are not dangerous materials. The study proved that it is feasible to replace some of the clay in brick making with SOI and SPOEI. The waste content significantly affected the bricks' characteristics; at 10 weight percent for SOI and 20 weight percent for SPOEI, an equilibrium between positive and negative impacts was noted. Leaching tests indicated that the bricks met criteria and could be categorised as non-hazardous materials. Overall, the study shed light on the possible application of industrial sludges in environmentally friendly brick manufacturing, emphasising the significance of waste kind and quantity in defining the calibre of the finished product.

(Goel & Kalamdhad, 2017) researched the creation of environmentally friendly bricks using paper mill sludge (PMS). The influence of adding PMS to soil for brick production is examined in this study, with an emphasis on the material's mechanical and durability qualities. The goal of the study is to meet the demand for affordable and sustainable building materials, particularly regarding the Indian brick sector. To ascertain the effect of PMS on the performance of the bricks, several brick parameters are assessed, including bulk density, modulus of elasticity, water absorption, compressive strength, linear shrinkage, and mass loss upon fire. It also entails making bricks with various PMS and soil ratios and burning them at various temperatures. The results show that adding PMS increases the bricks' porosity and decreases their bulk density, which may help with lightweight and sustainable building. On the other hand, it has been noted that bricks with larger percentages of PMS absorb more water and have lower compressive strength. The findings may help the brick industry, particularly in India, commercialise the manufacture of bricks with PMS inclusions, supporting resource sustainability in the process. All things considered, the study offers a thorough grasp of the characteristics and behaviour of bricks containing PMS, setting the stage for the creation of reasonably priced and ecologically friendly building materials.

(Nkolika Victoria, 2013) examines the possibility of using Nigeria's Lower Usuma Dam Water Treatment Plant sewage as a raw material for bricks. The goal of the project was to identify a commercially and ecologically sound method for disposing of water treatment sludge. Characterising the sludge, running experiments in the lab, and assessing the effectiveness of the sludge-clay burned bricks were all part of the research. The results show that the sludge may be added to clay and utilised as a colourant for producing bricks. The study involved varying the ratios of sludge to clay and firing temperatures for the bricks. The bricks' mechanical, chemical, and physical characteristics were assessed in accordance with Indian Standard Code of Specification for Fired Clay Bricks, British Standard Specifications, and Nigerian Standard Specifications. The results of the investigation showed that the fire temperature and sludge proportion affected the bricks' quality. Reduced compressive strength, lower density, and higher water absorption were the outcomes of increasing the sludge concentration. Nonetheless, it enhanced the bricks' physical look and workability. Environmental safety was shown by the fact that the leachability of heavy metals from the bricks was determined to be below permitted levels. The study concluded by showing that sludge from water treatment plants may be efficiently used as an additional material to produce bricks, providing a long-term and ecologically responsible way to dispose of sludge. The study adds to the sustainability of the building industry and the environment by offering insightful information on the possible use of sludge in construction and building materials.

(Zat et al., 2021) This study shows that it is feasible to use wastewater treatment plant sewage sludge as a raw material for extrusion-based manufacturing of red ceramic bricks. Because of the sludge's leachability of heavy metals, there are no environmental problems. Adding sludge to the clay mixture decreases its flexibility and marginally raises the water requirement. The ideal moisture range for extrudability was determined using dynamic torsional oscillatory experiments, which produced flawless micro bricks of superior quality. For sludge additions between 2 and 10 weight percent, the ideal moisture content was 31–33 weight percent; larger sludge content increased it to 35 weight percent. Water absorption was also impacted by the sludge, however there were no appreciable changes in the bricks' mechanical performance. The study emphasises how using sewage sludge as a substitute raw material for clay-based brick manufacture might lessen the negative environmental effects associated with sludge disposal.

(Maierdan et al., 2020) The primary goal of the project was to directly use Waste River Sludge (WRS) in the economical construction of bricks by including various doses of pozzolan additives, including sodium metasilicate (SMS), hemihydrate phosphogypsum (HPG), slag, and ordinary Portland cement (OPC). The sludge's heavy metal concentration in relation to the Chinese standard GB 5085–2007 limitations. Because WRS with a high moisture content cannot be utilised as a raw material for bricks, HPG was creatively employed to dehydrate WRS. The chemical formula of CA is $C_6H_8O_8$ Á H_2O; in addition, the purity of CA is better than 99.5%. Most of the hydration may occur after the compacting process if retarder was used. As the dose of CA increased, from 0% to 0.5%, the rate of water absorption dropped. It occurred because of hydration reactions' retardation mechanisms, which decreased the production of cavities early in the hydration process. When the CA content rose from 0% to 0.5%, the densely packed structure, strength, and water absorption characteristics were all improved. According to the study, when 0.5% CA was added to WRS and HPG, the UCS of brick specimens increased to 10.9 MPa and 20.7 MPa at 7 and 28 days, respectively. When 20% OPC was added to the mixes, it was discovered that UCS peaked at about 20.7 MPa, which was noticeably greater than previous specimens. When 20% OPC was added, the lowest water absorption rate was reported to be close to 9.8%.

Moreover, (Heniegal et al., 2020) The characteristics of clay bricks including agricultural waste such rice straw ash (RSA), sugarcane bagasse ash (SBA), and wheat straw ash (WSA) as well as sludge from water treatment plants (SWTP) were the focus of the investigation. The aim of the study was to examine the impact of adding agricultural wastes to clay bricks on their mechanical and physical characteristics as well as their microstructure. According to the study, the compressive strength of clay bricks including RSA, SBA, and WSA was lower than that of clay bricks without these ingredients. But adding 5–15% of RSA, SBA, and WSA by weight of SWTP to the brick moulding compound resulted in environmentally friendly bricks with a porous microstructure and a reduced bulk density, which made the constructions lighter and more cost-effective. According to the study's findings, brick samples with lower concentrations of RSA, SBA, and WSA (i.e., 5% SWTP weight) would both lessen their negative effects on the environment and promote more economical and efficient growth. Additionally, the results demonstrated that adding 5% of RSA, SBA, and WSA increased flexural strength and lowered bulk density, suggesting a possible method for producing bricks that is both economical and sustainable. In order to reduce the weight of construction materials, the study suggested using agricultural waste as a sustainable supply of raw materials for the brick industry.

(Salim et al., 2023) The study looked at how gas emissions during the firing process and indoor air quality (IAQ) evaluation were affected by adding 5% sewage sludge to burnt clay bricks. The addition of sewage sludge considerably enhanced CO, CO_2, and NO emissions, according to the results. Compared to other pollutants, SO_2 emissions from SBA and SBB were comparatively modest, but they were much higher in CB. Gas emissions during the burning process may increase because of bricks' growing organic content. Particulate matter (PM10), formaldehyde (HCHO), ozone (O_3), carbon dioxide (CO_2), total volatile organic compounds (TVOC), and carbon monoxide (CO) were among the parameters assessed in the IAQ evaluation. Apart from the PM10 result, which is beyond the allowable limit and violates the industry code of practice for indoor air quality (ICOP-IAQ), all metrics were lower when compared to CB. According to the study's findings, sewage sludge can be a suitable partial substitute for clay in the production of burnt clay bricks and help preserve natural resources.

The use of sewage sludge in the building industry was assessed in the study (Esmeray & Atıs, 2019), with particular attention to the effects on human and environmental health. In the study, various ratios of fly ash, oven slag, and sewage sludge were added to the clay brick manufacturing process. The produced brick samples underwent a variety of tests and analyses, including as microstructure analysis, thermal conductivity coefficient determination, porosity, density, water absorption, and Atterberg limit investigations, in addition to chemical analysis and heat conductivity testing. The results showed that the amount of water needed to achieve plastic consistency rose with the amount of sewage sludge. The addition of sewage sludge and higher temperatures both enhanced the overall linear shrinkage values and water absorption rates. The findings demonstrated that the strength and sintering of the bricks were adversely impacted by the inclusion of sewage sludge. On the other hand, the inclusion of fly ash and oven slag produced better outcomes. Additionally, the investigation discovered that all sample values for thermal conductivity were within allowable bounds. The study found that although sewage sludge negatively affected the characteristics of bricks, fly ash and oven slag shown promise for usage in the manufacturing of bricks. The study underlined the need for more research in this field and stressed the need of assessing waste materials for its consequences for human health and the environment. In conclusion, the study offered thorough insights into the utilisation of waste materials in the manufacturing of clay bricks and their consequences on the bricks' mechanical and physical qualities. The results highlighted how recycling waste materials may help reduce environmental problems and improve the sustainability of building materials.

(Gencel et al., 2020) This investigation looked at using leftover concrete to make burnt clay bricks instead of clay. Clay was combined with concrete waste powder up to 15% by weight. Pellets of the samples were produced and burned for two hours at 1000°C and 1100°C. Analysis was done on characteristics such as density, porosity, water absorption, compressive strength, and thermal conductivity. The findings demonstrated that while compressive strength and thermal conductivity declined with increasing concrete waste content, characteristics like porosity and water absorption somewhat increased. Nonetheless, bricks with up to 15% concrete waste were structurally sound. According to leaching tests, the burnt bricks included immobilized heavy metals from the source components. The study shows how leftover concrete may be used to make clay brick.

(Andiç-Çakır et al., 2021) This project uses waste materials, such as poplar and grapevine twig dust, to enhance the thermal insulating qualities of conventional clay bricks. To replicate a workable industrial manufacturing method, extrusion was used to create brick samples on a laboratory scale. Bricks' unit weight and thermal conductivity coefficient fell by 25% and 22%, respectively, at a replacement ratio of 7.5% by volume, enhancing the thermal insulation qualities. In contrast, a 2017 study by Abbas et al. explores the use of fly ash in the production of clay bricks to create more environmentally friendly bricks. In an industrial kiln, fly ash from a nearby coal-fired power station was utilised in place of clay at weight ratios ranging from 5 to 25% to produce 150 brick examples. Bricks' mechanical qualities, such as their compressive strength, flexural strength, and water absorption, declined as the fly ash level increased; yet bricks containing up to 20% fly ash still fulfilled code requirements. Bricks containing fly ash exhibited reduced efflorescence and were up to 18% lighter. According to the study's findings, clay bricks that replace up to 10% of fly ash can be utilised successfully in environmentally friendly building.

(dos Reis et al., 2020) The utilisation of sludge from the inert mineral portion of building and demolition waste (RA-S) as the main raw material for burned clay brick production is examined in this research. The physical, chemical, and mechanical qualities of bricks made with varying amounts of RA-S and earth material were assessed. The findings demonstrated that RA-S possesses qualities that make it a good material for bricks, and that adding up to 70% RA-S resulted in bricks that are up to par with international requirements.

It was discovered that RA-S enhanced the bricks' compressive strength and thermal insulation, especially those burnt at 800˚C.

