STRENGTH CHARACTERISTICS OF MORTAR INCORPORATING CHEMICAL ADDITIVES AND BROWN GLASS WASTE AS A PARTIAL SUBSTITUTE FOR SAND

ARAVINDA REDDY A/L THIAKARAJAN

UNIVERSITI TUNKU ABDUL RAHMAN

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ARAVINDA REDDY A/L THIAKARAJAN

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

September 2024

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature :

Name : Aravinda Reddy A/L Thiakarajan

ID No. : 2006150

Date : 16 September 2024

APPROVAL FOR SUBMISSION

I certify that this project report entitled **“STRENGTH CHARACTERISTICS OF MORTAR INCORPORATING CHEMICAL ADDITIVES AND BROWN GLASS WASTE AS A PARTIAL SUBSTITUTE FOR SAND”** was prepared by **ARAVINDA REDDY A/L THIAKARAJAN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours at Universiti Tunku Abdul Rahman.

Approved by,

Signature :

Supervisor : Ir Dr Lim Jee Hock

Date : 16 September 2024

ABSTRACT

This research focuses on addressing the impact of using brown glass powder as a partial sand replacement in cement mortar, in response to environmental concerns and resource depletion. The study investigates how varying concentrations of chemical additives affect the compressive strength, microstructure, and water absorption of the mortar with brown glass powder to optimize its performance. By exploring the effects of different chemicals and concentrations, it aims to understand how these factors influence both the fresh and hardened properties of mortar treated with brown glass waste. Brown glass waste was substituted for sand at 0%, 25%, 50%, 75%, and 100% and treated with Hydrochloric Acid (HCl), Calcium Hydroxide ($Ca(OH)_2$), and Calcium Nitrate ($Ca(NO_3)_2$) in concentrations of 0.05 M and 0.1 M. The mortar samples were subjected to flow table test, compression test, water absorption test, Scanning Electron Microscopy (SEM) analysis and Energy Dispersive X-ray (EDX) analysis. Results demonstrated that replacing sand with up to 25% glass powder, combined with 0.05 M Calcium Nitrate, yielded the highest compressive strength. The SEM analysis revealed that higher glass powder content reduced microstructural cracks and pores when incorporating Calcium Hydroxide and Calcium Nitrate. However, when incorporating Hydrochloric Acid, it negatively affects the microstructure of the mortar. The findings of this study suggest that the mortar incorporating 0.05 M Calcium Nitrate with 25% brown glass waste is the most optimal combination with the highest compressive strength, optimal workability, and lower water absorption.

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μm	micrometre
A	cross-section area of concrete tube specimen, mm^2
F	compressive strength of the specimen, kN/mm^2
M_1	initial mass of the dry specimen
M_2	mass of the specimen after water absorption
P	maximum load applied to the concrete cube specimen, kN

C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_3S	Tricalcium Silicate
C_4AF	Tetracalcium Aluminoferrite
$Ca(NO_3)_2$	Calcium Nitrate
$Ca(OH)_2$	Calcium Hydroxide
Cl^-	Chloride
C-S-H	Calcium Silicate Hydrate
EDX	Energy-Dispersive X-Ray
H^+	Hydrogen
HCl	Hydrochloric Acid
HF	Hydrofluoric Acid
HVFA	High-Volume Fly Ash
OPC	Ordinary Portland Cement
pH	Potential of Hydrogen
PPE	personal protective equipment
PU	Polyurethane
SEM	Scanning Electron Microscope
SEM-EDX	Scanning Electron Microscopy with Energy Dispersive X-Ray
SO_3	Sulphate
UV	Ultraviolet
W/C	water-cement ratio

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Building construction has changed into a complex and ever-evolving field that shows technological advances, green building practices, and new ideas in architecture. Concrete is an integral part of the world and is used in almost all modern buildings. It is the material of choice for everything from buildings to modest pavements due to its adaptability, longevity, and affordability.

Global problems with overflowing dumps and environmental damage make waste management a severe issue. Because of its unique qualities and possibility for recycling, glass stands out among the many types of waste. Firstly, glass production requires the extraction of raw materials such as sand, soda ash, and limestone (Ebert, 2023). Sand, the primary component of glass, is extracted at an alarming rate, leading to habitat destruction and erosion of coastal ecosystems. Similarly, the extraction of soda ash and limestone contributes to landscape alteration, biodiversity loss, and groundwater contamination. The consequences of resource depletion extend beyond environmental degradation.

Furthermore, there are multiple ways in which waste glass impacts the economy. Glass waste collection, transportation, and disposal cost municipalities a lot of money (Jacoby, 2019). Glass producers see their production costs rise due to the escalating depletion of natural resources caused by non-recycling. In addition, the recycling industry needs to take advantage of the opportunity to generate income and create jobs due to the unrealized economic potential of recycled glass.

Other than that, waste glass poses problems for society at large that go beyond economic and environmental concerns. The quality of life of communities is diminished due to unattractive waste and safety issues caused by inadequate waste management procedures. The unequal distribution of glass recycling facilities may worsen environmental justice issues, which may disproportionately negatively impact populations who are already socially underprivileged.

1.2 Importance of the Study

Recycling glass is a significant part of glass waste management that helps reduce the use of sand. According to Islam, Rahman, and Kazi (2017), using waste glass in cement as a partial substitution for cement will significantly enhance the development of environmentally friendly, economical, and promote sustainable infrastructure systems.

Glass waste management is one of the challenges that continues to be a consistent problem in Malaysia. The significance of doing this study lies in the abundance and easy accessibility of waste glass, particularly in areas characterized by high glass consumption and recycling rates. Disposal of broken glass, bottles, and containers in landfills can contaminate soil and water, harm wildlife, and diminish the aesthetic value of landscapes, among other environmental harms. Exploring waste glass as a substitute for sand for applications such as construction has been considered an environmentally friendly alternative.

Using waste glass reduces the necessity for extracting natural sand, aiding in the conservation of natural resources. A significant advantage of this study is that waste glass can be efficiently and inexpensively utilized as a substitute for sand, resulting in cost savings for construction companies.

The use of this waste glass in the construction industry can effectively promote the adoption of sustainable practices. Investigating the feasibility of utilizing waste glass as a construction material promotes ingenuity and enhances the comprehension of eco-friendly construction methods. It can potentially foster the creation of novel methodologies, benchmarks, and guidelines for integrating recycled materials into construction activities.

1.3 Problem Statement

Waste glass powder in replacement of sand in mortar significantly affects the fresh and hardened properties of the mortar. According to Anwar (2016), the compressive strength of cement mortar with the minimum compressive strength by incorporating waste glass powder to a certain percentage has been increased compared with conventional mortar without glass powder. In another study, according to research by Degirmenci et al. (2011), the compressive strength decreased as the proportion of glass powder to sand increased compared to smaller percentages. This can happen because of the variations in concentration and particle sizes of waste glass. Unlike sand particles, glass powder does not have irregular shapes. For this research, incorporating chemicals into mortar may help to improve the fresh and hardened properties of mortar. Parameters such as workability and compressive strength of the resulting mortar must be determined for the feasibility and potential benefits of utilizing chemical additives and brown glass powder in construction applications.

The microstructure of mortar containing glass powder exhibits a more consistent internal structure post-hydration, characterized by enhanced compactness and minimal pores and microcracks, as observed by Zhao et al. (2022). Incorporating chemical additives may not adequately help bonding to generate calcium silicate hydrate (C-S-H), which can weaken the final product. This has shown that the microstructure of mortar is directly affected by the waste glass particles and chemical additives. Few studies have investigated the impact of chemical additives and brown glass powder on cement mortar microstructure. This research intends to address that need by examining how chemical additives and brown glass powder affect the microstructural characteristics of cement mortar.

A study by A Kustirini, None Antonius and P Setiyawan (2022) have found that the concentration of sodium hydroxide plays a significant role in determining the compressive strength of concrete. Chemical treatments are often influenced by the specific concentration levels used. Despite this, there remains a research gap in understanding how varying concentrations of these chemicals impact the physical properties of mortar. This research gap poses a challenge for optimizing treatment processes to achieve the optimal combinations of types and concentrations of chemical additives that improve the overall performance of the cement mortar. To address this problem, obtaining a deeper understanding of how different concentrations of chemicals affect various properties of mortar is crucial. This includes its compressive strength, microstructural characteristics, and overall durability. Without this knowledge, it is difficult to adjust treatment methods to enhance the performance of the mortar. The research must, therefore, focus on exploring the relationship between chemical concentration, percentage of glass powder, and mortar properties to improve the efficiency of treatment processes and ensure optimal outcomes.

1.4 Aim and Objectives

The aim of this project is to examine the fresh and microstructure properties of cement mortar with chemical additives and brown glass waste as a partial substitute for sand.

The objectives are:

(i) To investigate the effects of chemical and brown glass waste on the fresh and hardened properties of cement mortar.

(ii) To assess how the varying concentrations of chemical and brown glass waste as partial sand replacement through the microstructure of cement mortar.

(iii) To determine the optimal combinations of types and concentration of chemical additive that improve the overall performance of the cement mortar.

1.5 Scope and Limitation of the Study

This study aims to research the strength characteristics of cement mortar with chemical additives containing brown glass powder as a partial substitute for sand. This study focuses on substituting sand with 0%, 25%, 50%, 75%, and 100% of brown waste glass and treating it with chemical additives. The selection of bottles for this investigation was based on their brown colour. Cement powder, sand, brown glass powder and water with chemical additives will be used to cast mortar. There will be 270 samples of mortar cube specimens, which are 50 mm x 50 mm x 50 mm, that will be cast for the research. The mortar will be chemically treated by diluting mixing water using three chemical types, which are Hydrochloric Acid (HCl), Calcium Hydroxide ($Ca(OH)_2$), and Calcium Nitrate ($Ca(NO_3)_2$). These samples will be tested with different concentrations, which are 0.05 M and 0.1 M. Subsequently, all the samples will be produced with the optimal blend ratio of 1:5:1.24 and subjected to a curing period of 7 and 28 days. Compressive tests were performed to evaluate the material properties of the mortar cube specimens after 7 days and 28 days.

Additionally, the water absorption test was performed to evaluate the durability of the mortar, as excessive water absorption can cause degradation over time. After that, the 28-day mortar specimen was used for microstructural and elemental composition testing using Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX) machine. Nevertheless, the aspect of this study concerns preparing the raw materials, particularly for the brown glass powder. Grinding the glass powder into a particular size is a challenging task. The brown glass powder must be below 4.75 mm, as the grinder used for manufacture is not a professional apparatus. As a result, human error may occur, leading to a lack of accuracy in the given dimension.

Nevertheless, it is critical to recognize the constraints of this research, including the proportion of sand replacement, the chemicals and amount of chemicals that will be diluted, the mix ratio of cement mortar, the particle size of waste glass powder, the colour of the bottles used, and the bottle type used. This study has limitations in collecting data for sand replacement percentages outside the range of 0%, 25%, 50%, 75% and 100%. Also, limitations in collecting data for sand replacement percentages that are not within the range of the selected cement mortar mix ratio of 1:5:1.24 may not be the most suitable mixture for this application.

1.6 Contribution of the Study

This study presents an alternative way of substituting sand with brown colour glass powder and adding chemical additives to the mortar mix. This practice has not been widely adopted in Malaysia. Using brown waste glass powder as a partial replacement for sand in various construction applications provides significant benefits regarding ecological responsibility and resource efficiency. To begin with, the worldwide construction sector is among the primary users of natural resources, such as sand. The extraction of sand, a significant part of concrete and mortar, occurs at unsustainable rates. It will result in environmental degradation, loss of ecosystems and aggravation of issues. Consequently, alternative materials to must be investigated to diminish the reliance on natural sand.

Furthermore, properly managing waste glass is significantly difficult for local government. Conventional approaches to glass disposal, such as burying it in landfills or burning it, are not only harmful to the environment but also not economically efficient. By utilizing waste glass as a replacement for sand in mortar mixes, a significant quantity of glass beyond landfills and generate a valuable secondary resource can be efficiently redirected.

The manufacturing process of conventional construction materials requires significant energy usage. A more energy-efficient manufacturing process can be achieved by incorporating brown glass waste into the mortar mixture. This study investigates the capacity of this new approach to conserve energy, which aligns with worldwide endeavours to diminish carbon footprints in the construction sector.

Ultimately, substituting waste glass for a portion of the sand contributes to mitigating environmental issues. This ecologically sustainable approach is advantageous for both the construction and environmental sectors.