(Maheswaran et al., 2023) The creation of sustainable goods with additional value from paper mill waste through experimentation is covered in the publication. It discusses the problem of what to do with leftover paper mill sludge and suggests using the secondary paper mill sludge to make eco-friendly composites, powdered chakra bases, bricks, and briquettes. Dewatering, grinding, combining with other materials, and testing for compressive strength, water absorption, and efflorescence are all steps in the experimental procedure. The publication examines the body of research on the use of paper mill waste in different building materials and the range of businesses in which the sludge may find use. Additionally, it outlines the precise procedures utilised in the production of the value-added goods, such as the preparation of brick samples, testing of brick samples, briquette manufacture, testing of briquettes, and production of ground chakra base and environmentally friendly composites. The findings and conversations emphasise the characteristics of the created goods, including the briquettes' ash content, volatile matter content, and moisture content as well as the brick samples' compressive strength, water absorption, and efflorescence. The potential of the created products to solve the problems associated with disposing of paper mill waste, increase income for the paper industry, and reduce environmental effect is highlighted in the document's conclusion. It also recognises that more research is necessary to fully understand the economics of the goods as well as the functionality of the eco-friendly composites and briquettes. Major study on the use of waste materials to make bricks by fire (refers Table 2.2). With this approach, waste material(s) can be used in place of all or part of the clay, and the material(s) are fired in a kiln to produce bricks as per normal procedure.

Table 2.2 Previous study on Brick with Sludge

No	Sludge waste type (wt.%)	Dimensions (mm)	Experimental conditions	Characterization	Reference
1	Fly ash and bottom ash (5,10,20,30)	12×40×80	Mixing, pressing in a mould using a hydraulic press (20 MPa); green compacted, removed, and stored for 24 hours; oven-dried for 24 hours at 40˚C, followed by 24 hours at 100˚C.	Shrinkage; loss in ignition; water absorption; bulk density; compressive strength; leaching behaviour	(Sutcu et al., 2019)
2	Sludge (1,3,7,15,20)	160×40×40	Mixing and moulding (6.5 Mpa); samples are cured for 28 days in a control room at 20˚C±1˚C. After that, they are oven-dried for a further 24 hours at 50˚C beginning temperature, with a 1.5˚C/h increment factor.	Bulk density, capillary water absorption coefficient and compressive strength	(Limami et al., 2021)
3	Wastewater treatment sludge (3.3-23.8)	50-120 in. length	Extruded at pressures between 0 and 2.05 MPa, broken into testing pieces of 5 to 12 cm in length, fired at 980˚C at a rate of 160˚C per hour, soaked for three hours, and cooled for twelve hours.	Compressive strength; density; porosity; leaching behaviour; thermal performance	(Devant et al., 2011)
4	Sludge from oil refining industry and pomace oil extraction industry (0-30)	30×10×60	Pressed under 54.5 MPa; firing to 950˚C at the ramp of 3˚C/min for 4 hrs	Appearance; density; shrinkage; loss on ignition; porosity; water absorption; compressive strength; thermal conductivity; leaching behaviour.	(Eliche-Quesada et al., 2015)
5	Paper mill sludge (0,5,10,15,20)	61×29×19	Combining sludge with clay at a moisture level of 20–25%; hand-moulding; let to air dry for 24 hours at room temperature; baking for 24 hours at 105˚C; fire for 7-8 hours at 850 and 900˚C; soak for 1 hour.	Shrinkage; water absorption; density; porosity; compressive strength; modulus of elasticity.	(Goel & Kalamdhad, 2017)

6	Sludge from Lower Usuma Dam Water Treatment Plant (0,5,15,20)	70×70×70	Aggregate mixing (0:100; 1:19; 1:10; 3:20; 1:50); hand-moulding; mixture cover with polyethylene bag 7day and air drying 7 days at 23˚C; fired at 850˚C,900˚C,950˚C,1000˚C and 1050˚C for 6hrs; cooling overnight	Compressive strength, water absorption, density, shrinkage, and weight loss on ignition	(Nkolika Victoria, 2013)
7	Sewage sludge from Brazilian wastewater treatment plant (4.8)	(0.9m long conical entry consist of 150mm diameter circular entry section and 990 mm^2 rectangular exit section	Mixture and mechanical homogenization for 10 minutes; extruder under vacuum 10 mm/hg at a speed of 22 to 39 mm/s; 40 hours of drying at 25 to 30 C; oven drying at 60 to 100 C for 12 hours; air firing for 5 hours	Shrinkage, water absorption, bulk density, and compressive strength.	(Zat et al., 2021)
8	Water river sludge (20-100)	40×40×80	Mixed 5min; cast in self-made Molds and exerted force 3kN until height 40mm; cured in natural air 7 or 28 days; thermogravimetric analysis (TGA) 30 to 900˚C	Unconfined compressive strength (UCS), water absorption, thermogravimetric analysis (TGA)/SEM, cost analysis	(Maierdan et al., 2020)
9	Dry alum sludge from water treatment plant and agriculture wastes(ashes) (5,10,15)	(250×120×60) (50×50×50)	Mix; transfer to a brick mould; bake for 24 hours at 110 degrees Celsius; let cool to room temperature.	Compressive strength, flexural strength, bulk density, apparent porosity, water absorption and efflorescence.	(Heniegal et al., 2020)
10	Sewage sludge (5)	215×102×65	Mixing; dried 24hr at 105˚C; firing at 1˚C/min until reached 1050˚C	Gas emission during firing and indoor air quality	(Salim et al., 2023)
11	Clay, sewage sludge. Ground blast furnace slag and fly ash (5,10)	Rectangular shape (1.5×4mm^2)	Mixing stirred 10 min; dried room temperature 3day not exposed to sunlight; dried 105 ± 5˚C for 24hr; cured at 900˚C and 1050˚C; reached temperature for 8hr and stay at desired temperature for 2h;	Shrinkage, porosity, density, compressive strength, thermal conductivity, and water absorption	(Esmeray & Atıs, 2019)
12	Fly ash (0,50,60,70,80 %vol)	60×60×25	UNFIRED BRICK - Mixed; casted; dried 2day at 60˚C for 4 hr and at 100˚C for 6hr. HEATING PROGRAM	Compressive strength, water absorption, bulk density, and porosity	(Lingling et al., 2005)

			- Unfired brick is fired in an electric furnace set to sinter at a temperature of 100˚C per hour below 500˚C and 50˚C per hour above 500˚C for eight hours.		
13	Clay, sludge from textile production and quarry dust	N/A	Clay, sludge from textile production and quarry dust	Compressive strength, water absorption test and efflorescence test.	(Padmalosan et al., 2023)
14	Paper sludge (0,5,10,15)	70×70×70	Mixed; dried at 105 ± 5˚C; fired at 900˚C and 1000˚C for 1hr	Water absorption, compressive strength, bulk density, and durability.	(Kizinievič et al., 2018)
15	Concrete wastes (0,2.5,5,7.5,10,12.5,15)	2mm diameter and 11mm thickness	Mixed; cured 35˚C one day and 100˚C one day in oven; fired 2˚C/min in oven 1000 and 1100˚C for 2hr.	Bulk density, porosity, water absorption and compressive strength.	(Gencel et al., 2020)
16	Twig dust and poplar dust	Plate sample 22×22×3cm; cylindrical sample 6cm diameter and 10cm in length; perforated samples 5×7.5×10 cm	Mixed; extrusion; perforated and cylindrical specimens conditioned for 24h and plate specimens for 7 days at 20˚C; perforated and cylindrical kept in oven for 24h and plat for 72h at 40˚C; fired at 800 and 1100 ˚C	Thermal conductivity test, compressive strength, and freezing-thawing tests.	(Andiç-Çakır et al., 2021)
17	Fly ash	225×112×75	Hand mixing and moulding method; air-dry for 4–5 days; put in kiln and fire for 3 days at 800˚C; fired clay brick is taken out of kiln after 20 days. Unfired brick is fired in an electric furnace set to sinter at a temperature of 100˚C per hour below 500˚C and 50˚C per hour above 500˚C for eight hours.	Compressive strength and water absorption	(Abbas et al., 2017)
18	Sludge construction and demolition waste (RA-S) (0.30.50,70,100)	100 mm diameter and 7mm height	Homogenization; 20 Kpa forming/pressing; 45 Kpa drying for 24 hours and 105 Kpa drying for an additional 24 hours; firing at 800 and 1000 Kpa, heating at a rate of 6 Kpa for two hours at the final temperature.	Bulk density, compressive strength, and firing shrinkage.	(dos Reis et al., 2020)

2.3 Scheduled Waste and Residue

Scheduled waste and residue are words used in Malaysia to describe waste products that, because of their hazardous nature, may provide concerns to the environment and human health. The Environmental Quality Act of 1974 regulates how the Department of Environment (DOE) handles planned waste. Any waste item or substance that is included in the First Scheduled of the Environmental Quality (Scheduled Wastes) Regulations 2005 is referred to as scheduled waste. Its properties—physical, chemical, or biological—allow for its classification into several groups. Used lubricating oil, discarded solvents, chemical sludges, and certain medical waste are a few examples.

(Anwar Zainu, 2019) The concept of waste and hazardous waste is explained in this document. Waste is defined as any material that is worthless, defective, or useless that has been discarded after serving its original function. Any garbage that fits into one of the categories listed in the First Scheduled of Environmental Quality (Scheduled Wastes) Regulations 2005 is considered hazardous waste. Because of the risks to human health and the environment, normal treatment methods used for non-hazardous industrial wastes are insufficient for hazardous wastes, which have the potential to be destructive. In industrialised countries, thermal disposal methods like incineration with energy recovery are frequently used for waste management. However, there is no comprehensive control over emission reductions for other substances, such dioxins and heavy metals. Industries must comply with ISO 9000 standards for emission control, which will lead to the promotion of various conversion technologies like as combustion or gasification. For the last thirty years, waste management has been a major problem in Malaysia, with policies aiming at minimising or controlling trash through legislative changes, new technologies, infrastructure development, and complicated management networks.

(Che Jamin & Mahmood, 2015) this paper study about scheduled waste management in Malaysia. This study has listed the category of waste that comes from scheduled waste as shown in Table 2.2.

Table 2.3 Quantity of scheduled waste generated by category (Che Jamin & Mahmood, 2015)

Waste category	Waste code	Quantity of waste	
		MT/year	Percentage (%)
Dross/ash/slag	SW 104	364,425.95	21.33
Gypsum	SW 205	337,771.68	19.77
Mineral sludges	SW 427	316,938.39	18.55
Oil & hydrocarbon	SW 305	154,113.37	9.02
Heavy metal sludges	SW 204	120,793.29	7.07
E-waste	SW 110	78,278.05	4.58
Used containers	SW 409	67,406.83	3.94
Batteries	SW 102	42,919.49	2.51
Spent acids	SW 206	33,411.90	1.96
Mixed wastes	SW 422	30,154.40	1.76
Rubber sludges	SW 321	22,401.82	1.31
Residue	SW 501	22,055.21	1.29
Pathogenic waste clinical	SW 404	20,865.09	1.22
Contaminated paper & plastic	SW 410	18,921.38	1.11
Others		78,251.73	4.58
Total		1,708,708.73	100.00

The importing of hazardous waste, including e-waste, for recovery or disposal is prohibited under Malaysian law. Nonetheless, it is only permitted to import trash from old electrical and electronic equipment for direct reuse after three years from the date of production. On a case-by-case basis and with strong proof, DOE will be permitted if local recovery institutions are unable to complete such an activity. Because of the current Malaysian management system's preference for disposal over alternative management strategies, there are environmental issues with rising demand for disposal land, leachate issues from illegal dump sites, and greenhouse gas emissions. To reduce pollution and promote sustainable growth, the emphasis has switched to cleaner manufacturing and zero-discharge engineering. Malaysia has promoted a new way of thinking about planned waste management that views resource recovery and trash recycling as potential resources, rather than as a means of getting rid of waste. This framework aims to develop manufacturing methods that are practically waste-free in addition to being efficient. To promote appropriate industrial waste management, incentives are also offered for the storage, handling, and elimination of hazardous and toxic waste.

2.3.1 Toxicity Level

When discussing hazardous waste, the term "toxicity level" describes the extent to which a certain waste material's poisonous constituents endanger public health or the environment. The term "toxicity" describes a substance's innate ability to be harmful, especially when it meets living things or is discharged into the environment. The phrase "hazardous waste" refers to waste products that have the potential to have a negative impact on ecosystems, human health, or the environment. One of the four criteria used to classify hazardous waste is toxicity (Aja et al., 2016). The last three attributes are reactivity, corrosivity, and ignitability. A waste material exhibiting toxicity indicates the presence of potentially dangerous compounds in the trash's quantities.

To ascertain if a waste substance is dangerous, toxicity testing is also carried out. To evaluate the effect of the waste on various creatures, including bacteria, plants, and animals, including human cells, a variety of tests and techniques are used. One important consideration is the leachability of harmful chemicals from a waste material. Contamination and injury to the environment are more likely if harmful components may seep into the soil, water, or air. Another factor considered is the harmful chemicals' mobility inside the trash. Regulatory bodies that set thresholds and limitations for certain harmful compounds in trash are the Environmental Protection Agency (EPA) in the United States and similar agencies in other nations. If the concentration of a toxic substance in a waste material exceeds these limits as shown in Table 2.3.1 (*A Guidebook on The Identification and Classification of Scheduled Waste, Jabatan Alam Sekitar,2015*), the waste is classified as hazardous. Hazardous waste with high toxicity levels requires special management and disposal procedures to minimize the risk of exposure and environmental impact. Treatment methods may be employed to reduce toxicity before disposal, and specific facilities, such as hazardous waste landfills or incinerators, may be used.

Table 2.1.1 Maximum Concentration of Contaminants for the Toxicity Characteristic Leaching Procedure (TCLP)

DOE CW No. [1]	Contaminant	CAS No. [2]	Maximum Level (mg/L)
C004	Arsenic	7440-38-2	5.0
C005	Barium	7440-39-3	100.0

C018	Benzene	71-43-2	0.5
C006	Cadmium	7440-43-9	1.0
C019	Carbon tetrachloride	56-23-5	0.5
C020	Chlordane	57-74-9	0.03
C021	Chlorobenzene	108-90-7	100.0
C022	Chloroform	67-66-3	6.0
C007	Chromium	7440-47-3	5.0
C023	o-Cresol	95-48-7	200.0[3]
C024	m-Cresol	108-39-4	200.0[3]
C025	p-Cresol	106-44-5	200.0[3]
C026	Cresol		200.0[3]
C016	2,4-D	94-75-7	10.0
C027	1,4-Dichlorobenzene	106-46-7	7.5
C028	1,2-Dichloroethane	107-06-2	0.5
C029	1,1-Dichloroethylene	75-35-4	0.7
C030	2,4-Dinitrotoluene	121-14-2	0.13
C012	Endrin	72-20-8	0.02
C031	Heptachlor (and its epoxide)	76-44-8	0.008
C032	Hexachlorobenzene	118-74-1	0.13
C033	Hexachlorobutadiene	87-68-3	0.5
C034	Hexachloroethane	67-72-1	3.0
C008	Lead	7439-92-1	5.0
C013	Lindane	58-89-9	0.4
C009	Mercury	7439-97-6	0.2
C014	Methoxychlor	72-43-5	10.0
C035	Methyl ethyl ketone	78-93-3	200.0
C036	Nitrobenzene	98-95-3	2.0
C037	Pentachlorophenol	87-86-5	100.0
C038	Pyridine	110-86-1	5.0
C010	Selenium	7782-49-2	1.0

C011	Silver	7440-22-4	5.0
C039	Tetrachloroethylene	127-18-4	0.7
C015	Toxaphene	8001-35-2	0.5
C040	Trichloroethylene	79-01-6	0.5
C041	2,4,5-Trichlorophenol	95-95-4	400.0
C042	2,4,6-Trichlorophenol	88-06-2	2.0
C017	2,4,5-TP (Silvex)	93-72-1	1.0
C043	Vinyl chloride	75-01-4	0.2

2.4 Environmental Impact Assessment

Brick factories are situated close to sources of raw materials, making brick production a very effective use of resources. Clay and shale that have been processed are put back into the production stream, while bricks that don't meet criteria are removed and pulverised into grog or crushed for landscaping. The brick business strives to minimise the number of resources utilised throughout the manufacturing process, and there is almost no waste of raw materials. The main ingredient, clay, is thought to be a plentiful resource. Non-hazardous waste materials from other industries are occasionally employed as well. The most popular energy source for the brick industry is natural gas, however many producers also use waste materials like sawdust for brick fire and methane gas from landfills. It is essential to follow by local, state, and federal laws pertaining to clean air and the environment. For example, air emissions can be reduced by installing scrubbers on kiln exhausts; dust in plants can be managed using water mists, vacuums, additives, and filtering systems; and mined areas can be reclaimed by adding topsoil and overburden. Bricks are safe and long-lasting goods for society, as evidenced by the fact that current brick production techniques are similar to those employed over the previous 3500 years. One essential element of sustainable pavements and buildings is brickwork's extended lifespan.

(Cusidó & Cremades, 2012) This study investigates the environmental effects of producing clay bricks using sewage sludge. According to the study, it is both possible and environmentally friendly to include sewage sludge into ceramic goods used for deconstruction and building materials. Tests for toxicity and leachability were done to evaluate the products' environmental qualities. According to the results of the leaching tests, the ceramic materials containing sewage sludge are compliant with environmental regulations and can be utilised without any limitations as construction materials. In order to assess the possibility of gas and particle emissions from the ceramic goods, the research also includes off gassing and outgassing tests. The findings show that there are no issues of this kind. According to the study's findings, adding sewage sludge to ceramic items is a practical and ecologically beneficial solution that carries no dangers to human health or the environment.

Moreover, (Gherghel et al., 2019) This paper examines the difficulties associated with wastewater sludge valorisation within the framework of the circular economy. It highlights the necessity of viewing sludge as a resource as opposed to a waste and talks about methods for extracting nutrients and carbon from sludge. In the framework of the circular economy, the assessment addresses technology for resource and energy recovery as well as conventional treatment and disposal techniques. It also covers the types of sludge generated and how to reduce the quantity of sludge produced. It also offers a thorough explanation of urban biorefineries, which are used to recover nutrients, cellulose, and produce bioplastics. The assessment emphasises how crucial it is to have the right methodology when putting out "end-of-waste" standards for items made from wastewater sludge. In addition, the study analyses several solutions for lowering sludge in the wastewater and sludge treatment line and evaluates European Union legislation on wastewater sludge management. It talks about nutrient recovery, heavy metal recovery, and sludge-based adsorbent manufacturing. The utilisation of methods such pyrolysis, hydrothermal treatment, microwave treatment, and ultrasonication for resource recovery from municipal wastewater sludge is highlighted in the review. The paper offers an overview of resource recovery systems from municipal wastewater sludge, with a focus on the primary outcomes, placements of the products in the process diagram, and recovery efficiency. It provides a succinct summary of the difficulties and possibilities associated with wastewater sludge management.

(Galvín et al., 2023) The possibility of reusing rejected blocks from a precast concrete factory to meet "zero waste" targets during the manufacturing process is covered in the document. Using varying percentages of recycled aggregate (RA) replacement from precast concrete block rejects, the study assessed the leaching performance and technical viability of recycled vibro-compacted dry mixed concrete blocks. The findings demonstrated that concrete blocks with a 20% RA inclusion had the best physico-mechanical characteristics. Certain elements, such as Mo, Cr, and sulphate anions, showed increased mobility during the diffusion leaching tests, according to the environmental evaluation based on leaching tests. The solitary emission of sulphate anions that slightly above the inert limit was identified by the investigation as the reason why RA from the rejected concrete blocks was classed as non-hazardous material. The metals and anions discharged from the concrete blocks had leachate concentrations below the inert limits. The study also showed that the reference block's characteristics and the maximum compressive strength were attained by the concrete blocks containing 20% RA. The diffusion tank test's long-term trends of the leaching cumulative curve revealed that the release levels were significantly beyond the SQD's construction product limitations. The effective diffusion coefficient demonstrated the strong mobility of the sulphate, molybdate, and cr anions. According to the study's findings, precast enterprises may contribute to the circular economy paradigm without endangering the environment by leaching by employing a 20% RA integration ratio into recycled concrete blocks to generate sustainable concrete. The findings complement the objectives of environmentally friendly and sustainable building practices by offering insightful information on the technical and environmental aspects of employing recycled aggregates in the manufacturing of concrete.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter illustrates the important procedure by which the study will be carried out. It focuses on the approach to solving the problem. The entire procedure is represented in a flowchart. The flowchart shows how the problem will be solved step by step depending on the objectives that must be met. The subject of this work is restricted to developing composite bricks using scheduled treated sludge waste. This section includes raw materials, equipment, tools, and techniques. According to the flowchart, the process begins with the collecting of raw materials such as treated sludge and clay from the companies involved in this study. Next, use an X-Ray Fluorescence (XRF) and Energy Dispersive X-ray (EDX) analysis on treated sludge to determine whether any heavy metals are present in the sludge. Next, combine clay and treated sludge to create the composite brick. Curing, firing, and cooling following the chosen specification will be the next steps in the fabrication process. Following manufacturing, composite bricks must be tested using mechanical and leaching testing, depending on the goal. We are doing this test to ensure that our research will meet the sustainable criteria needed to manufacture composite bricks. Figure 3.1 show the overview of process methodology.