1.7 Outline of the Report

This study is divided into five chapters. The first chapter introduces the importance and problems of using chemical additives and brown glass waste in construction projects. This chapter provides a discussion of the problem statement, aim and objectives, and the contributions of the study.

After that, chapter two is focused on the literature review, specifically examining the materials used and the experimental work conducted in this project.

Furthermore, chapter three explores the methods for adding chemical additives and substituting brown glass waste in mortar. The discussion extensively covered the mix proportion and test methods, including the compressive strength test, water absorption test and SEM-EDX analysis for mortar specimens.

Moreover, chapter four is focused on presenting and analysing the data obtained from the experimental study. The data collected was analysed using tables, Figures, and graphs, and the findings are provided in written format.

Chapter five includes a comprehensive conclusion and summary of the research, along with recommendations for incorporating chemical additives and waste glass powder as a partial substitute for sand in future construction projects.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The growing human population has greatly increased the demand for natural resources, especially in the construction industry. Experts are concerned as the competition for these finite resources has escalated over time. To separate resource use from its environmental impacts, significant changes in global resource management will be required, relying on innovations that encourage more sustainable use of resources (United Nations Environment Programme International Resource Panel, 2011). The incorporation of waste materials in mortar production has been extensively investigated in recent literature. Researchers have explored waste materials such as fly ash, silica fume, slag, and recycled aggregates as partial substitutes for conventional ingredients like sand and cement. Several investigations have been conducted on using glass waste powder as an alternative to sand in concrete production. Despite the growing interest in sustainable construction materials, limited research has been conducted on the strength characteristics of chemically treated mortar incorporating brown glass waste.

Thus, there is a research gap in the existing literature regarding the mechanical properties, microstructural behaviour, and long-term performance of such mortars. Addressing this gap is essential for promoting the widespread adoption of chemical additives as a viable supplementary material in mortar production. Several factors may influence the results of these studies, including the type of chemical and chemical concentration used to treat mortar. Further research in these areas may help identify the optimal conditions for the beneficial use of chemical additives in making chemically treated mortar.

Next, cement, chemicals, sand, and water are the essential raw materials that is considered to produce cement mortar. The potential benefits and limitations of incorporating brown glass waste in mortar mixtures can be identified through comprehensive experimental analysis and evaluation of its effects on the properties of the mixture. By contributing to the knowledge base in this field, our research endeavours to advance sustainable construction practices and facilitate the effective utilization of waste materials in the built environment.

2.2 Mortar

Mortar, composed of sand, water, and binding agents like cement or lime, stands as an unsung hero in construction, quietly but indispensably holding together the fabric of the built environment. The connective tissue binds building blocks and bricks into sturdy, resilient structures, providing structural integrity and cohesion. By creating a strong bond between individual building elements, mortar prevents collapse or deterioration over time, ensuring stability and longevity. Additionally, mortar is crucial in distributing loads and stresses throughout a structure, evenly dispersing weight and pressure to prevent cracks or failures (Thamboo et al., 2019). Beyond its structural functions, mortar contributes to the aesthetics of a building, influencing its visual appeal through colour, texture, and finish.

Moreover, mortar provides waterproofing and weatherproofing properties, protecting interior spaces from moisture infiltration and external elements (Suryakanta, 2017). Its versatility allows customization to suit specific construction requirements, with different combinations of ingredients tailored to achieve desired properties such as strength, durability, and workability. Specialized mortars may be used in seismic zones or marine environments to address unique challenges. Mortar is the backbone of construction, quietly supporting the edifices of human ingenuity with its structural, aesthetic, and functional contributions.

2.3 Raw materials for mortar

Mortar, a vital component in construction, typically comprises cement, sand, water, and optional additives like plasticizers or accelerators. Cement acts as the binder, while sand fills the gaps and provides bulk. Water activates the cement, forming a paste that binds the other components together (Lavagna and Nisticò, 2022). Additives can enhance specific properties like workability or curing time. Additionally, aggregates such as crushed stone or gravel may be included to bolster strength. Adjusting the proportions of these raw materials allows for customization to suit various applications and performance requirements in construction projects. However, some replacements were made to those raw materials. This research included a new material, brown waste glass, to replace sand. Many research studies supported this suggestion.

2.3.1 Cement

The type of cement most frequently used for buildings is Ordinary Portland Cement (OPC). Production begins with grinding clinker, which contains mainly calcium silicates with a small proportion of other compounds, including calcium sulphate. The ingredients that go into making it are gypsum, clay, iron ore, and limestone (Korkmaz, 2019). It is mainly constituted of four major compounds, which are Tricalcium Silicate (C_3S), Dicalcium Silicate (C_2S), Tricalcium Aluminate (C_3A), and Tetracalcium Aluminoferrite (C_4AF) (Lea, 2024). Ordinary Portland Cement acts as a binder when mixed with water. It forms a workable and resistant paste, serving as the primary construction material for building structures, roads, and infrastructural works. Its wide application has made it the mainstay of modern construction, enabling the growth of cities and industrialization.

2.3.2 Sand

Sand used for mortar is typically a fine aggregate with grains between 0.075 mm and 4.75 mm in size. It is often composed of quartz, silica, or limestone particles, though the specific composition. The sand should be clean and free from organic material, debris, and excessive clay content, as these impurities can weaken the mortar and hinder its bonding properties. It is often sourced from natural deposits, such as riverbeds or quarries, or it can be manufactured through processes like crushing and screening (Přikryl, 2021). The proportion of sand to cement in mortar mixtures can be adjusted according to the task and desired result.

2.3.3 Water

The quality of the water used to mix mortar determines the durability and strength of mortar. Typically, drinking water is suitable for mixing mortar. Using water that is too hard or contains high levels of impurities like salts or organic matter can adversely affect the setting time, workability, and, ultimately, the strength of the mortar.

It is essential to use the right amount of water in mortar mixtures. Too much water can weaken the mortar, while too little water can make it challenging to work with and compromise its bonding properties (Judd et al., 2023). The water content in mortar mixtures should be adjusted based on factors like the type of cement and aggregates being used, environmental conditions, and the desired consistency of the mortar.

2.3.4 Brown Glass

Brown glass possesses distinctive physical, chemical, and mechanical properties. Amber glass is produced by melting a combination of iron, sulfur, and carbon, which is then incorporated into the molten mixture (AGI glaspac, 2021). Its characteristic brown colour is achieved through the addition of iron oxide during the manufacturing process. This colouration not only provides ultraviolet (UV) protection but also enhances its aesthetic appeal. Additionally, brown glass exhibits excellent resistance to corrosion, making it ideal for packaging applications (Finney, 2021). Its density, thermal conductivity, and mechanical strength vary depending on composition and manufacturing methods. Traditionally, brown glass has been widely used in the packaging industry for beer bottles, pharmaceutical containers, and food jars.

2.3.5 Chemicals

Chemically treated mortar with chemical solutions enhances its reactivity and pozzolanic properties, making it suitable for mortar production. Chemicals are categorized based on their composition, structure, and properties. This includes organic, inorganic, and organometallic compounds, elements, and alloys. This research uses chemicals such as Hydrochloric Acid, Calcium Hydroxide, and Calcium Nitrate to chemically treated the mortar with various concentrations by diluting the chemical in water that be used to make mortar.

Firstly, Calcium Hydroxide is a compound with the chemical formula $Ca(OH)_2$. It is a white, powdery substance that forms when calcium oxide reacts with water (Stewart, 2023). Calcium Hydroxide is a strong base and reacts readily with acids to form salts and water. It is sparingly soluble in water, meaning it dissolves only to a limited extent, resulting in a slightly alkaline solution. It has many applications, including in cement production, as a pH regulator in water treatment, preparation of ammonia, and various chemical processes. Calcium Hydroxide is used in various construction applications, including as a mortar binder, in soil stabilization, and the production of lime plaster and lime wash (García-Vera et al., 2020). For this research, it will be used to chemically treat the mortar at various concentrations. Figure 2.1 illustrates the Calcium Hydroxide.

Figure 2.1: Calcium Hydroxide ($Ca(OH)_2$).

Secondly, Calcium Nitrate is a chemical compound with a $Ca(NO_3)_2$ formula. In construction, Calcium Nitrate can be used as a concrete accelerator, typically in cold weather conditions where faster setting times are desired (Kičaitė, Pundienė and Skripkiūnas, 2017). By accelerating the hydration process of cement, Calcium Nitrate helps concrete reach its desired strength more quickly. This can be advantageous in construction projects with tight timelines or cold climates where conventional concrete may take longer to cure. This research will chemically treat the mortar at various concentrations. Figure 2.2 shows the Calcium Nitrate.

Figure 2.2: Calcium Nitrate ($Ca(NO_3)_2$).

Hydrochloric Acid (HCl) is a binary compound consisting of hydrogen and chlorine. It is a colourless to slightly yellowish liquid with a pungent odour. Its pure form is highly soluble in water, and its aqueous solution is known as Hydrochloric Acid. When combined with water, HCl completely decomposes into hydrogen ions (H^+) and chloride ions (Cl^-), making it a strong acid (Libretexts, 2019). This high acidity gives HCl its corrosive properties, making it helpful in cleaning, pickling, and pH adjustment in industrial processes. It is a common acid used in titration experiments to determine the concentration of basic solutions. HCl is also used to lower the pH of solutions in laboratory procedures and experiments. It is a reactant in various chemical reactions carried out in laboratory settings. In the construction industry, hydrochloric acid is used to remove efflorescence and mineral deposits from concrete surfaces (Lab Pro, 2023). In this research, the mortar will be treated at various concentrations. Figure 2.3 illustrates the Hydrochloric Acid.

Figure 2.3: Hydrochloric Acid (HCl).

2.4 Previous Research about the Use of Waste Glass Powder as Sand Replacement in Mortar

Nyantakyi et al. (2020) conducted a study focusing on using glass bottle powder as a substitute for cement in concrete applications. The research explored the effects of replacing ordinary Portland cement with green, brown, white, and mixed-coloured waste glass bottle powder in varying proportions of 30%, 50%, and 70% during the mixing process. The concrete cubes were placed in curing tanks and left to cure for 7 and 28 days to assess the strength and durability of the different mixtures. Overall, four distinct types of concrete mix proportions were prepared and tested to evaluate the feasibility and performance of utilizing glass bottle powder as a partial replacement for cement in concrete technology. Figure 2.4 shows the slump test result of the concrete mix.

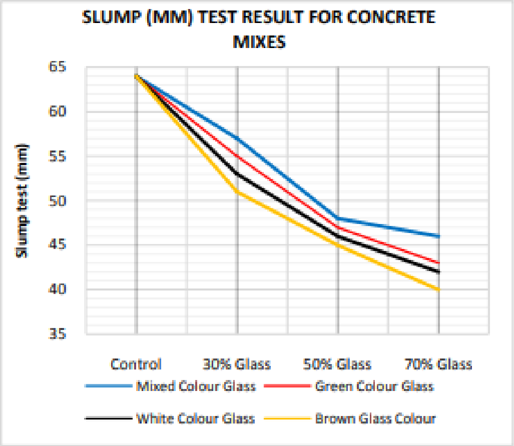


Figure 2.4: Slump test for concrete mixes (Nyantakyi et al., 2020).

One of the studies included the slump test, which was done with different mixes. According to Nyantakyi et al., the 30%, 50%, and 70% slump values for both mixed and single-colour glass concrete were slightly lower than the values for the control concrete mix that did not have any glass powder. Using a larger amount of glass bottle powder in the concrete mix could be the cause of the decrease in slump values. Furthermore, it was observed that slump values were greater in mixed-colour glass bottle concrete than in single-colour glass bottle concrete at all ratios. This provides more evidence that the pozzolanic characteristics of glass are affected by its colour. Chemical admixtures used to add colour to the glass mixture were another factor that affected the slump test. The dry density of the mixtures after 7 days and after 28 days are shown in Figures 2.5 and 2.6, respectively.

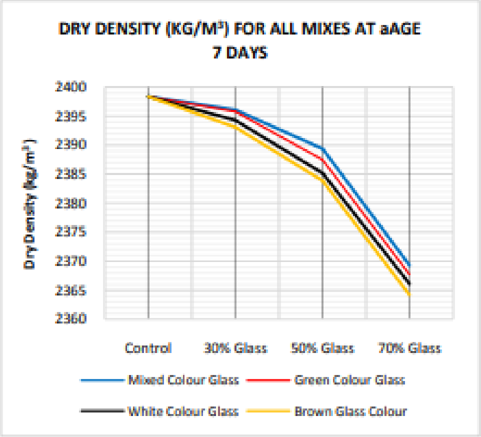


Figure 2.5: Dry density for mixes at 7 days (Nyantakyi et al., 2020).