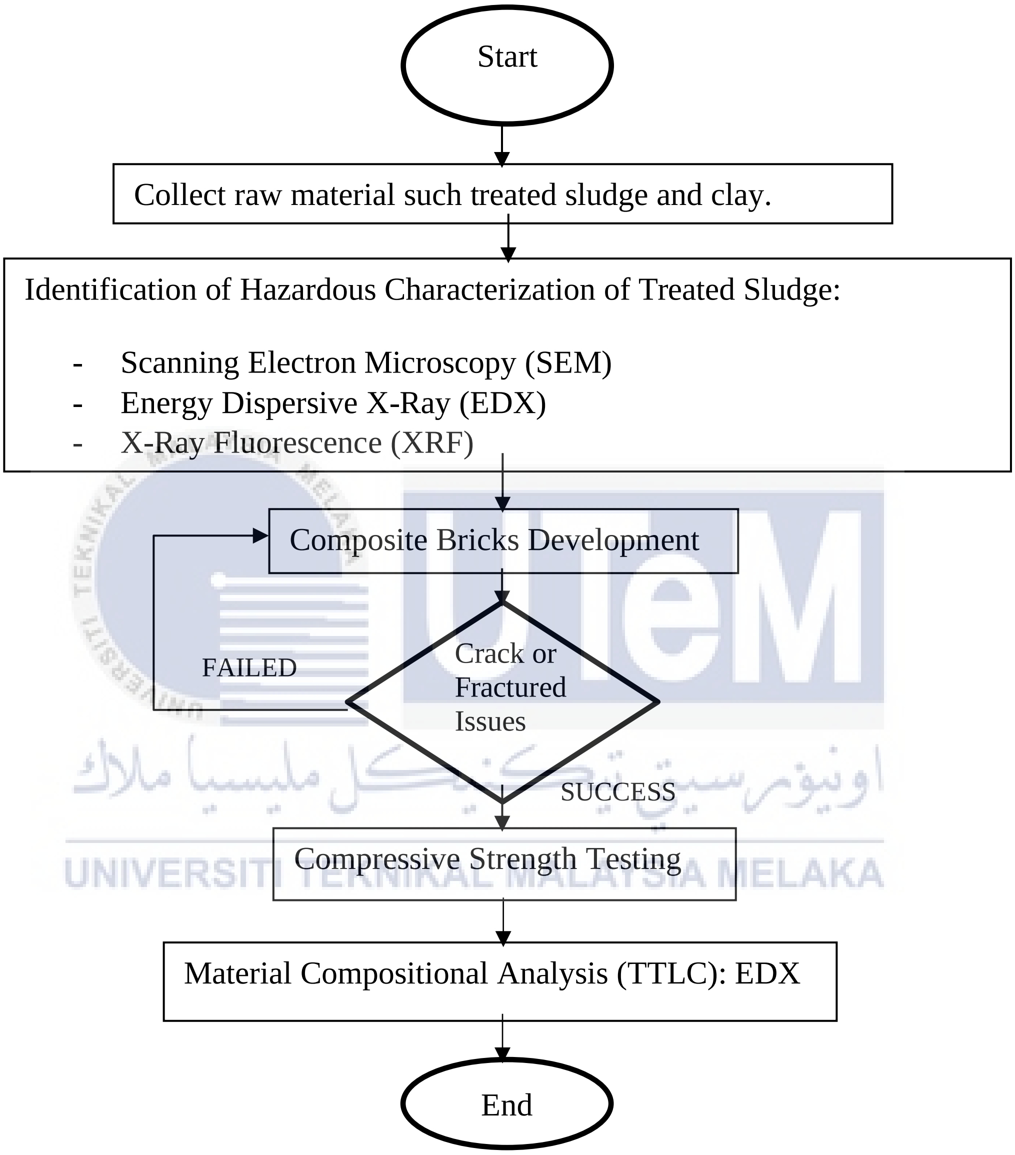


Figure 3.1 Overview of Process Methodology

3.2 Material

In this research, in Figure 3.2 around ±5.0kg of treated sludge and clay are used as raw material for eco-bricks development. OCI company will supply an adequate amount of clay. While the treated sludge was collected from Victory Recovery Resources Sdn Bhd. This treated sludge has done the process of firing up to 400˚C temperature.

Figure 3.2 Raw material for eco-brick development

3.3 Hazardous Characterization

Figure. 3.3 shows a step-by-step working schematic that explains how samples were made from raw treated sludge. The element present in the treated sludge was subjected to a qualitative and quantitative examination utilising XRF, EDX and SEM to determine its chemical composition. The material was ground into a powder to make studies easier. After that, it was sieved and kept for further testing in polybags. To ensure a precise comparison of elemental composition, samples from the structural layer were prepared as similarly as feasible.

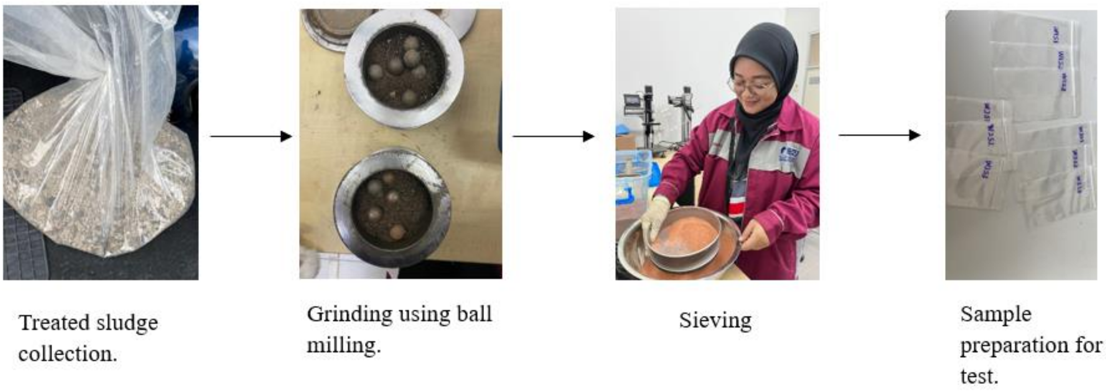


Figure 3.3 Step-by-step for sample preparation of treated sludge

3.3.1 Scanning Electron Microscopy (SEM)

The scanning electron microscope (SEM) is a technique used to examine the shape and structure of a material. It utilises a highly focused electron beam, with a spot size of few nanometers, that is accelerated by 10 to 20 kilovolts. Secondary electrons are generated from inelastic interactions between the electron beam and the electrons present on the surface of the sample, particularly at low energies. The primary reason why these SEM images sources are widely employed is because they are greatly influenced by beam contact, resulting in the maximum spatial resolution and little sample distortion. The elastic collision between the speeding electron and the material surface is caused by backscattered electrons. This showcases the most comprehensive comparison, a wider production sample area, and atomic number, which aids in creating a more precise differentiation between two separate chemical compositions. Ultimately, when a beam interacts with an atom at its innermost level, it gives rise to distinct X-rays and Auger electrons, causing the expulsion of one of its internal electrons. When a higher-level electron moves to an empty place, it releases a photon with a consistent amount of energy. Consequently, one of two outcomes occurs: either a more advanced electron assimilates the photon and releases it from the molecule, or there is a discharge of an Auger electron or x-ray. The energy of x-rays is accurately quantified and specific to each atom, enabling the identification and measurement of the elements present in the sample (Brundle & Crist, 2020).

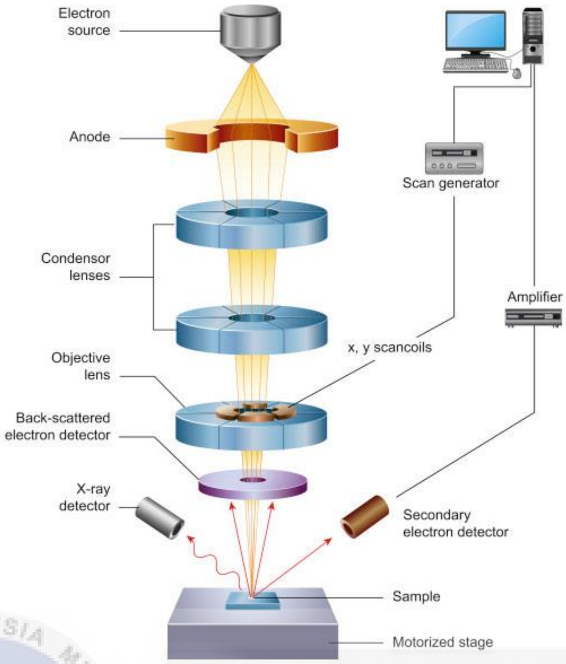


Figure 3.3.1 Working Principle of SEM

3.3.2 Energy Dispersive X-Ray (EDX)

Energy dispersive X-ray (EDX) analysis can be used to identify the elemental composition and perform chemical analysis of a substance. It is commonly used in conjunction with a SEM. During the analysis process, the specimen is subjected to a bombardment of high-energy electrons. When electrons collide with atoms on the surface of the specimen, it leads to the emission of X-rays. The X-rays produced from the interaction can be categorized into types: Bremsstrahlung X-rays, also referred to as continuous X-rays, and characteristic X-rays. The interaction between electrons and atomic nuclei in a specimen is generated by the emission of X-rays known as Bremsstrahlung. This is seen in the presence of the background spectrum combined with the usual X-ray spectra. Characteristic X-rays are generated when high-energy electrons collide with atoms, causing higher state electrons to transition to lower energy state vacancies. The disparity in energy levels between the higher and lower states is directly related to the energy of the emitted X-rays and is influenced by the characteristics of the specimen. The unique X-rays are visible as X-ray lines in the X-ray spectra. An X-ray detector records both the Bremsstrahlung and the characteristic X-ray emissions, which are then shown as a spectrum showing the energy of the X-rays and their intensity. The energy of the distinctive X-rays enables qualitative analysis, which identifies the elements present in the specimen. The intensity of the X-rays allows for quantitative investigation, which determines the concentration of the elements.

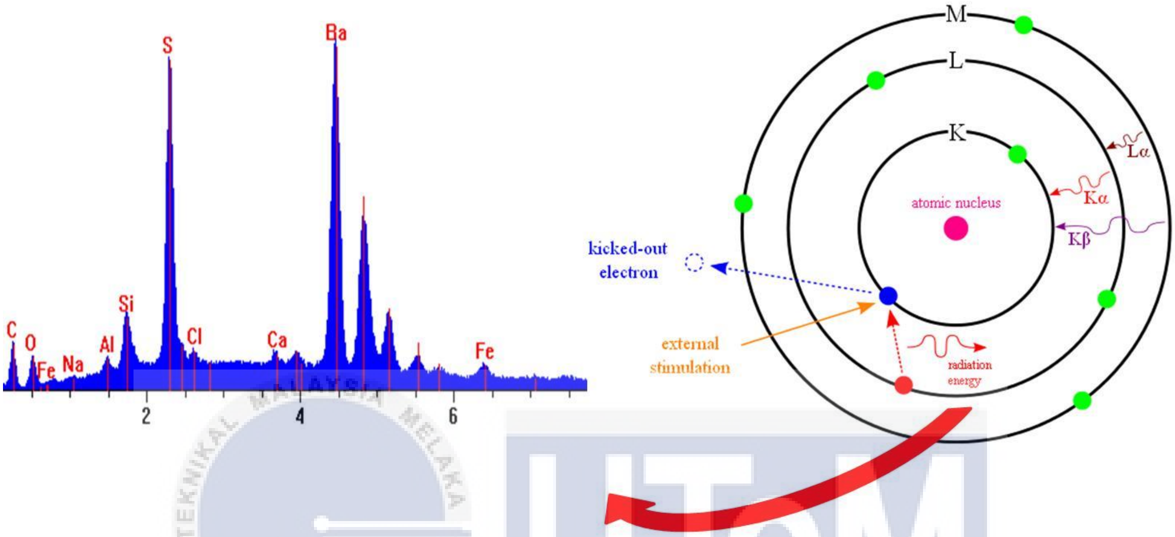


Figure 3.3.2 Working Principle for EDX

3.4 Sustainable Brick Development

Eco-brick were manufactured according to the conventional method adopted in industrial scale local brick manufacturing plant. The criteria of brick has been given from the industry as shown in Table 3.4. The process to develop eco-bricks has shown in Figure 3.4. To develop this brick need to done the process below such as crushing, ball milling, sieving, mixing, compaction, natural drying, and firing.

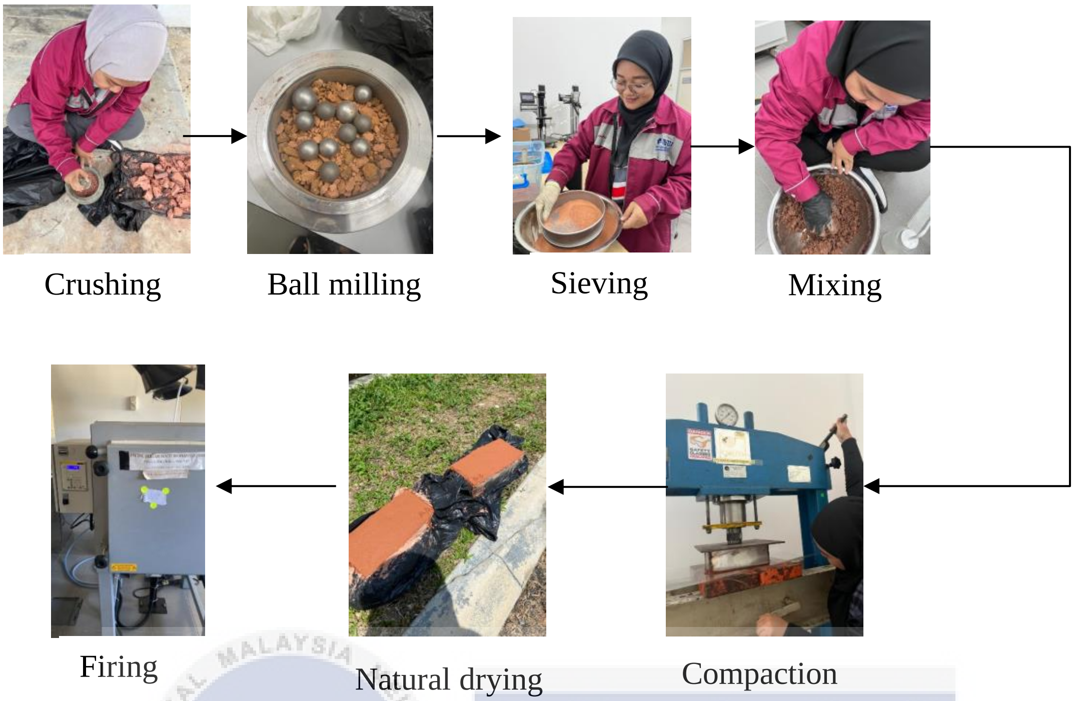


Figure 3.4 Eco-Brick Development Procedure

Table 3.4 Criteria Brick from Industry

	Dimension (mm)			Wt (kg)	Moisture Content (%)
	L	W	Ht		
Green	231 ±4	105 ±3	73 ±3	3.4 ±0.3	
Dried	225 ±4	103 ±3	71 ±3	2.7 ±0.3	17-23%
Fired	215 ±4	100 ±3	68 ±3	2.4 ±0.3	11-18%

3.4.1 Sieving

Before sieving process, the pure brick that have been take from the factory need to crush into small size then use Restech Ball Mill to grinding the clay brick until it become clay powder. After that, both powder clay and sludge need to seived with sieve diameters ranging 3mm to 5mm. The sieving stage in eco-brick development is a pivotal step focused on meticulously selecting and preparing raw materials with specific particle size requirements. This process is crucial for achieving uniformity in the brick composition and ensuring the overall quality and performance of the final product.

3.4.2 Mixing

Next, mixing process which is called Green condition by industry. The mixing stage in eco-brick development is aimed at achieving a homogeneous blend of the carefully sieved raw materials. After the sieving procedure ensures the desired particle size distribution, the materials, which may include treated sludge and clay are thoroughly combined to create a consistent brick mix. The mixing process can take place through compression. Moreover, The eco-brick composition were measured in weight basis to make different mixtures as in Table 3.4.2.Water is often added to attain the necessary plasticity and workability of the brick mix. This phase is essential not only for ensuring uniformity in the composition but also for promoting efficient bonding between the different components. The outcome of the mixing stage directly influences the performance and structural integrity of the eco-bricks. The mixture was then poured into industry scale moulds (112 mm × 235 mm × 75 mm). The brick were cast using mould and have pressure was applied over them.

Table 3.4.2 Sample formulation

Sample	Weight percentage of treated sludge (Wt%)	Weight percentage of Clay (%)	Treated Sludge, TS (%)
1	0	100	0
2	5	95	5
3	10	90	10
4	20	80	20
5	30	70	30
6	40	60	40
7	50	50	50

3.4.3 Drying

Once the brick mix is shaped into forms, commonly referred to as "green" bricks, these contain an excess of moisture. The brick were kept for sun-drying for 4 days under ±35˚C temperature. The drying stage aims to remove this excess water before the bricks undergo the firing process. Controlled drying is essential to prevent issues such as cracking and distortion in the bricks. During the drying process, the green bricks are exposed to controlled air circulation to gradually reduce their moisture content.This careful approach helps maintain the structural integrity of the bricks and ensures that they retain their desired shape and dimensions. Sustainable practices in this stage include optimizing the drying time and conditions to reduce energy consumption. Properly dried bricks are essential for achieving the necessary strength and durability in the final product, and this stage plays a significant role in preparing the bricks for the subsequent firing process.

3.4.4 Firing

The firing stage is a critical phase in sustainable brick development that transforms the dried, shaped bricks into a hardened, durable material. This process takes place furnace where the bricks are subjected to required temperatures, typically up to 900 degrees Celsius as shown in Figure 3.4.4. From the figure, it shown that the process ramps up temperature take for 2 hours to avoid the firing too fast. After 2 hours, it is getting up to 900 ˚C then it will be firing for 2 hours and naturally cooling process. The firing process induces chemical reactions within the brick composition, leading to vitrification—the fusion of particles and the creation of a solid, crystalline structure. This results in the development of key properties such as strength, hardness, and resistance to weathering.

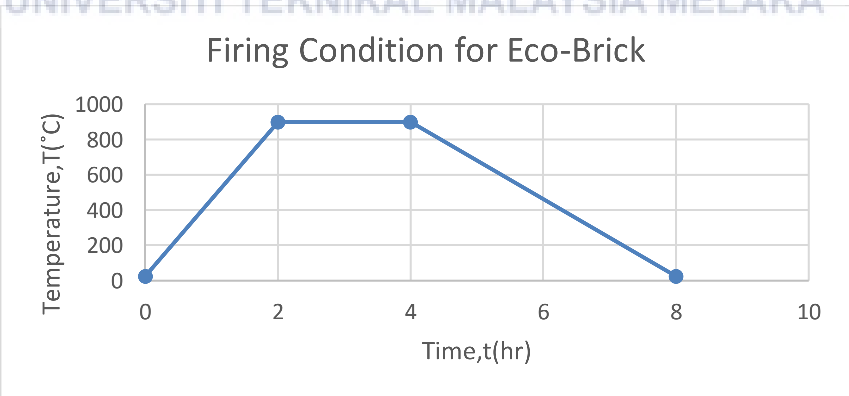


Figure 3.4.4 Firing Condition for Bricks

3.5 Compressive Strength Test

The brick's resistance to axial stresses and distortion during compression is determined by the compressive strength test. To make sure eco-bricks fulfil performance criteria as indicated in the Table 3.5, it is imperative that they undergo this test to assess their structural integrity and longevity. The SIRIM standard (Methods of Test for Masonry Units-Part 1: Determination of Compressive Strength Department of Standards Malaysia, 2007), the BSI Standards Publication Methods of Test for Masonry Units, 2011, and the BSI Standards Publication Specification for Masonry Units, 2016, are followed in conducting the compressive strength test. A representative sample of bricks is chosen for the test, and each brick is put in a testing apparatus that exerts compressive force progressively until failure happens. By dividing the greatest force that the brick experienced throughout this operation by its cross-sectional area, the compressive strength of the brick is determined. Optimising the mix design, fire procedure, and raw material selection to meet the required compressive strength while reducing environmental impact is a key component of sustainable brick development. The compressive strength test findings offer useful information for quality assurance, supporting ongoing development of sustainable brick formulas and production techniques.

Table 3.5 Compressive strength requirement from industry

	Strength N/mm^2
Minimum	**12.5**
Maximum	**13.5**
Average	**12.9**

3.6 Conclusion

This chapter started with collect the raw material and follow for the other step according to the flow chart. This chapter give the overview on how to handle the material and the details about the quantity that used in this study. It then went on to present a full critical assessment of the study process, including the challenges encountered through different phases. Methods and procedures for collecting and analysing data are then presented and explored.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter consists of all the results obtained from previous experiments. First, the investigation seeks to identify the elements that present in the treated sludge. This characterization of raw material is used XRF, SEM and EDX to determine the properties of treated sludge including morphology and the element according to Total Threshold Limit Concetration (TTLC). Next, justify the result of development Eco-Brick in term of amount of weight percentage that utilize, proportion of the mixture, condition of firing and weight of green, dried and firing eco-brick. Then, identify the materials compositional such TTLC element and morphology of the Eco-Brick through SEM and EDX.

4.2 Characterization of Raw Material (Treated Sludge)

From the result in Table 4.2.1, several heavy metals, including Chromium (Cr), Copper (Cu), Vanadium (V), and Zinc (Zn), have been found in treated sludge using X-ray fluorescence (XRF) testing. The amounts of these metals are 69 mg/kg, 267 mg/kg, 92 mg/kg, and 1493 mg/kg, respectively. When these data are compared to Department of Environment's (DOE) guidelines, it becomes obvious that the treated sludge meets environmental safety standards. This compliance indicates that sludge treatment techniques are effective in reducing heavy metal concentrations to levels regarded as safe for disposal or possible usage in applications such as soil supplements. However, the possibility of these metals accumulating in the environment over time must be considered. Continuous monitoring and adequate management procedures are required to prevent heavy metals from reaching dangerous levels over time, particularly in industrial contexts where sludge is regularly put into the atmosphere.

Table 4.2.1 XRF result analysis for treated sludge waste

Analysis TTLC: Heavy Metals	Result (mg/kg)	DOE Specification
Antimony (Sb)	ND	500
Arsenic (As)	ND	500
Barium (Ba)	ND	10000
Beryllium (Be)	ND	75
Cadmium (Cd)	ND	100
Chromium (Cr)	69	2500
Cobalt (Co)	ND	8000
Copper (Cu)	267	2500
Lead (Pb)	ND	1000
Mercury (Hg)	ND	20
Molybdenum (Mo) 3500	ND	350
Nickel (Ni)	ND	2000
Selenium (Se)	ND	100
Silver (Ag)	ND	500
Thallium (Ti)	ND	700
Vanadium (V)	92	2400
Zinc (Zn)	1493	5000

Note: Not Detected (ND)

The SEM image as shown in Figure 4.2 revealed that the treated sludge included irregular block-based particles with aggregated shape. This morphology was consistent with those commonly observed by Gencel (Gencel et al., 2020). In accordance with the particle size distribution, particles of various sizes were found (Kazmi et al., 2017). Energy-dispersive X-ray spectroscopy (EDX) was carried out to identify the elements present in the natural material studied. Table 4.2.2 shows the other elements that have in the treated sludge other than heavy metal that found in XRF analysis.