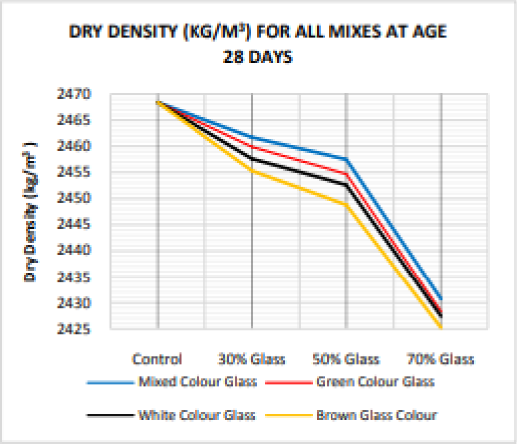


Figure 2.6: Dry density for mixes at 28 days (Nyantakyi et al., 2020).

Nyantakyi et al. (2020) observed that the dry density of the concrete mix decreased as the amount of glass bottle powder in the mix increase, in comparison to the control mix that did not contain any glass bottle powder. This pattern persisted throughout the 7-day and 28-day curing periods.

Glass bottle concrete mixes, both single-colour and mixed colour, had lower dry densities than the control mix. It also had a lower unit weight than the control mix made from powder from a glass bottle. The findings demonstrated a gradual increase in the dry density measurements of the concrete mixtures throughout the period of 7 to 28 days of curing. In contrast to single-colour concrete, mixed-colour glass concrete demonstrated significantly greater density values in the glass concrete ratio of 30% after curing for both 7 and 28 days. In general, the concrete mixture with mixed-colour glass showed more beneficial outcomes compared to the concrete mixture with single-colour glass. Figure 2.7 shows the percentage of water absorption at 28 days.

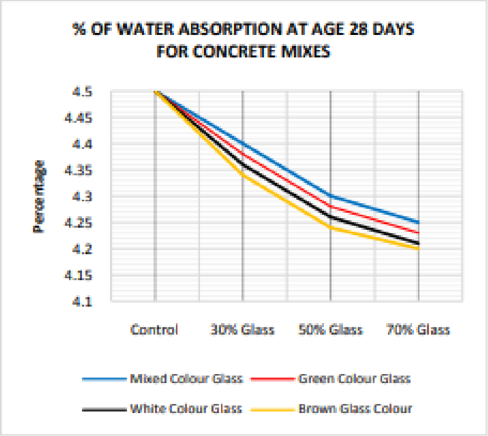


Figure 2.7: Percentage of water absorption at 28 days (Nyantakyi et al., 2020).

The study found that by incorporating different proportions of glass bottle powder into concrete (30%, 50%, and 70% partial replacement), there was a decrease in water absorption compared to concrete without any glass (0% glass). The concrete lacking glass powder showed the highest water absorption, while the one with 70% glass powder substitution exhibited the lowest. This can be attributed to water and cement paste loss during curing and a reduction in average pore size.

In Tan and Du (2013) study, they explored the use of waste glass as a replacement for sand in mortar. They replaced fine aggregates with varying percentages of waste glass particles (0%, 25%, 50%, 75%, and 100%), using four types of glass sand which are brown, green, clear, and mixed colour. They found that fresh density decreased as the proportion of glass sand increased, due to the lower specific gravity of glass compared to natural sand. The colour of the glass had no noticeable effect on fresh density.

Furthermore, they observed a decrease in compressive strength at 7 and 28 days for mortar with glass sand, attributed to the smoother surface and sharper edges of glass particles, leading to weaker bonding. Among the glass colours tested, green glass sand mortar showed the least reduction in compressive strength, while clear glass sand mortar exhibited the most significant decrease, possibly due to micro-cracks formed during crushing. Figures 2.8, 2.9 and 2.10 show the results of the test.

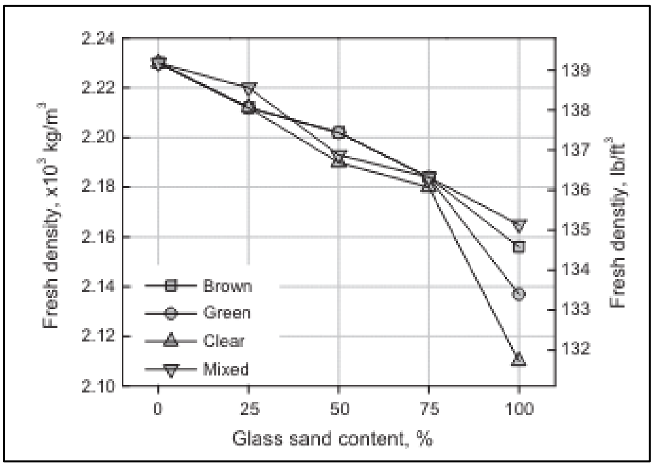


Figure 2.8: Fresh density of glass sand mortar (Tan and Du, 2013).

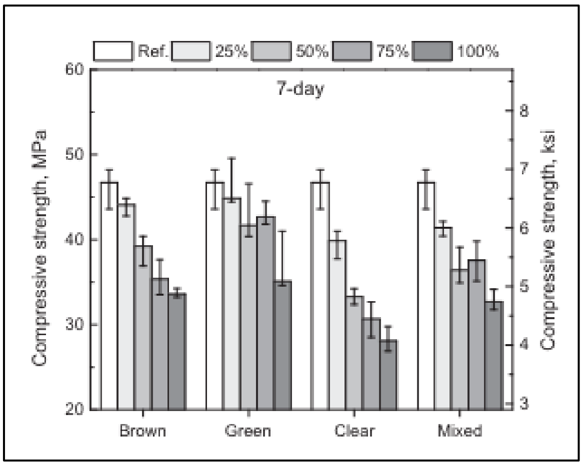


Figure 2.9: Compressive strength of the 7 days of the glass sand mortar (Tan and Du, 2013).

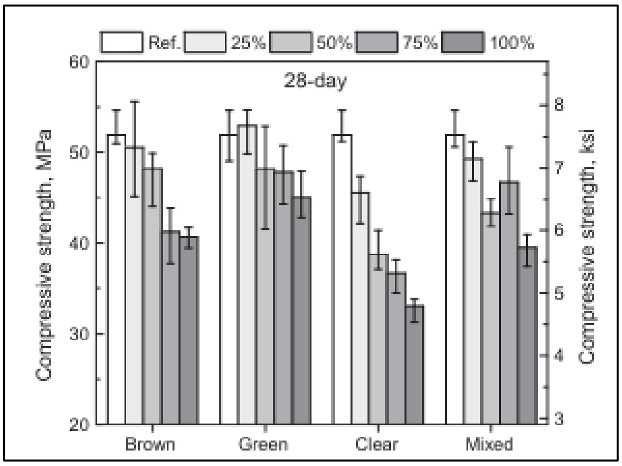


Figure 2.10: Compressive strength of the 28 days of the glass sand mortar (Tan and Du, 2013).

In previous research conducted by Joener et al. (2023), the impact of adding Calcium Hydroxide to high-volume fly ash (HVFA) mortar and concrete was investigated to enhance the properties of these mixtures. The study focused on mixtures where fly ash replaced 50% and 60% of Portland cement by mass. Calcium Hydroxide was introduced in powder form to react with class C and F fly ash present in the concrete, with the aim of improving the performance of the material. The research experimented with varying amounts of Calcium Hydroxide, adding it at 10%, 20%, and 30% of the fly ash content by mass. Figure 2.11 shows the results for the compressive strength of High-Volume Fly Ash (HVFA) with Calcium Hydroxide.

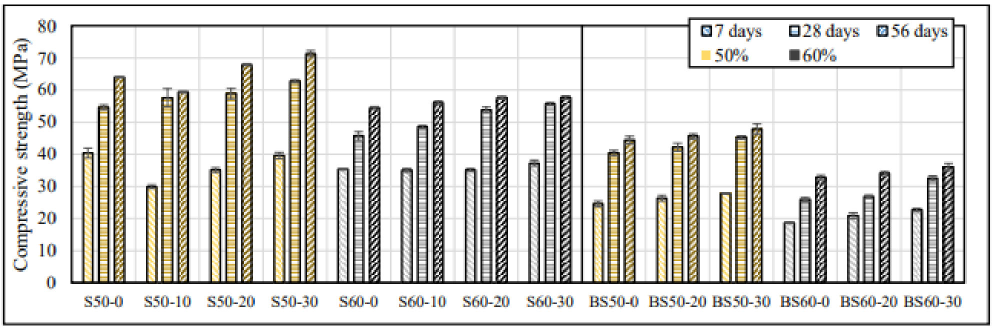


Figure 2.11: Compressive strength of High-Volume Fly Ash (HVFA) with Calcium Hydroxide (Joener et al., 2023).

Initially, it was found that the early-stage compressive strength at seven days did not significantly change with the addition of Calcium Hydroxide. This was due to the relatively slower pace of the pozzolanic reaction, which occurs between fly ash and Calcium Hydroxide, compared to the faster hydration reaction of cement. However, a significant increase in compressive strength was observed between 7 and 28 days for both HVFA mortar and concrete. This increase was attributed to the inclusion of Calcium Hydroxide, which enhanced the pozzolanic reaction over time.

Despite the benefits in strength, the addition of Calcium Hydroxide affected the workability of the mixtures. As more Calcium Hydroxide was added, the demand for superplasticizer increased to maintain the desired workability, indicating that the mixtures became less fluid. This adjustment was necessary to counteract the reduced slump, which measures the workability of the concrete. Figure 2.12 shows the results for the initial setting time of High-Volume Fly Ash (HVFA) with Calcium Hydroxide.

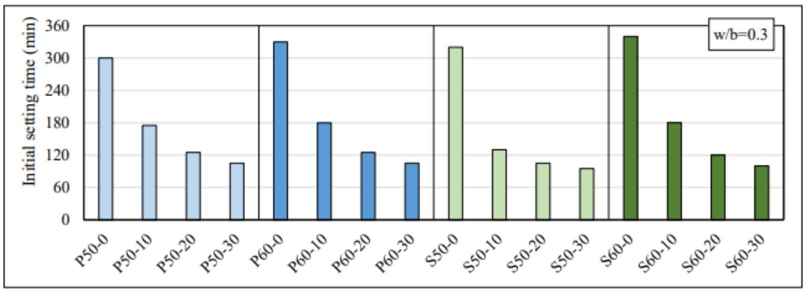


Figure 2.12: Initial Setting Time of High-Volume Fly Ash (HVFA) with Calcium Hydroxide (Joener et al., 2023).

Furthermore, the presence of Calcium Hydroxide significantly accelerated the initial setting times for both mortar and concrete. Lower initial setting time directly affects the workability for both mortar and concrete (Hindustan Infrastructure Solution, 2024). A higher proportion of Calcium Hydroxide corresponded to faster initial setting times which also means that it has lower workability.

In a study conducted by Abubakar, Muazu, and Attah (2020), the researchers explored the effects of Hydrochloric Acid (HCl) on the compressive strength of concrete at early ages. They investigated concrete specimens with a grade 20 mix, which were submerged in 5% and 10% HCl solutions 24 hours after casting. The compressive strength of these specimens was evaluated at various intervals which are 1, 2, 3, 7, 14, 21, and 28 days of curing in the acidic solutions. For comparison, control specimens cured in water were also tested for compressive strength at the same intervals. Figure 2.13 shows the Mean Compressive Strength of concrete specimen.