Table 4.2.2 Average EDX result for 3 week of treated sludge collection

ELEMENT	AVERAGE (Treated Sludge)		
	weight%	mg/kg	Atomic%
C	46.8	468000	56.77
N	5.40	54000	5.73
O	32.2	322000	29.7
Na	1.01	10100	0.64
Ai	6.00	60000	3.51
Si	0.40	14000	0.2
P	3.07	30700	1.47
S	2.40	24000	1.1
Ca	1.12	11200	0.4
Fe	1.96	19600	0.51

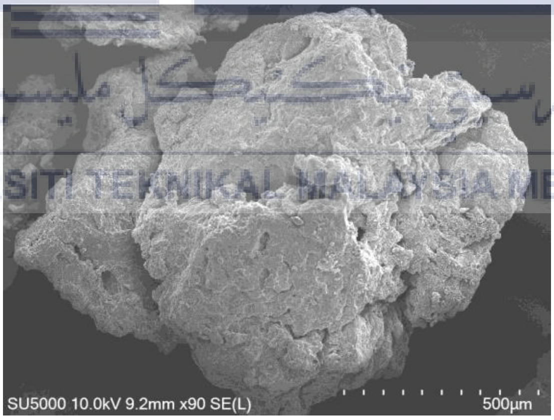


Figure 4.2 SEM treated sludge

4.3 Development of Eco-Brick

The composite development experiments show that achieving a solidly constructed product requires a precise balance of various factors such as sludge content, compaction pressure and burning conditions. Each sample's performance demonstrates the difficulty of optimising these variables. Samples with different sludge contents, exposed to varying compaction pressures and fire techniques, revealed results, from success to failure as shown in Figure 4.3. Analysing these findings assists in identifying the important causes of failures, revealing insight into the complex material qualities and processing conditions required to develop strong and dependable composite materials. The summary of nine (9) samples of eco-brick development is at Table 4.3.

Sample 1, which had a sludge content of 20wt% and was exposed to a compaction pressure of 30 bars, experienced failure due to the quick increase in temperature to 900˚C within a 30-minute timeframe. The quick growth in temperature likely resulted in thermal stress, leading to cracks or other structural problems before the material could sufficiently sinter (Wang et al., 2022). On the other hand, Sample 2, which had the same amount of sludge (20wt%) but was compressed at a lower pressure of 10 bars, was successful. The main distinction was in the regulated fire procedure, involving a progressive increase in temperature over a period of 2 hours to reach 900˚C, followed by a stable state phase. This allowed the material to slowly adapt to the high temperature and undergo correct sintering, resulting in a structurally robust composite.

Sample 3, which was comparable to Sample 2 in terms of the amount of sludge present and the firing circumstances, was likewise successful. However, Sample 3 was exposed to a greater compaction pressure of 30 bars. This suggests that, with the right firing regimen, it is possible to get the desired results with both lower and greater compaction pressures, if they are paired with the required amount of sludge. On the other hand, Samples 4, 5, and 6, which included 50wt%, 40wt%, and 30wt% sludge respectively, were all unsuccessful despites being exposed to the same high compaction pressure and controlled fire circumstances as the samples that were successful. Due to the presence of an excessive amount of sludge in these samples, the clay matrix's capacity to bind and support the structure was most likely disturbed, which resulted in insufficient sintering and ultimately led to the collapse of the structure.

Sample 7 was likewise unsuccessful, although having a lower sludge concentration of 10 weight percent and a high compaction pressure. This implies that even small levels of sludge could damage the structural integrity of the structure if the fraction exceeds the ideal threshold. This is likely due to inadequate binding within the clay matrix. The same thing happened with Sample 8, which had the lowest sludge concentration of all the samples that failed, although it only had 5 weight percent of sludge. It may be deduced from this that the incorporation of even minute quantities of sludge into the composite material could not result in an improvement in its structural qualities unless it is properly matched with other factors.

Finally, Sample 9, which was composed entirely of clay without any sludge, succeeded. This sample served as a control, reaffirming the effectiveness and reliability of traditional clay composites. It demonstrated that pure clay, when subjected to the same high compaction pressure and controlled firing conditions, maintains its structural integrity, providing a benchmark against which the sludge-incorporated samples were evaluated. The overall analysis suggests that while the integration of sludge into clay composites is feasible, it requires precise control and optimization of the sludge content, compaction pressure, and firing process. The successful integration of 20wt% sludge presents a promising avenue for sustainable material development, but only if the process parameters are meticulously managed to ensure the structural integrity of the final product.

The amount of moisture present in the material is an important factor in the production of eco-bricks(Koçyiğit, 2023) since it affects not only the material's capacity to work while it is being prepared but also the structural integrity of the finished product after it has been fired. When clay and treated sludge are mixed, the amount of moisture present in the mixture is what controls its plasticity and its capacity to be moulded (Y. Chen et al., 2020). Having the right amount of moisture in the mixture makes it possible to properly and evenly combine the components, which in turn makes it easier to combine the clay and the sludge. When there is insufficient moisture in the mixture, it might become excessively dry and difficult to deal with, which can result in an uneven distribution of sludge or insufficient binding between the particles. On the other hand, an excessive amount of moisture might cause the mixture to become excessively sticky, which can have an impact on the compaction process and perhaps result in an uneven density in the finished product.

In addition, the possible causes that might be failed the development of the eco-brick is the pressure imposed during the process of compaction has a significant impact on the density, strength, and overall structural integrity of eco-bricks, making it an essential component in their development. The density of the eco-brick will typically increase as the compaction strain on the eco-brick increases (Gund et al., 2023). This indicates that the particles of clay and sludge are packed closer together, which in turn reduces the quantity of voids or air pockets that are present inside the material. Porosity that is lower than average often results in increased mechanical strength and resistance to the infiltration of moisture, both of which are essential characteristics for eco-bricks that are designed for use in building. The compaction pressure is another factor that plays a role in determining how successful the firing process is. Because the particles that are compacted are less sensitive to change direction or distort when subjected to heat, eco-bricks that have been well-compacted tend to keep their shape and structural integrity better throughout the firing process. This helps to ensure that the sintering process, in which the particles combine to produce a material that is both solid and long-lasting, is carried out successfully.

Inadequate binding material can have a substantial influence on the development of eco-bricks, which can lead to a variety of problems throughout the production process and in the final product. Eco-bricks are often made by combining clay with other materials, such as sludge, to improve specific qualities or to make the product more environmentally friendly. If the amount of binding material in the mixture, such as clay, is insufficient, the eco-brick that is produced may not have the structural integrity that it should have. Clay functions as a binder, which forces the particles to remain together while they are being compacted and fired. In the absence of sufficient clay, the particles of other materials, such as sludge, could not cling exactly as they should. If this occurs, the brick may become more prone to cracking or breaking when subjected to force.

There is a possibility that insufficient binding substance will cause issues in the process of producing the brick during the compaction process. There is a possibility that the mixture may not compact evenly, which will result in an uneven density and weak places inside the brick. The overall strength and durability of the eco-brick may be negatively impacted because of this uneven compaction (Vaithiyasubramanian & Kanagarajan, 2021) . An insufficient amount of binding material might also affect the firing process. To complete the sintering process, which involves the fusion of particles at a high temperature, clay is an essential component. Without an adequate amount of clay, the eco-brick could not sinter correctly, which would result in a structure that is either porous or brittle after it has been fired. The capacity of the brick to endure environmental variables like weathering or mechanical stress decreases because of this.

Table 4.3 Summary of Composite Development

Sample	Mixing	Compaction	Natural Drying	Weight(kg)			Firing	Result
				Green	Fried	Fired		
1	• 20wt% sludge • 3.8kg clay + 0.95kg sludge • ±1.5ml water	±30bars=3MPa	About 4 days	3.4	2.78	-	30 min ramp up temperature to 900˚C, steady state 2 hours.	Fractured
2	• 20wt% sludge • 3.8kg clay + 0.95kg sludge • ±1.5ml water	±10bars=1MPa	About 4 days	3.34	2.72	2.16	2 hours ramp up temperature to 900˚C, steady state about 2 hours.	Non-fractured
3	• 20wt% sludge • 3.0kg clay + 0.95kg sludge • ±1.5ml water	±30bars=3MPa	About 4 days	3.5	2.74	2.05	2 hours ramp up temperature to 900˚C, steady state about 2 hours.	Non-fractured
4	• 50wt% sludge • 3.0kg clay + 3.0kg sludge • ±1.5ml water	±30bars=3MPa	About 4 days	3.45	2.73	-	2 hours ramp up temperature to 900˚C, steady state about 2 hours.	Fractured
5	• 40wt% sludge • 3.0kg clay + 2.0kg sludge • ±1.5ml water	±30bars=3MPa	About 4 days	3.60	2.75	-	2 hours ramp up temperature to 900˚C, steady	Fractured

							state about 2 hours.	
6	• 30wt% sludge • 3.0kg clay + 1.3kg sludge • ±1.5ml water	±30bars=3MPa	About 4 days	3.55	2.79	-	2 hours ramp up temperature to 900˚C, steady state about 2 hours.	Fractured
7	• 10wt% sludge • 3.0kg clay + 0.3kg sludge • ±1.5ml water	±30bars=3MPa	About 4 days	3.40	2.69	-	2 hours ramp up temperature to 900˚C, steady state about 2 hours.	Fractured
8	• 5wt% sludge • 3.0kg clay + 0.15kg sludge • ±1.5ml water	±30bars=3MPa	About 4 days	3.50	2.74	-	2 hours ramp up temperature to 900˚C, steady state about 2 hours.	Fractured
9	• 0wt% sludge • 3.0kg clay • ±1.5ml water	±30bars=3MPa	About 4 days	3.65	2.77		2 hours ramp up temperature to 900˚C, steady state about 2 hours.	Non-fractured

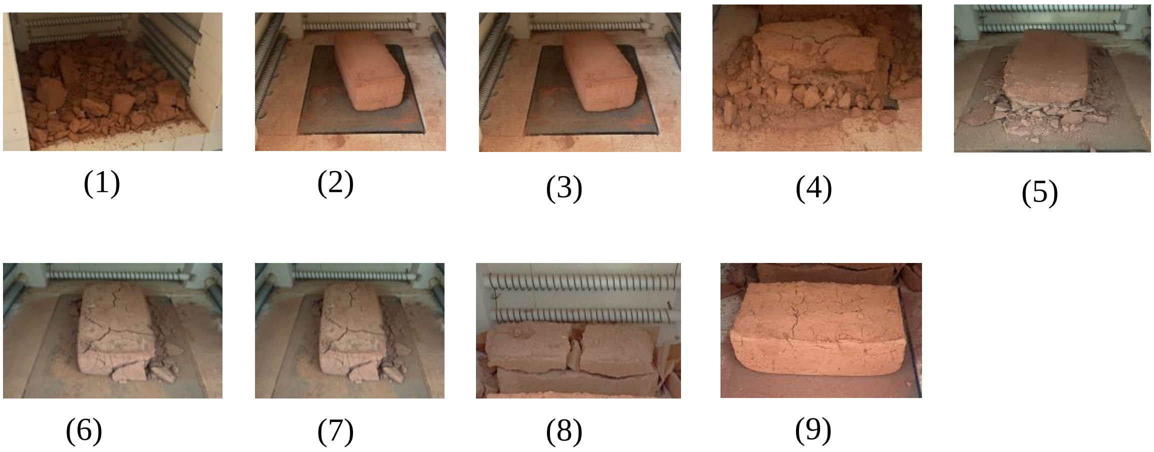


Figure 4.3 Structure condition of eco brick for nine (9) samples

4.4 Element Composition of Developed Eco-Brick According TTLC

Table 4.4 provides crucial information on the elemental composition of Eco-Brick Sludge at different weight percentages. This data is essential for comprehending and following the Total Threshold Limit Concentration (TTLC) recommendations established by regulatory agencies like the Department of Environment (DOE). The TTLC recommendations set limits on the highest allowable quantities of potentially dangerous compounds in materials designed for environmental purposes, such as eco-bricks (Martínez-Ángeles et al., 2022). The table offers extensive data on constituents such as Carbon (C), Oxygen (O), Aluminium (Ai), and Silicon (Si), allowing developers to evaluate if the sludge compositions fit these strict standards.