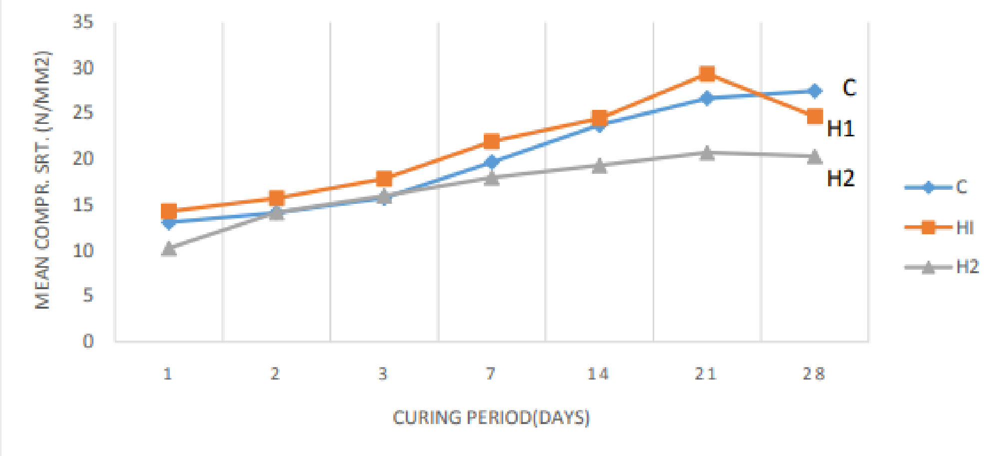


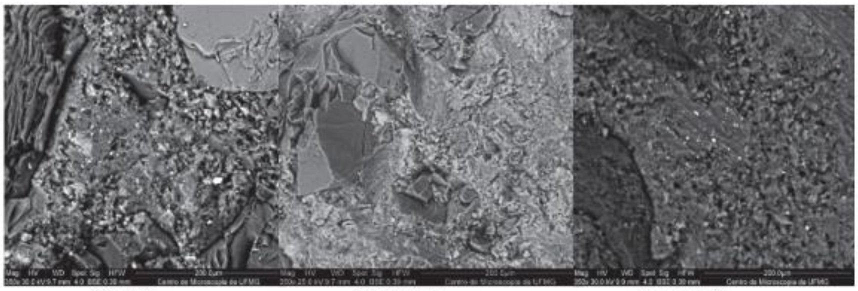
Figure 2.13: Mean Compressive Strength of concrete specimen (Abubakar, Muazu and Attah, 2020).

The findings revealed that the compressive strength of the concrete specimens exposed to a 5% HCl solution increased up to 21 days of curing. This increase suggests that in the early stages of exposure, the lower concentration of acid might facilitate some beneficial reactions, possibly involving the densification of the concrete matrix or the development of acid-resistant compounds. However, beyond the 21 days, the strength of the concrete began to decline significantly, particularly at 28 days. This indicates that prolonged exposure to the acidic environment eventually led to the deterioration of the concrete matrix, compromising its structural integrity.

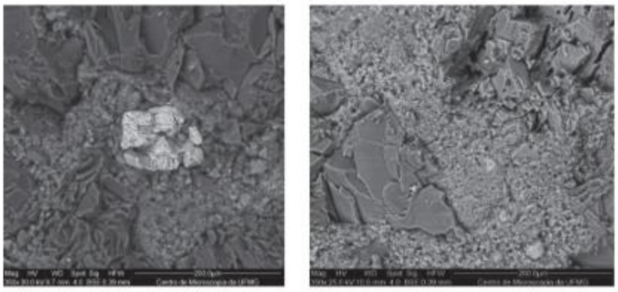
In contrast, concrete samples exposed to the 10% HCl solution exhibited a marked decrease in compressive strength throughout the testing period, particularly evident by the 28-day measurement. The higher concentration of HCl likely accelerated the degradation process, undermining the material's durability and structural capacity much earlier.

Based on these results, the researchers concluded that normal strength concrete, particularly at early ages, is unsuitable for environments where it may be exposed to HCl concentrations of 5% or higher. Such exposure can lead to premature degradation and failure of the concrete, posing significant risks in structural applications. The study highlights the importance of considering chemical exposure in the design and application of concrete structures to ensure long-term durability and safety.

In another study, Sales et al. (2017) examined the impact of glass powdered particles on the durability of mortar. The investigation was to replace 10% and 20% of the cement in Portland cement mortars with colourless, amber soda-lime glass particles, each measuring about 9.5 μm. Remarkably, the study discovered that mortars containing glass particle replacements showed smaller crystals and a lower Calcium Hydroxide content than mortars composed entirely of cement, even though there were no glass particles observable in the paste. This was related to the pozzolanic reaction, indicating possible advantages for the strength of the compound. Energy-Dispersive X-Ray (EDX) analysis of the magnified pictures revealed no appreciable variations in the size of the sodium hydroxide crystals. Figure 2.14 presents images obtained through Scanning Electron Microscopy (SEM).



Glass 0% Colorless 10% Colorless 20%



Amber 10% Amber 20%

Figure 2.14: Scanning electron microscopy images of mortar samples with 0%, 10%, and 20% of colourless and amber glass powder (Sales et al., 2017).

2.5 Summary

In a nutshell, sand can be replaced with waste glass because of its unique qualities, including strong compressive strength, durability, and workability. With the help of chemical additives, mortar quality with glass waste powder has improved. By keeping waste glass out of landfills and lowering the demand for sand extraction, using waste glass as a partial replacement for sand can help lessen the environmental impact of construction activities. To find the ideal amount of glass to use and the types of chemicals and concentrations to use, it is essential to test and assess the performance of the finished product. The amount of glass used will depend on the individual application and the properties of the glass.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter used a flow chart to demonstrate the work plan. The process for making chemically treated mortar with Hydrochloric Acid (HCl), Calcium Hydroxide ($Ca(OH)_2$), and Calcium Nitrate ($Ca(NO_3)_2$) with different concentrations, including 0%, 25%, 50%, 75%, and 100% brown glass powder treated as a partial sand replacement, was discussed. First, the chemicals and raw materials were prepared. Then, the chemicals were diluted in mixing water. The materials were then combined with the new specimen. After that, the property was subjected to Fresh Properties Testing. It was then cast, cured, and demoulded. Tests for hardened properties, such as compression and water absorption, were conducted on the mortar of 50 mm × 50 mm × 50 mm. The Scanning Electron Microscopy (SEM) machine was also used to test the properties of the specimen.

3.2 Flow chart of the Study

Figure 3.1 shows the design flow chart for the investigation of the strength characteristics of chemically treated mortar with Hydrochloric Acid (HCl), Calcium Hydroxide ($Ca(OH)_2$), and Calcium Nitrate ($Ca(NO_3)_2$) with different concentrations and using 0%, 25%, 50%, 75%, and 100% brown glass powder as a partial replacement for sand.

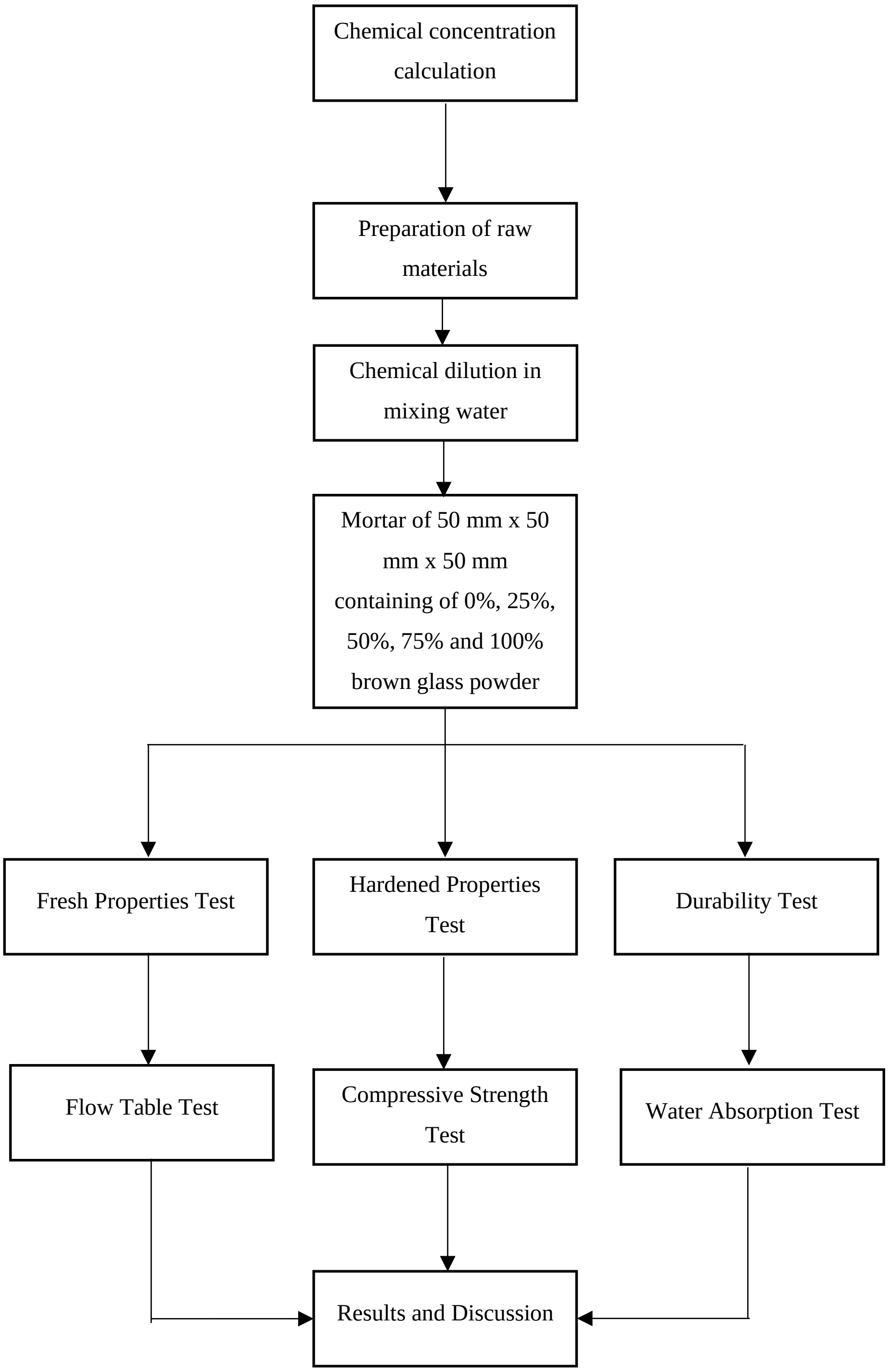


Figure 3.1: Design flow chart.

3.3 Equipment

There are number of equipment that used in this project such as crusher, grinder, sieving machine, flow table test cone, compression testing machine, Scanning Electron Microscope machine.

3.3.1 Crusher

The crusher used in this project is shown in Figure 3.2. It is a standard method to make a solid mix of raw materials easier to work with by crushing it into smaller pieces. A crusher was used to crush the brown glass bottles for this project.

Figure 3.2: Crusher.

3.3.2 Grinder

Figure 3.3 shows the grinder used in this project. For this project, the grinder turns pieces of brown glass into powder.

Figure 3.3: Grinder.

3.3.3 Sieving Machine

Figure 3.4 shows the sieving machine used in this project. It was used to agitate the sand and glass powder to sort particles of different sizes mechanically. The particles could remain on the surface or pass over a mesh surface based on size.

Figure 3.4: Sieving Machine.

3.3.4 Weighing Machine

Figure 3.5 shows the scale used in this project. The scale was used to determine how much the mortar specimens weighed for this project. The weighing machine used a digital display to show the mass.

Figure 3.5: Weighting Scale.

3.3.5 Flow Table Test Apparatus

Figure 3.6 shows the flow table test cone used in this project. The workability of the mortar specimen was determined using a flow table test equipment.

Figure 3.6: Flow Table Test Cone.

3.3.6 Compression Test Machine

Figure 3.7 shows the compression test machine from UTAR. The machine measured the compressive strength of mortar of 50 mm × 50mm × 50mm after 7 days and 28 days. It works by mounting a specimen in fixtures and gradually increasing compressive force until it fails. The applied force that caused the specimen to fail was taken during the test, and the data was recorded for analysis.

Figure 3.7: Compression Test Machine.

3.3.7 Scanning Electron Microscope with Energy Dispersive X-Ray Spectroscopy (SEM-EDX)

Figure 3.8 shows the Scanning Electron Microscope with Energy Dispersive X-Ray Spectroscopy (SEM-EDX) machine from UTAR. The SEM-EDX machine is a very advanced science tool for observing the microstructure of specimens. It works by carefully moving an electron beam over the surface of the specimen.

This makes the atoms close to the surface interact with each other. SEM-EDX machine can show how the surface of the mortar specimen is structured in exceptional detail. This machine is utilised to determine if the microstructure of the mortar specimen would be affected with various chemical additives and by replacing the sand with brown glass powder.

Figure 3.8: SEM-EDX Machine.

3.4 Preparation of Raw Materials

Ordinary Portland cement, water, and fine aggregate are the primary components used to make mortar for this project. The water used for making mortar specimens is diluted with different chemicals at different concentrations. Hydrochloric Acid (HCl), Calcium Hydroxide ($Ca(OH)_2$), and Calcium Nitrate ($Ca(NO_3)_2$) were utilized for the project. Then, the mixture was combined with brown waste glass powder, which was replaced with varying percentages of sand, ranging from 0% to 100%.