Moreover, Table 4.4.1 shows that there are no measurable amounts of TTLC heavy metals element as shown in Table 4.4.2, suggesting that these dangerous elements are present in quantities that are too small to be detected. The reason for this absence can be attributed to the exceptional quality of source materials, a precise and regulated production procedure, and a careful selection of additives and binders that are devoid of any heavy metals. The advantages of this are significant: from a sustainability perspective, the Eco-Bricks do not release harmful compounds, ensuring their safety for diverse uses without causing harm to the environment. From a health standpoint, they do not pose any risk to workers or residents, hence preventing long-term exposure to hazardous substances. Adhering to DOE criteria guarantees that the Eco-Bricks satisfy regulatory standards, making them suitable for use in construction projects. Moreover, the utilization of non-toxic substances is following sustainable construction methods, thereby promoting the advancement of environmental structures. At last, the market benefit is evident, as these Eco-Bricks can be positioned as a safer and more sustainable substitute for traditional bricks, attracting environmentally aware consumers and builders.

Figure 4.4 indicates a clear trend of increasing weight percentage of Carbon, rising from 12.93% at 0 wt.% to 21.6% at 5 wt.% and 29.13% at 10 wt.% for collection of sludge batch 1. while the raising trend also happen for collection sludge batch 2 which is 20.07% at 20 wt.% and 29.07% at 30 wt.% as shown in Figure 4.4. This implies that greater concentrations of sludge in the eco-bricks result in elevated levels of Carbon content. The trend shows an important variation based on the sludge content, which might impact the characteristics of the material, such as its ability to burn and its stability. The oxygen content is very consistent throughout a wide range of sludge concentrations, with only small variations being detected. Oxygen, for instance, has a range that goes from 42.93% to 50.70%, reflecting a very small amount of variance in comparison to other elements. This stability is essential because the amount of oxygen present might influence the bonding of materials and the interactions with the environment.

For instance, regulation limitations for aluminium (Al) in eco-bricks can be defined to save the environment from pollution or to protect people from potential health concerns(Alasfar & Isaifan, 2019). With the use of this data, it is possible to analyse compliance across a variety of Eco-Brick Sludge compositions, identifying whether the concentrations fall within the permitted parameters that are set by TTLC regulations. Not only is this evaluation essential for ensuring compliance with regulations, but it is also essential for improving the formulations of eco-bricks. It is possible to optimise production procedures to minimise or eliminate components that could violate TTLC restrictions by gaining an understanding of the elemental composition at various weight percentages. This will ensure that eco-bricks are both ecologically safe and sustainable.

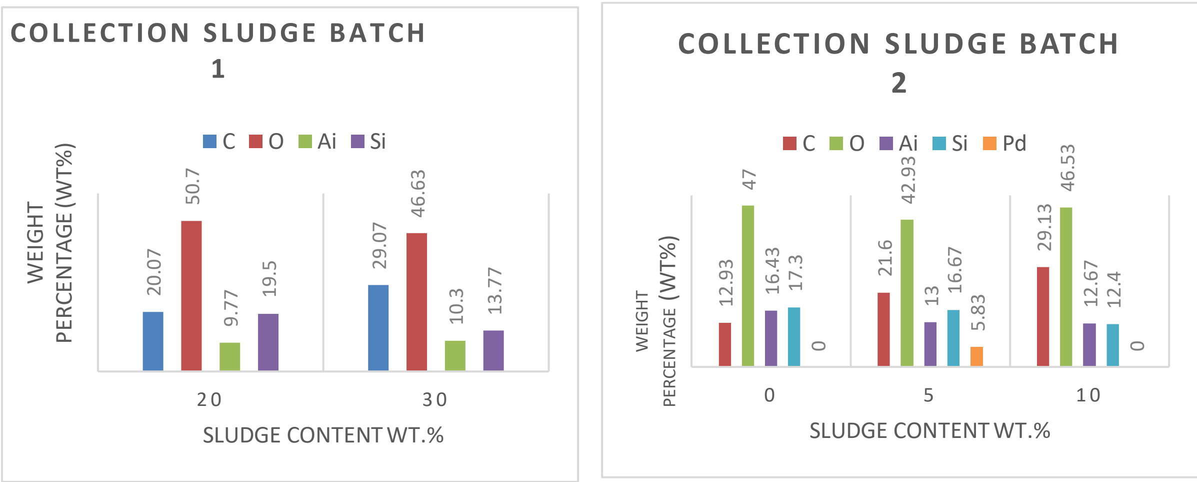
Table 4.4.1 Elements composition in Eco-Brick Sludge

ELEMENT	Eco-Brick Sludge, wt%									
	0wt%		5wt%		10wt%		20wt%		30wt%	
	wt.%	**mg/kg**	**wt.%**	**mg/kg**	**wt.%**	**mg/kg**	**wt.%**	**mg/kg**	**wt.%**	**mg/kg**
C	12.93	129300	21.60	216000	29.1	291300	20.07	200700	29.1	290700
O	47.00	470000	42.93	429300	46.5	465300	50.70	507000	46.6	466300
Ai	16.43	164300	13.00	130000	12.7	126700	9.77	97700	10.3	103000
Si	17.30	173000	16.67	166700	12.4	124000	19.50	195000	13.8	137700
Pd	0.00	0	5.83	58300	0	0	0.00	0	0	0

Table 4.4.2 TTLC Element Detection

Analysis TTLC: Heavy Metals	Result (mg/kg)	DOE Specification
Antimony (Sb)	ND	500
Arsenic (As)	ND	500
Barium (Ba)	ND	10000
Beryllium (Be)	ND	75
Cadmium (Cd)	ND	100
Chromium (Cr)	ND	2500
Cobalt (Co)	ND	8000
Copper (Cu)	ND	2500
Lead (Pb)	ND	1000
Mercury (Hg)	ND	20
Molybdenum (Mo)	ND	350
Nickel (Ni)	ND	2000
Selenium (Se)	ND	100
Silver (Ag)	ND	500
Thallium (Ti)	ND	700
Vanadium (V)	ND	2400
Zinc (Zn)	ND	5000

Note: Not Detect (ND)



(a) (b)

Figure 4.4 Eco-Brick element composition for (a) collection sludge batch 1 (b) collection sludge batch 2

4.5 Compressive Strength

Beginning with a composition without sludge (0% sludge, 100% clay), the material demonstrates a substantial maximum load capacity of 167595.3 N and a compressive strength of 7.87 N/mm². On the other hand, as the sludge concentration rises to 20% alongside 80% clay, there is a significant decrease in both the maximum load capacity, which drops to 3808.91 N, and the compressive strength, which decreases to 0.18 N/mm². This trend demonstrates a distinct inverse correlation between the amount of sludge present and the mechanical durability of the mixture. The observed decrease in maximum load capacity and compressive strength with increasing sludge concentration indicates that sludge is not as efficient as clay in enhancing the structural integrity of the material. This can be due to variables such as the physical characteristics of sludge, which may not possess the same amount of cohesiveness or load-bearing capacity as clay.

This trend demonstrates a distinct inverse correlation between the amount of sludge present and the mechanical durability of the mixture. The observed decrease in maximum load capacity and compressive strength with increasing sludge concentration indicates that sludge is not as efficient as clay in enhancing the structural integrity of the material. This result also same as previous study (Zari et al., 2023) .This can be due to variables such as the physical characteristics of sludge, which may not possess the same amount of cohesiveness or load-bearing capacity as clay. Furthermore, the non-linear characteristic of this association implies the existence of thresholds or critical points in sludge content, at which even little alterations result in significant reductions in mechanical qualities. Comprehending these patterns is essential for applications where the material's ability to withstand pressure is of utmost importance, as it guides judgments on the best combination of clay and sludge in mixes designed for structural or load-bearing purposes. Additional research might investigate alternative compositions and experimental circumstances to authenticate and enhance these discoveries, yielding a further understanding of the behaviour of clay-sludge mixes in real-world engineering and construction scenarios.

The maximum compressive strength of 7.87 N/mm² found in the study's observed results is far less than the maximum strength value of 12.7 MPa reported by the reference industry. There are several possible reasons for this variation. For starters, there's a chance that the reference company's raw materials and this study's raw materials have different qualities and characteristics. Changes in the mineral content, sludge and clay purity, and particle size distribution could harm the mixture's overall mechanical strength(Zhang et al., 2022). Furthermore, variations in the mixing procedure may have a significant impact. The combined use of sludge and clay, involving factors such as the duration of mixing, the level of homogeneity achieved, and the inclusion of any added substances or agents, can exert an important impact on the resultant strength of the product. Insufficient blending or the lack of necessary additions may lead to a less robust substance. Another potential factor is the process of curing. The reference firm may employ precise curing conditions, including controlled temperature and humidity levels, to enhance the mechanical qualities of the mixture. Insufficiently strict or optimized curing conditions in this study may result in a decrease in compressive strength.

Moreover, the ratio of sludge in the mixture is a crucial influence. Our findings demonstrate that higher sludge content has a substantial negative impact on compressive strength. There is a possibility that the amount of sludge in our mixtures exceeds the optimal level set by the reference firm, which may result in the material becoming weaker (H. J. Chen et al., 2022). Ultimately, the reason for the lower compressive strength we saw in our findings, in comparison to the value provided by the reference business, can be related to variations in the quality of raw materials, the methods used for mixing and curing, the presence of sludge, the procedures employed for testing, and the possibility of microstructural flaws. To attain compressive strength values closer to the industry standard of 12.7 MPa, it is crucial to address these variables by carefully controlling and optimising the production process

Table 4.5 Compressive strength of Eco-Brick

Sample	Sludge (Wt.%)	Clay (wt.%)	Maximum Load, F(N)	Compressive Strength (N/mm^2)
1	0	100	167595.3	7.87
4	20	80	3808.91	0.18

4.6 Summary

In this chapter, this chapter provides a comprehensive examination of the compressive strength of Eco-Bricks that incorporate treated sludge. It also highlights interesting findings about the mechanical performance of these bricks. According to the findings of the study, which involved a detailed assessment of a variety of sludge compositions, there was an obvious loss in compressive strength as the sludge concentration increased. Bricks with a higher clay content displayed improved mechanical qualities, highlighting the function that clay plays as an efficient binder. Sludge-containing bricks were found to have higher carbon levels, which indicated the presence of organic stuff, according to the results of an elemental analysis. When it comes to the creation of Eco-Bricks, these results highlight the difficulty of striking a balance between the environmental advantages and the structural integrity. To make progress in the development of sustainable brick formulations, it is essential to optimise the ratio of sludge to clay, carry out detailed toxicity evaluations, and investigate alternative binders.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Conclusion

The primary aim of the investigation was to figure out the precise elements found in the treated sludge, including any potentially dangerous chemicals. The objective was effectively accomplished by conducting an extensive investigation utilizing XRF and EDX techniques. The XRF examination yielded extensive information regarding the levels of heavy metals in the processed sludge, indicating the existence of potentially dangerous elements such as Chromium (Cr), Copper (Cu), Vanadium (V), and Zinc (Zn). Significantly, the findings indicated that all detected heavy metals were present in amounts that were below the permissible limits set by the Department of Environment (DOE). This discovery suggests that the processed sludge does not present a notable threat to the environment or human health in relation to the presence of heavy metals. In addition, the EDX analysis provided information about the chemical composition of the sludge, which further confirmed the existence of important elements. As a result, it provides evidence for the feasibility of utilising the sludge in the creation of environmentally friendly bricks. Accurate detection and measurement of these constituents guarantee the safety of the substance for future progress and utilisation, adhering to regulatory guidelines regarding the presence of heavy metals.

The study intended to create environmentally friendly bricks by using treated sludge, with a maximum weight percentage of 50%. The study explored several combinations of materials to accomplish this objective. Although the construction of bricks with different levels of sludge content was accomplished effectively, the findings revealed considerable difficulties, especially when using higher percentages of sludge. Bricks containing sludge 20 wt.% exhibited potential since formulations that met the required criteria had acceptable structural integrity. However, efforts to include a higher amount of sludge, specifically 50 wt.%, continually led to failure, suggesting that such high amounts of sludge degrade the mechanical stability and performance of the bricks. Thus, although the study made some progress by successfully creating sustainable bricks containing up to 20 wt.% sludge, additional improvements, and fine-tuning are required to produce bricks that are fully functional with even greater sludge levels.

The study accomplished its goal of assessing the toxicity level of the sustainable bricks that were created, using EDX analysis. The EDX analysis revealed the absence of any ingredients that are generally regulated under TTLC standards in the eco-bricks that were created. This discovery indicates that the eco-bricks have no presence of any toxic substances that could potentially cause harm to the environment or human health, hence verifying their safety in compliance with TTLC regulations (Koppula et al., 2023). Thus, the eco-bricks that have been created not only showcase the sustainable utilisation of treated sludge but also guarantee adherence to toxicity regulations, providing them with a feasible and environmentally aware building material.

The analysis successfully examined the compressive strength of sustainable bricks made from treated sewage. Through experimentation with several formulas containing varying amounts of sludge, it was proven that higher sludge concentration had a substantial negative impact on the compressive strength of the bricks. Bricks that included no sludge had a much higher compressive strength of 7.87 N/mm^2, whereas bricks containing 20% sludge had a considerably lower compressive strength of 0.18 N/mm^2. The strong association seen between the amount of sludge and the compressive strength of the bricks offers useful information about the mechanical characteristics of the bricks. This highlights the difficulties in preserving the structural stability when using increasing fractions of sludge. The extensive data collected provides a strong basis for optimising the composition of eco-friendly bricks to achieve a balance between environmental advantages and mechanical efficiency. Table 5.2 show the summary of result that relate to all objectives.

Table 5.1 Summary of results based on all objective

Objective	Result
1. To identify the specific components that present in the treated sludge including any hazardous substances.	Treated sludge was examined for harmful compounds. Chromium, Copper, Vanadium, and Zinc were found in the sludge using XRF and EDX. These metals were below DOE guidelines, posing no environmental or health risks. EDX analysis showed essential constituents, proving sewage may be used to make eco-friendly bricks.
2. To develop sustainable bricks using up to 50 wt.% of treated sludge.	Treatment sludge at 50% weight was used to make eco-friendly bricks. Despite effective construction, the study showed issues, especially with greater sludge percentages. Mechanical stability decreases crushed 20% sludge bricks at 50%. Fully functioning bricks with greater sludge levels require further refinement.
3. To analyse the toxicity level of the developed sustainable brick as referred to Total Threshold Concentration (TTLC)	The study used EDX to determine sustainable brick toxicity. It detected no TTLC-regulated substances in the eco-bricks, assuring safety and toxicity compliance. This shows the sustainable usage of treated sludge and creates an ecologically friendly construction material that meets TTLC criteria.

4. To investigate compressive strength of the developed sustainable brick	The study found that increasing sludge content decreased sustainable sewage-treated brick compressive strength. Bricks with 20% sludge were weaker than those without. For eco-friendly bricks, the research advises optimising sludge content for environmental and mechanical efficiency.

5.2 Recommendation

To encourage the development and use of sustainable bricks using treated sludge, future studies should prioritize four crucial approaches. Primarily, it is crucial to enhance the sludge content in brick compositions. This study examined various proportions of sludge, ranging from 0% to 50%. However, future research should focus on investigating intermediate ratios, specifically between 25% and 40% sludge, to determine the right balance between environmental sustainability and mechanical strength. Simultaneously, it is crucial to extend the range of toxicity analysis. Although hazardous substances in treated sludge have been detected, it is essential to conduct a thorough evaluation, including Total Threshold Concentration (TTLC) testing on the bricks made from the sludge, to determine their potential environmental impact and ensure compliance with safety regulations throughout their lifespan.

Furthermore, it is crucial to conduct long-term durability studies to assess the long-term performance of sustainable bricks in various environmental circumstances, including degradation, moisture exposure, and heat cycling. These studies will confirm their suitability for practical use and offer an understanding of their long-term structural durability. Investigating alternate binding agents or additives is another encouraging approach. Exploring natural additives, polymers, or other materials has the potential to improve the mechanical characteristics of bricks with increased sludge content (Jagadeshwaran & Sundravel, 2019). This would help reduce any adverse impact on compressive strength and expand their usefulness in construction attempts.

Also, it is necessary to conduct a thorough Life Cycle Assessment (LCA) to assess the complete environmental consequences associated with the production, utilisation, and disposal of sustainable bricks derived from treated sludge. This comprehensive method will offer a strong comprehension of their sustainability qualifications in comparison to traditional building materials, facilitating well-informed decision-making in construction processes. Finally, it is necessary to investigate the feasibility, cost-effectiveness, and flexibility of implementing treated sludge to scale up production processes for Eco-Bricks. To promote the widespread adoption and integration of these environmentally friendly building materials into mainstream construction processes worldwide, it is crucial to tackle logistical obstacles, ensure market acceptance, and comply with regulatory requirements. Future studies can make major contributions to the advancement of sustainable construction materials, the support of environmental conservation efforts, and the promotion of sustainable development goals by tackling these research topics.

5.3 Sustainability Element

This research refers to numerous critical aspects of sustainability, beginning with waste use. By using treated sludge, a scheduled waste, in brick manufacturing, the study drastically decreases reliance on conventional clay. This strategy not only diverts sludge from landfills, which helps to manage the rising solid waste problem, but it also repurposes sludge as a valuable resource, enhancing the circular economy.

The smaller carbon footprint gained by lowering clay reliance, as well as possible energy savings, demonstrate the reduced environmental effect. The study's complete toxicity tests verify that the created bricks fulfil environmental requirements by detecting and controlling dangerous chemicals in the sludge. This encourages the use of safer and more sustainable construction materials, in line with worldwide initiatives to decrease greenhouse gas emissions and battle climate change.

Economic and social sustainability will also be addressed. Using treated sludge, which is commonly seen as a waste product, can reduce the material costs involved with brick manufacture, making sustainable bricks more economically viable and accessible. Adoption of these approaches may boost local economies by producing jobs in waste management, brick manufacture, and other businesses, as well as establishing local knowledge in sustainable construction.

Finally, the study promotes building material innovation by creating eco-bricks, so encouraging a move toward more sustainable construction techniques. This breakthrough promotes the use of green materials with reduced environmental consequences, which aligns with the construction industry's overall sustainability goals and paves the way for future developments in sustainable building materials.

5.4 Lifelong Learning Element

First and foremost, this study emphasizes the significance of ongoing education and professional growth in environmental engineering and material sciences. Professionals in the sector may continuously enhance their methods by staying up to date on the newest breakthroughs in waste management and sustainable materials, ensuring they are effective and relevant in solving modern environmental challenges. This research promotes continuous education on the qualities and prospective applications of treated sludge, hence encouraging its safe and efficient use in building. Furthermore, this study highlights the importance of adaptive learning and creativity. As new difficulties and possibilities emerge in the field of sustainable building, it is critical to stay flexible and open to new ideas. This includes continually upgrading research techniques, resources, and technology to reflect the most recent breakthroughs and best practices. For example, when the characteristics of treated sludge and its interactions with clay are more known, further research might improve brick formulas to maximize both environmental advantages and mechanical performance.

5.5 Complexity Element

This complexity is centred on the variable composition of treated sludge, which varies greatly depending on its source and treatment procedures. This variation makes it difficult to achieve consistent material qualities and anticipate the performance of the bricks. Furthermore, the presence of potentially hazardous substances in sludge needs extensive compositional analysis and strict adherence to environmental standards to assure the safety and regulatory compliance of the produced bricks. Mechanically, integrating sludge changes the compressive strength and durability properties of the bricks, necessitating careful optimization of the sludge-to-clay ratio to combine environmental advantages with structural integrity. The burning process, which is critical in brick manufacture, adds a degree of complexity due to possible emissions and the requirement for emission control methods to successfully manage environmental and health concerns.

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APPENDICES

Appendix A

PROJECT ACTIVITIES															
	PSM 1														
	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PSM 1															
Confirmation topics								M							
Identify objective and problem statement								I							
Literature review								D							
Methodology of study								S							
Collect raw material from industry								E							
Hazardous Characterization								M							
Preparation report writing PSM 1:															
1) Chapter 1: Introduction								B							
2) Chapter 2: Literature								R							
3) Chapter 3: Methodology								E							
Poster presentation								A							
Submission Report								K							

Appendix B

PROJECT ACTIVITIES	PSM 2														
	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PSM 2															
Lecture Series								M							
Material Preparation								I							
Hazardous Characterization								D							
Eco-Brick Development								S							
Compressive Strength								E							
Material Compositional Analysis								M							
Analysis Data															
Submission Logbook								BR							
Presentation Week								EK							
Submission Report															