3.4.1 Ordinary Portland Cement

Figure 3.9 shows the Ordinary Portland Cement used for the project. The type of Ordinary Portland Cement used is CEM I high-strength Portland cement, which is specifically designed for early de-moulding, handling, and use. This cement is manufactured by YTL Cement Sdn. Bhd. and is packaged in 50 kg bags. The certificate number specified is MS EN 197-1:2014 CEM I 52.5N. This cement is excellent for various applications, including structural concreting, precast, brickmaking, and general-purpose projects that demand exceptional strength and increased productivity. Table 3.1 shows the cement properties.

Table 3.1: Cement Properties (YTL Marketing Sdn Bhd, 2017).

Tests		Units	Specification MS EN 197-1 : 2014 CEM I 42.5N	Test Results
			Chemical Composition	
Insoluble Residue		%	≤5.0	0.4
Loss On Ignition		%	≤ 5.0	3.2
Sulphate Content (SO3)		%	≤ 3.5	2.7
Chloride (CI-)		%	≤ 0.10	0.02
			Physical Properties	
Setting Time (Initial)		min	≥ 60	130
Soundness		mm	≤10	1.0
Compressive Strength (Mortar Prism)(1:3:0.5)	2days	MPa	≥10	29.7
	28days	MPa	≥ 42.5; ≤ 62.5	48.9

Figure 3.9: Cement.

3.4.2 Fine Aggregate

For this project, sand was utilized as a fine aggregate, as shown in Figure 3.10. Before mixing, the sand was heated in the oven at 100°C for 24 hours to remove moisture. The accuracy of the water-cement ratio (W/C) ratio in mortar can be affected by the moisture content of the sand. Once the sand had been oven-dried, it was carefully filtered through a 4.75 mm sieve. By carefully sieving the fine aggregate, the mortar mixture can achieve the ideal particle size distribution, resulting in high strength and workability. Additionally, it eliminates any unwanted particles.

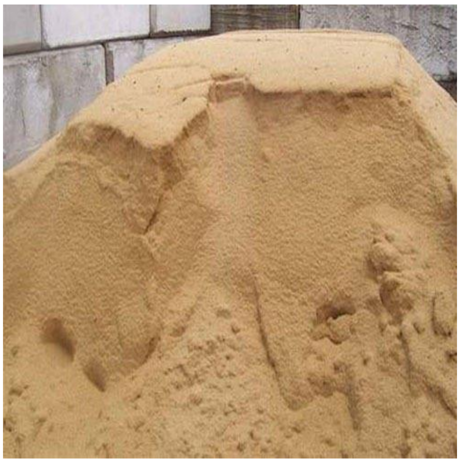


Figure 3.10: Fine Aggregate.

3.4.3 Water

According to ASTM C1602, water acts as the primary lubricant in a mortar mixture. The tap water from the UTAR building was utilised to make mortar specimens for the project. The tap water is perfectly suitable for mixing raw materials, as it is entirely free from impurities like oil, chemicals, and organic matter. Contaminants have the potential to impact the strength and durability of mortar. The water utilised at ambient temperature between 20°C and 25°C to maintain consistency in the mixing process and ensure uniformity in the properties of the mortar specimens.

3.4.4 Brown Colour Glass Powder

As the main ingredient, the brown glass powder is utilised for the project. It was included in the mortar mix as a substitute for sand at different percentages: 0%, 25%, 50%, 75%, and 100%. The brown glass was primarily sourced from recycled beer bottles as part of our commitment to environmental conservation. Before being mixed with other materials, the labels on the bottles were removed and thoroughly cleaned. Then, it was crushed into pieces using a hammer. After that, the fragments were placed into the crusher to be crushed into smaller pieces. After crushing, it then underwent grinding to form powder. After forming the brown glass powder, it was sieved using a sieve with a mesh size of 4.75 mm. The brown glass powder needed to be sieved to match the size of the sand used in the project. Figure 3.11 shows the brown glass powder.

Figure 3.11: Brown glass powder.

3.4.5 Chemicals

Three different chemicals were used: Hydrochloric Acid (HCl), Calcium Hydroxide ($Ca(OH)_2$), and Calcium Nitrate ($Ca(NO_3)_2$) to dilute the water that was used to make mortar cubes. Each mortar specimen had different chemical concentrations of 0.05 and 0.1 mol. The chemicals were used to assess the impact on the mortar specimens in terms of their fresh and hardened properties.

3.5 Preparation of Apparatus

Before casting, equipment, including a mixing container, mixing tool, water, ruler, and trowel, was prepared. When mixing the mortar, a large pan and a shovel were used. Water was added to the mortar mix to ensure the correct procedure was followed. Measurement instruments such as a bucket and a measuring cup were used to measure the water and dry mix. A mould of 50 mm

× 50 mm × 50 mm was used to give the mortar the desired shape as shown in Figure 3.12. In this project, the mortar was cast in a plastic mould. Oil was put into the mould to make the cured mortar easier to remove. A trowel was used to smooth out any rough spots in the mortar before it was spread over the mould.

Figure 3.12: 50 mm x 50 mm x 50 mm Plastic Cube Mould.

3.6 Chemical Dilution

For the chemical treatment of mortar, three types of chemicals were used, each at a different concentration. First, proper personal protective equipment is essential when handling these chemicals. Next, the required amount of chemical for treating the mortar cubes with additives was calculated. Then, the weights of Calcium Hydroxide ($Ca(OH)_2$) and Calcium Nitrate ($Ca(NO_3)_2$) were measured using a scale. Afterward, the chemicals were diluted in water, and a spoon was used to thoroughly mix the solution, ensuring full dilution. In contrast, Hydrochloric Acid (HCl), being in liquid form, was prepared using a pipet. Finally, the volume of HCl was deducted from the required amount of mixing water.

3.7 Mixing Procedures

In this task, proper safety protocols were followed by ensuring the use of protective equipment such as safety boots, safety glasses, and gloves to maintain safety throughout the process. The ratio of 1:5:1.24 of cement powder, sand, water was used for the project. A shovel was used to combine the dry ingredients in the dry pan. Water was consistently blended into the dry mixture following a comprehensive mixing of the dry materials. It was combined with other substances until it reached a uniform consistency and became workable. Before the fresh mortar was set, a flow table test determined its workability. The purpose was to determine if fresh mixed mortar has proper workability. The fresh mortar was then placed in an oiled plastic cube mould. Excess mortar was removed to create a smooth mortar surface in the mould. The freshly blended mortar was given 24 hours to cure and harden. Before testing, the hardened mortar had to be demoulded. After the mortar specimens had adequately hardened, hardened density was measured. Following curing, the mortar specimens were stored at room temperature. The mixture was cured for 7 and 28 days.

3.8 Fresh Properties Test

The fresh properties tests determine the characteristics of freshly mixed chemically treated mortar having 0%, 25%, 50%, 75%, and 100% brown waste glass powder. This subchapter discusses the flow table test as the fresh properties test.

3.8.1 Flow Table Test

The flow table test was conducted to evaluate the consistency, workability, and flow of fresh mortar. A sample of freshly mixed mortar was tested on a flow table with a flat and smooth surface. All procedures followed the guidelines set out by ASTM C1437-07. After filling the fresh mortar into a cylindrical shape, the sample was struck off at a level with the top of the table. Following a predetermined number of lifts and lowering of the table (25 runs in 15 seconds), the measurement of the fresh mortar spread was subsequently determined in four different directions. The flow diameter was calculated by averaging these data and then used to assess the flow parameters of the mortar. Figure 3.13 shows the flow table test.

Figure 3.13: Flow Table Test.

3.9 Hard Properties Test

Harden properties test was conducted to assess the hardening properties of the chemically treated mortar of 50 mm × 50 mm × 50 mm, which includes 0%, 25%, 50%, 75% and 100% brown waste glass powder. Among the tests for hard properties of the mortar is the compression test.

3.9.1 Compressive test

This was one of the most fundamental tests for determining the strength of mortar after it had been hardened. The compression force was applied to the specimen and gradually increased until the cement failed under compression in accordance with BS EN 12390-3. It was a test in which a specimen underwent compression and experienced the force from both sides. Typically, a 50 x 50 x 50 mm cube was placed between two plates, with the upper plate adjustable and the lower plate fixed. Each sample demonstrated substantial deformation. The compressive strength of mortar and concrete samples was measured at 7 and 28 days. The compressive strength was calculated using Equation 3.1, as shown.

$$F = \frac{P}{A} \tag{3.1}$$

where:

F = compressive strength of the mortar cube specimen, kN/mm^2

P = maximum load applied to the mortar cube specimen, kN

A = cross-section area of the mortar cube specimen, mm^2

3.10 Durability Test

Durability test was conducted to assess the durability of the chemically treated mortar of 50 mm × 50 mm × 50 mm, which includes 0%, 25%, 50%, 75% and 100% brown waste glass powder. Among the tests for hard properties of the mortar is the water absorption test.

3.10.1 Water Absorption Test

The water absorption test was conducted to determine the ability of the mortar to absorb water in accordance with ASTM C140. This test helped to evaluate the durability and quality of concrete by determining the amount of water it can absorb. The test was conducted using a mortar specimen of 50 mm x 50 mm x 50 mm. Before testing, the mortar cubes were placed in an oven to dry for at least 24 hours. After oven dry, the specimen was left in room temperature to cool down for at least 8 hours. The initial mass of each sample was measured and recorded using a weighing scale. Following the weighing process, the specimens were immersed in a water tank for 10 minutes, 30 minutes, 1 hour, 2 hours, and 24 hours. After each immersion period in the water tank, the specimen was removed, wiped clean with a towel, and then its weight was measured. The specimens were then measured for their final mass. Equation 3.2 illustrates the water absorption.

$$\text{Water Absorption (\%)} = \frac{M_2 - M_1}{M_1} \times 100 \tag{3.2}$$

where:

M_1 = initial mass of the dry cube specimen.

M_2 = mass of the cube specimen after water absorption.

3.11 Scanning Electron Microscopy with Energy Dispersive X-Ray Spectroscopy (SEM-EDX)

First, mortar fragments were collected in an airtight container before starting with the SEM-EDX experiment. Next, the fragments were placed onto the specimen container and put in a high vacuum sputter coater. A concentrated stream of electrons emitted by the electron gun located at the top of the column of the scanning electron microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDX) strikes the mortar fragments after passing a sequence of lenses and openings. A mortar fragment was placed on a chamber platform to begin the operation. A vacuum was established inside the chamber and columns using a series of pumps. The vacuum level generated by the microscope was determined directly by its design. The specimen was then placed into the SEM-EDX machine.

3.12 Summary

This chapter provided an overview of the processes involved in preparing raw materials, chemically etching glass powder, and conducting tests to evaluate the qualities of the material in both its fresh and hardened properties. In this project, mortar mixes were prepared, including a mortar trial mix and mortar with 0%, 25%, 50%, 75%, and 100% brown glass powder as partial sand replacements, respectively. The mortar mixtures were chemically treated at various concentrations of Hydrochloric Acid, Calcium Hydroxide, and Calcium Nitrate. Mortar cube specimens underwent compressive strength tests. Subsequently, a water absorption test was performed on the mortar cube specimens.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter thoroughly presented and discussed all the results. The initial subtopic focused on sieve analysis. Subsequently, the fresh and hardened properties of the mortar were showcased and elaborated. The third objective was meticulously explored through SEM-EDX analysis, leading to a detailed comparison and discussion of the findings.

4.2 Sieve Analysis

Sieve analysis is a material testing technique used to determine the particle size distribution of a given material. This method provides crucial insights into the gradation of the material, which can significantly influence its mechanical properties, permeability, and behaviour under various load conditions. The sieve sizes used in this analysis include 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm. In this experiment, sand and brown glass powder were tested, with 1 kg of each sample subjected to the sieve analysis. The outcomes are displayed in a graph in Figure 4.1.

Table 4.1: Sieve Analysis Results.

Sieve Size (mm)	Lower Limit (BS EN-883)	Cumulative Percentage for sand (%)	Cumulative Percentage for Brown glass powder (%)	Upper Limit (BS EN-883)
Basin	0	0.00	0	0
0.15	0	3.795	8.02	15
0.30	5	28.386	20.18	70
0.60	15	69.550	44.90	100
1.18	30	85.072	50.25	100
2.36	60	97.964	78.65	100
4.75	89	100.00	100.000	100

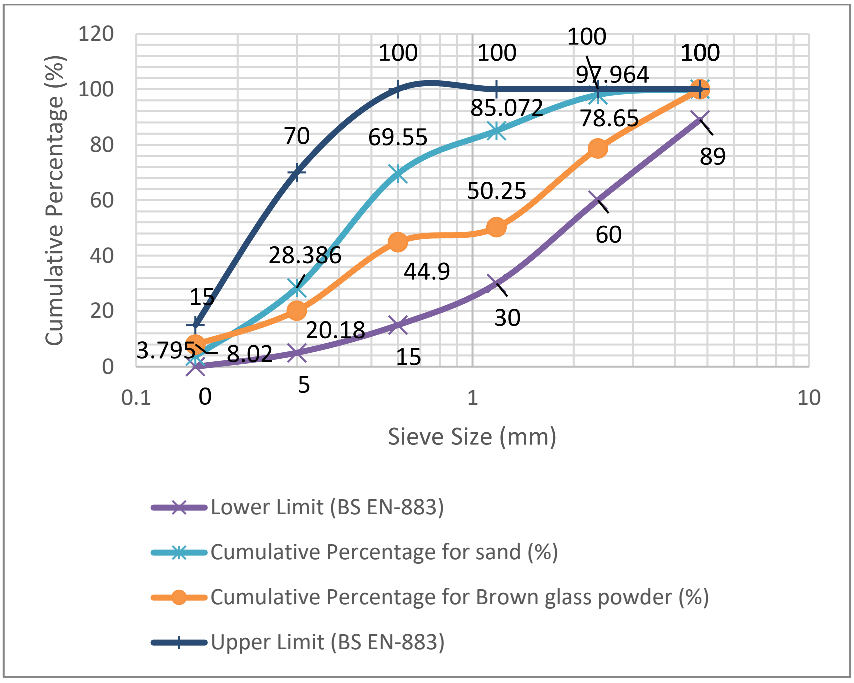


Figure 4.1: Sieve Analysis.

Based on BS EN883:2004, the particle size distribution curve of the sand was slightly closer to the upper limit, shows that the sand specimen was coarser. The fineness modulus is used to assess the fineness or coarseness of aggregate. The particle size distribution curve for the glass was slightly closer to the lower limit, showing that the brown glass powder was finer. The fineness modulus is an index that represents the level and type of grain size in fine aggregate. It is determined by summing up the total percentages of the aggregate sample retained on a specified series of sieves and then dividing that sum by 100 to obtain an empirical value (Lzzgchina.com, 2015). Equation 4.1 shows as follows,

$$Fineness\ modulus = \frac{total\ mass\ retained\ (\%)}{100} \tag{4.1}$$

As a result, the fineness modulus for sand and brown waste glass powder used as a substitute for sand are 2.15 and 2.98, respectively.

4.3 Fresh Properties Test

Mortar flow table tests were performed in this experiment before casting. This is to evaluate the workability and consistency of the fresh mortar mixed. The test is performed on a flow table. In this experiment, a total of 30 fresh mortars were tested. This includes fresh properties of the mortar treated with 0.05 M and 0.1 M of Calcium Hydroxide, Calcium Nitrate, and Hydrochloric Acid and containing 0%, 25%, 50%, 75%, and 100% brown glass powder. To provide a consistent result, mortar spread is measured on four different axes using the ruler. The workability of the mortar may vary depending on several factors, including the water-cement ratio, glass powder particle size and shape, the type of treated chemicals, chemical concentration, the mixing method, and time consumed during the mixing process.

Below are the results of the Flow Table Test of the mortar treated with 0.05 M and 0.1 M of Calcium Hydroxide, Calcium Nitrate, and Hydrochloric Acid and containing 0%, 25%, 50%, 75%, and 100% brown glass powder. Figures 4.2, 4.3, and 4.4 presents the results of 30 Flow Table Tests, which are the Flow Table Test for mortar treated with 0.05 M and 0.1 M of Calcium Hydroxide, Calcium Nitrate, and Hydrochloric Acid and containing 0%, 25%, 50%, 75%, and 100% brown glass powder.

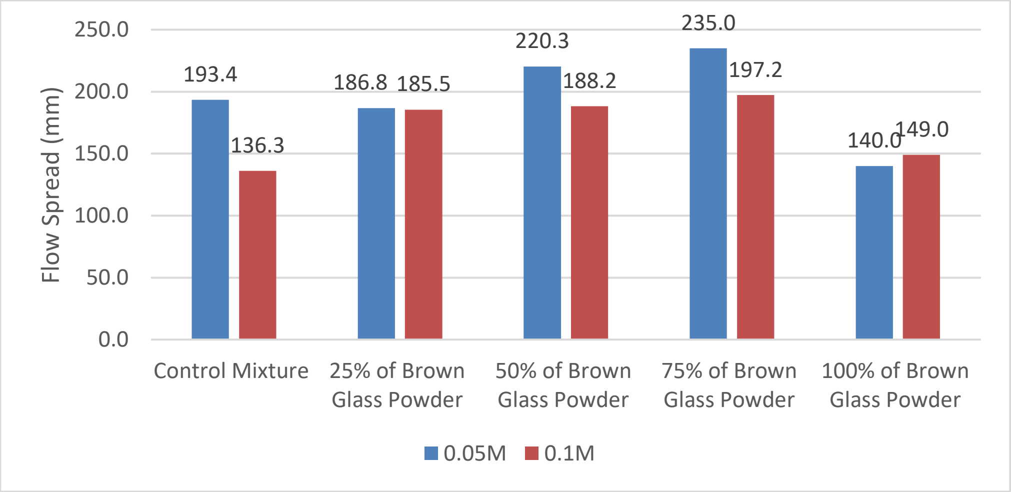


Figure 4.2: Results of Flow Table Test for mortar treated with Calcium Hydroxide ($Ca(OH)_2$).

From Figure 4.2, the mortar with 75% brown glass powder treated with both 0.05 M and 0.1 M of Calcium Hydroxide ($Ca(OH)_2$) has the highest mortar flow spread which are 220.3 mm and 188.2 mm respectively. The 0.1 M of the treated $Ca(OH)_2$ in the mortar shows lower workability for most specimens, except for 100% replacement, where a increment is observed. This is because the presence of $Ca(OH)_2$ might also reduce the free water content in the mix because of its chemical reactivity, further lowering the workability. The water that would otherwise contribute to the flowability of the mortar could be consumed in these reactions. This is similar to Joener et al. (2023), the reduction in workability of the mortar and concrete mixture with the addition of Calcium Hydroxide was expected. The $Ca(OH)_2$ absorbs free water in the mixture due to the irregular shape of its particles, which increases surface area and water absorption.

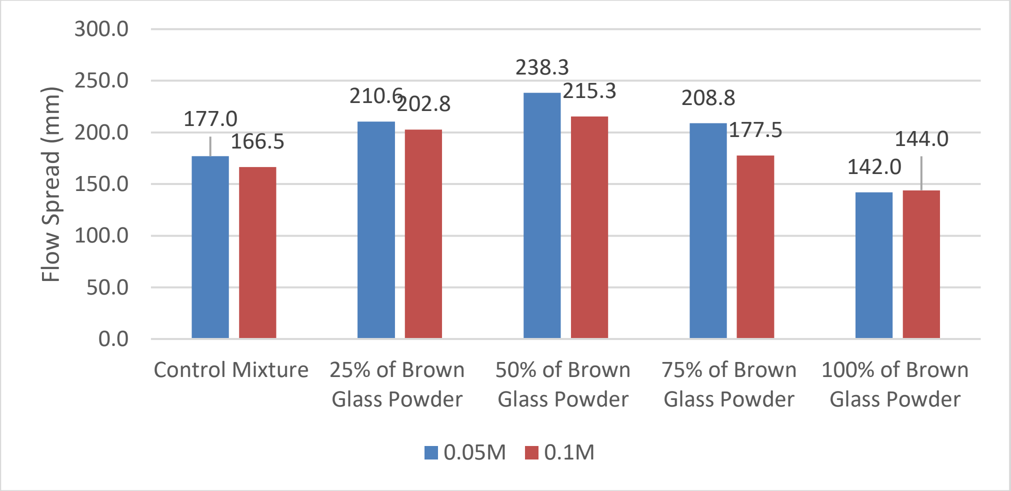


Figure 4.3: Results of Flow Table Test for mortar treated with Calcium Nitrate ($Ca(NO_3)_2$).

From Figure 4.3, as the replacement level increases from 0% to 50%, the molar flow spread increases. Both concerntrations reached its highest at 50% replacement which are 238.3 mm and 215.3 mm respectively. The increase in flow spread up to 50% Brown Glass Powder is likely due to the improved packing density and reduced friction between particles. When the replacement level exceeds 50%, the mortar flow spread decreases. At 100% replacement, the flow spread drops to levels comparable to the control mixture. When the Brown Glass Powder content exceeds 50%, the disruption in particle size balance leads to a denser mix with reduced spaces between particles, and it increases water demand as the higher surface of fine particle area absorbs more water, thereby reducing the workability of the mortar mix and flow.

Besides that, $Ca(NO_3)_2$ is often used as a setting accelerator in cementitious materials (Dorn, Hirsch and Stephan, 2022). At higher concentrations of 0.1 M, it can accelerate the hydration of cement, leading to faster stiffening of the mix. This would reduce the flow spread since the mortar starts to set more quickly.

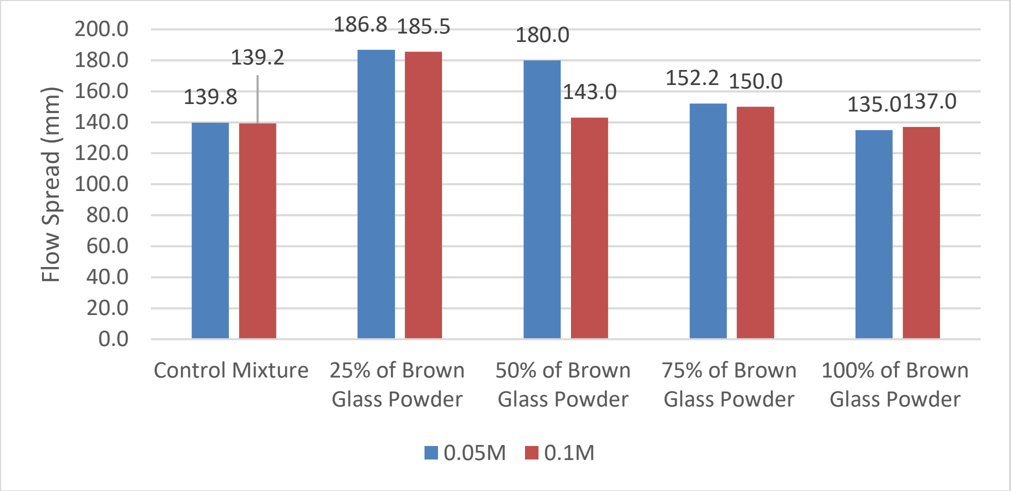


Figure 4.4: Results of Flow Table Test for mortar treated with Hydrochloric Acid (HCl).

From Figure 4.4, the mortar with 25 % of brown glass powder for both 0.05 M and 0.1 M concentrations has the highest mortar flow spread which are 186.8 mm and 185.5 mm respectively. The mortar flow spread increases up to 25% of sand replacement, but then gradually decreases, especially at higher replacement levels. It was also observed that the flow spread was generally higher for the 0.05 M compared to 0.1 M. This indicates that increasing the concentration of Hydrochloric Acid (HCl) slightly reduces the workability of the mortar. The reduction in workability with higher HCl molarity may be due to the more aggressive chemical reaction between the acid and the glass powder. The acid could potentially alter the surface properties of the glass powder, or it can influence the hydration process of the cement, which can lead to a denser and less workable mix.

4.4 Compressive Strength Test

Figures 4.5, 4.6, and 4.7 show the results of the compressive strength test for the actual mix containing 0%, 25%, 50%, 75%, 100% of brown glass powder treated with 0.05 M, and 0.1 M of Calcium Hydroxide, Calcium Nitrate, and Hydrochloric Acid.

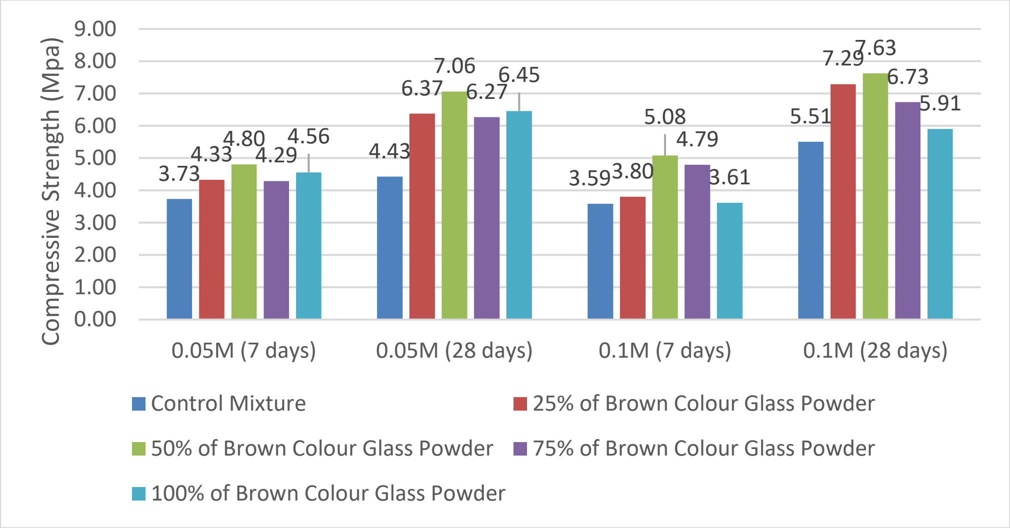


Figure 4.5: Results of 7 days and 28 days compression test for mortar cubes treated with Calcium Hydroxide ($Ca(OH)_2$).

From Figure 4.5, a clear trend of increasing strength from 7 days to 28 days can be observed, which aligns with the normal behaviour of cementitious materials due to ongoing hydration and pozzolanic reactions. At 28 days, both 0.05 M and 0.1 M concentrations, the mortar with 50% glass powder exhibits the highest compressive strength which are 7.06 MPa and 7.63 MPa respectively. This shows an optimal balance between the pozzolanic activity and the effect of the glass powder. This optimal percentage likely allows for the maximum formation of calcium silicate hydrates, which are responsible for strength development.

Additionally, the results demonstrate that a higher concentration of $Ca(OH)_2$ generally leads to slightly better compressive strength compared to a lower concentration. This is due to the increased availability of $Ca(OH)_2$ enhances the pozzolanic reaction, thus promoting a greater strength increase. This is similar to Joener et al. (2023), where the addition of $Ca(OH)_2$ increased the compressive strength. The overall analysis indicates that a 50% replacement of sand with brown colour glass powder, combined with a 0.1 M $Ca(OH)_2$, is most effective in achieving optimal compressive strength over time.

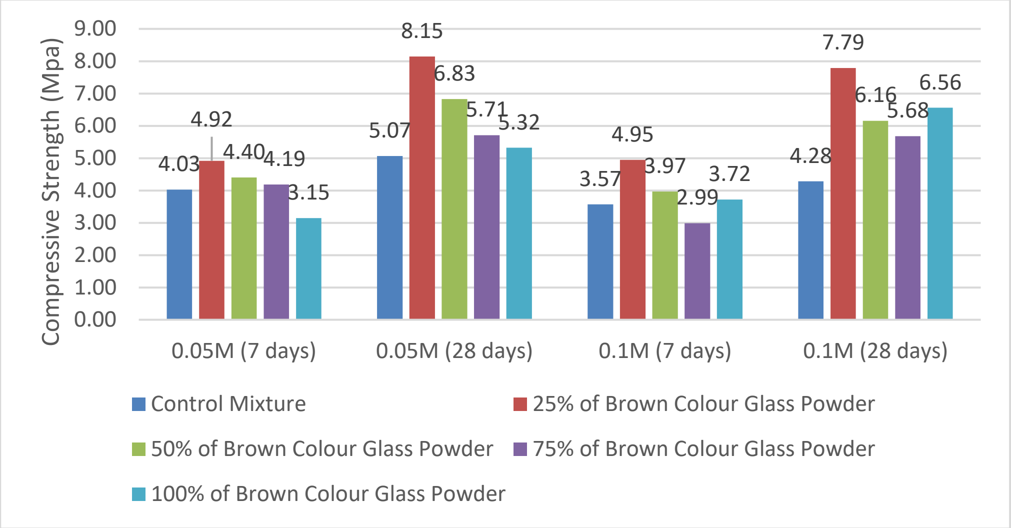


Figure 4.6: Results of 7 days and 28 days compression test for mortar cubes treated with Calcium Nitrate ($Ca(NO_3)_2$).

The data from Figure 4.6 shows that at the 7 days and 28 days compression strength, both concentrations at 25%, the compressive strength achieved the highest. This is due to the pozzolanic properties of glass powder that reacts with $Ca(NO3)_2$, which forms additional calcium silicate hydrates. However, as the percentage of glass powder increases to 50% and 100%, the compressive strength declines.

Calcium Nitrate ($Ca(NO3)_2$) accelerates the cement hydration process which leads to quicker strength gain, particularly at 7 days strength. However, this acceleration might not have the same beneficial effect for higher glass powder replacements. At higher glass levels, it is less capable of taking full advantage of the early hydration products, which may result in a reduced compressive strength compared to the 25% replacement.

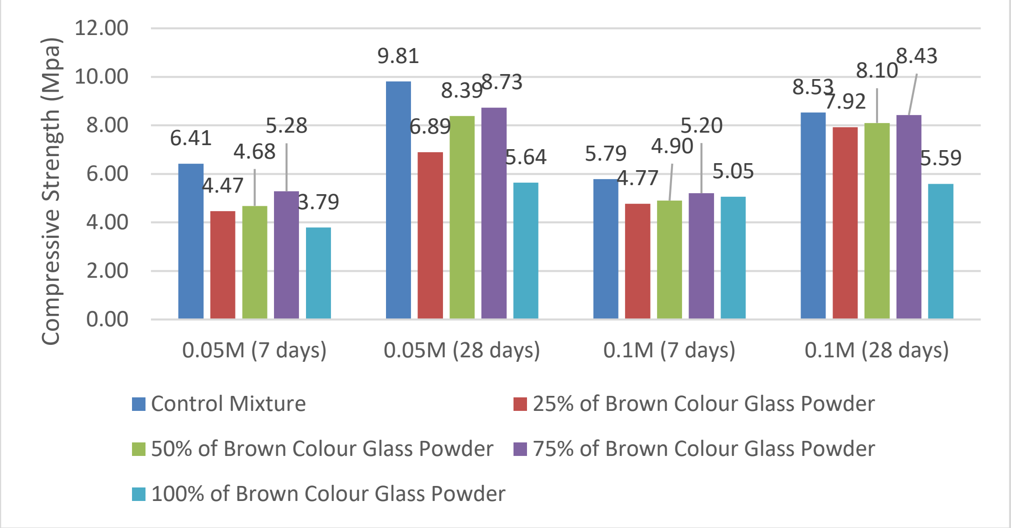


Figure 4.7: Results of 7 days and 28 days compression test for mortar cubes treated with Hydrochloric Acid (HCl).

From Figure 4.7, the control mixture consistently exhibited the highest compressive strength at both 7 and 28 days. At 28 days, the mortar with 0.05 M HCl concentration reached the highest strength which is 9.81 MPa. However, specimens with 25% to 75% glass powder showed notable strength gains, indicating a delayed but beneficial pozzolanic activity. The mixtures with brown glass powder exhibited lower compressive strengths, especially at 7 days when the 100% glass powder mixture displayed the weakest results. This may be due to the replacement of sand with glass powder, which initially offers less structural integrity. Despite these, the presence of HCl at the higher concentration of 0.1 M continued to impair overall strength, likely due to the acid attack disrupting the mortar matrix and inhibiting the full potential of the pozzolanic reaction. This is similar to Abubakar, Muazu, and Attah (2020), where the addition of HCl reduces compressive strength.

4.5 Water Absorption Test

The water absorption test for mortar specimens is an important test to determine the porosity and durability. It helps assess how much water a mortar can absorb, which in turn provides information about its durability and suitability for specific construction purposes. Figure 4.8 to 4.13 show the graph of the water absorption test containing 0%, 25%, 50%, 75%, and 100% of brown glass powder treated with 0.05 M and 0.1 M of Calcium Hydroxide ($Ca(OH)_2$), Calcium Nitrate

($Ca(NO_3)_2$), and Hydrochloric Acid (HCl). Table 4.2 shows the data for water absorption percentages.

Table 4.2: Water Absorption Data.

Type of Chemical	**Sand Replacement with Glass**	**Water Absorption Percentage (%)**				
		10 minutes	**30 minutes**	**1 hour**	**2 hours**	**24 hours**
$Ca(OH)_2$ 0.05 M	0%	2.0508	3.3701	3.7143	4.0011	6.0376
	25%	6.4935	11.5814	11.8411	12.8953	13.4148
	50%	4.8993	8.2206	10.2495	11.0460	11.6171
	75%	3.5900	6.2899	8.6782	10.3100	12.9803
	100%	4.1420	7.4647	9.6495	11.0909	12.0164
$Ca(OH)_2$ 0.1 M	0%	1.3183	2.1295	3.8099	4.2011	5.4034
	25%	3.0677	6.2857	7.8045	9.6842	11.0101
	50%	5.9974	9.4223	11.0980	11.5243	11.9065
	75%	1.3471	4.4005	6.3164	8.5466	10.8005
	100%	4.0576	7.5945	9.4473	11.2846	12.2340
$Ca(NO_3)_2$ 0.05 M	0%	2.0383	3.4526	3.7438	3.7715	5.3383
	25%	2.7749	5.0127	7.1013	9.4137	10.6000
	50%	4.4003	7.4319	9.8160	12.0088	13.3039
	75%	3.2792	5.7993	7.9095	9.6706	10.8699
	100%	4.5599	7.3230	10.1163	11.6865	13.5286
$Ca(NO_3)_2$ 0.1 M	0%	2.4491	4.2618	4.7184	5.1197	5.9222
	25%	4.4045	7.2008	9.4031	10.8374	11.1707
	50%	4.1196	7.0940	9.5479	11.6597	13.0874
	75%	3.3175	6.3752	8.5308	10.2125	11.4661
	100%	5.0824	7.9262	10.4977	12.0103	12.4489
HCl 0.05 M	0%	1.0832	1.3738	1.7041	2.5099	3.5403
	25%	2.0275	3.7147	5.2686	7.1629	8.8000
	50%	1.8413	3.2734	4.4133	6.3569	8.0000
	75%	3.3668	5.9953	7.7377	9.8346	11.3408
	100%	4.7321	7.8274	9.5685	10.1935	10.2530

Table 4.2 (Continued)

HCl 0.1 M	0%	1.2948	1.7480	1.9681	2.3566	3.6903
	25%	2.1639	4.1934	5.6857	7.6407	10.0001
	50%	1.6331	2.8083	4.1056	6.0897	8.0198
	75%	3.1274	5.7818	7.9634	10.2212	11.7468
	100%	2.7093	4.3165	5.8013	7.8371	10.0413

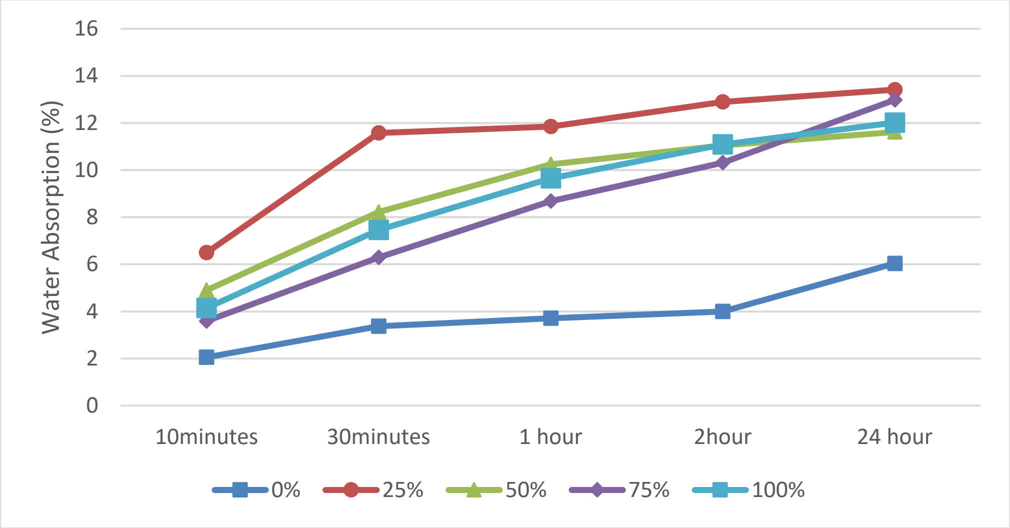


Figure 4.8: Results of water absorption test for mortar cubes treated with 0.05 M $Ca(OH)_2$.

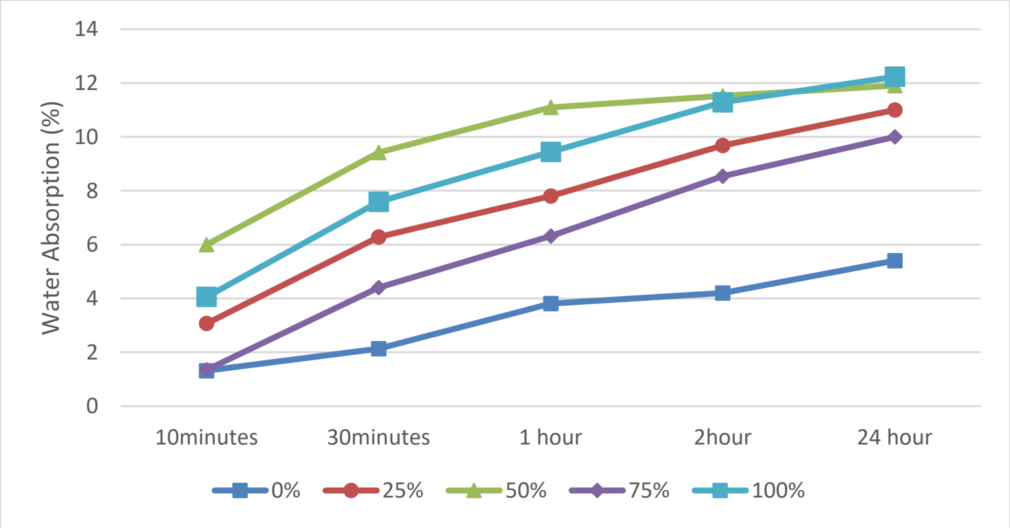


Figure 4.9: Results of water absorption test for mortar cubes treated with 0.1 M $Ca(OH)_2$.

For water absorption, the 25% glass powder replacement with 0.05 M $Ca(OH)_2$ was the highest, and 0% replacement is the lowest. For the mortar treated with 0.1 M $Ca(OH)_2$, the 50% glass powder replacement is also the highest, and 0% and 75% are the lowest. The results indicate that mortar with 0% glass powder replacement consistently exhibits the lowest water absorption. As the percentage of brown glass powder increases, water absorption increases across all time intervals, which shows an increase in porosity and a decrease in the water resistance of mortar. When comparing between concentrations, 0.1 M $Ca(OH)_2$ consistently shows lower water absorption across all substitution levels compared to 0.05 M. This indicates that the higher concentration of $Ca(OH)_2$ enhances the water resistance of the mortar, possibly by improving the binding and reducing the overall porosity of the mortar matrix. The higher concentration might help better seal the pores or improve the hydration process, leading to a denser and less permeable structure. In contrast, the 0.1 M $Ca(OH)_2$ treatment results in significant fluctuations in water absorption, particularly at higher glass powder replacements.

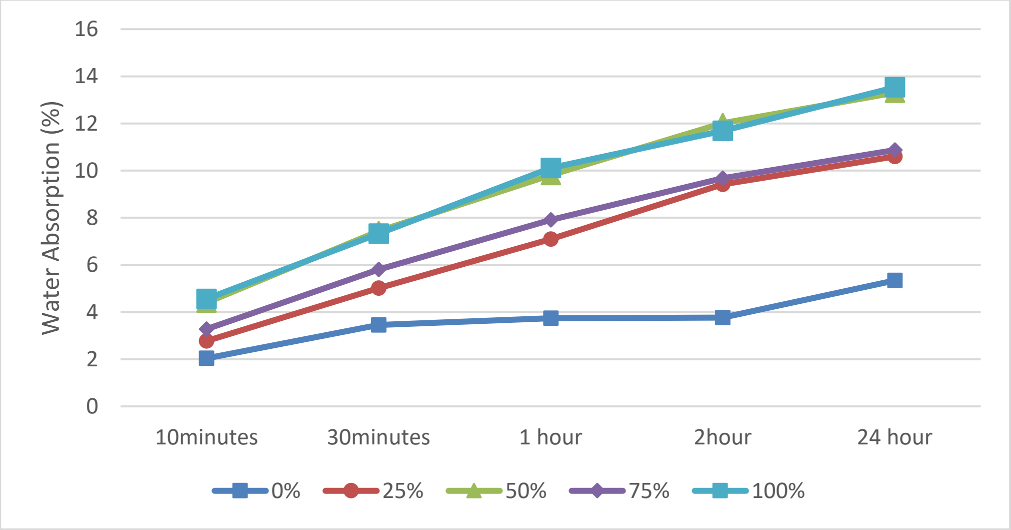


Figure 4.10: Results of water absorption test for mortar cubes treated with 0.05 M $Ca(NO_3)_2$.

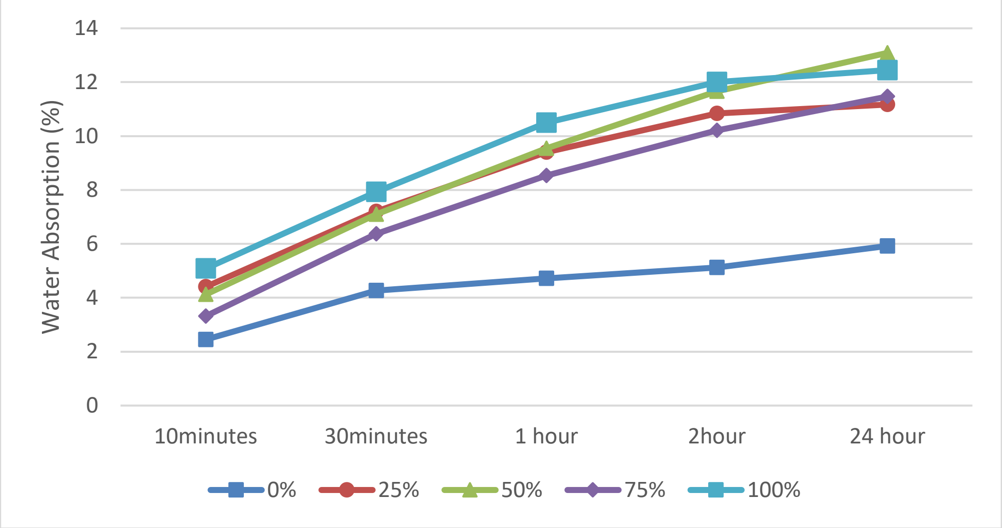


Figure 4.11: Results of water absorption test for mortar cubes treated with 0.1 M $Ca(NO_3)_2$.

For the water absorption, the 100% glass powder replacement with both 0.05 M and 0.1 M $Ca(NO_3)_2$ exhibited the highest absorption. The higher water absorption at 100% glass powder replacement. This is due to increased porosity and weaker bonding in the mortar, which makes it more susceptible to water penetration. Both results suggest that mortar with 0% glass powder replacement consistently exhibits lower water absorption, likely due to the less porous nature of the cement-based mortar, which effectively resists water penetration. Overall, the 0.1 M $Ca(NO_3)_2$ concentration generally exhibits slightly lower water absorption compared to the 0.05 M concentration, especially after 2 hours. Adding $Ca(NO_3)_2$ can accelerate hydration and promote the formation of dense C-S-H gel, reducing the size and connectivity of capillary pores. This refined pore structure further limits water absorption.

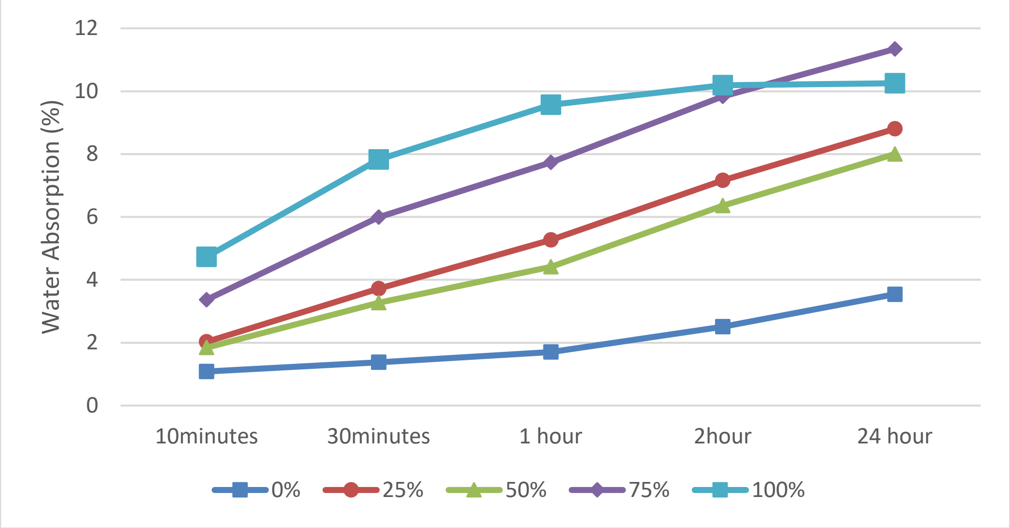


Figure 4.12: Results of water absorption test for mortar cubes treated with 0.05 M HCl.

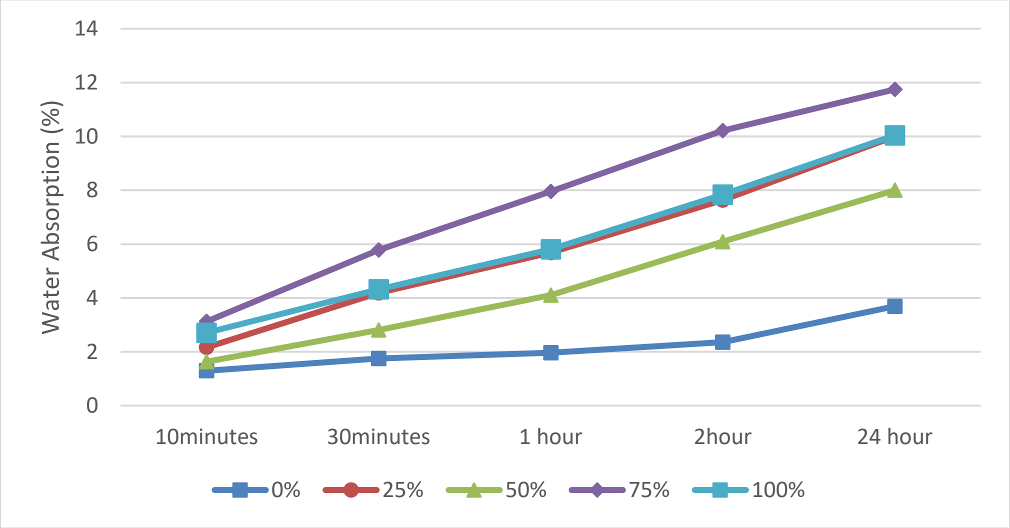


Figure 4.13: Results of water absorption test for mortar cubes treated with 0.1 M HCl.

At a 0.05 M concentration, the mortar with 100% glass powder replacement exhibited the highest initial absorption, while at a 0.1 M HCl concentration, initial absorption was more uniform, with 75% glass powder having the highest absorption. This is due to the higher percentage being susceptible to acid attack. The 0.1 M HCl results in increased water absorption, especially after 2 hours compared with 0.05 M HCl. The increased water absorption in mortar treated with a 0.1 M concentration can be attributed to the ability of the acid to degrade the mortar matrix. Higher acid concentrations can dissolve Calcium Hydroxide and other alkaline components in the cement, leading to micro-cracks and increased porosity. This weakening of the structure of mortar allows more water to penetrate, increasing absorption. The higher the acid concentration, the more significantly the integrity of the material will be affected and the more porosity it will have. The behaviour is more pronounced in mortars with glass powder, as they tend to be more porous and thus more susceptible to acid attack and water penetration.

4.6 Scanning Electron Microscopic (SEM)

Figures 4.14 to 4.25 show the SEM Micrograph of the mortar specimen containing 0%, and 75% brown waste glass powder treated with 0.05 M and 0.1 M Calcium Hydroxide ($Ca(OH)_2$), Calcium Nitrate ($Ca(NO_3)_2$), and Hydrochloric Acid (HCl) at 28 days with the magnification of 2000× accordingly.

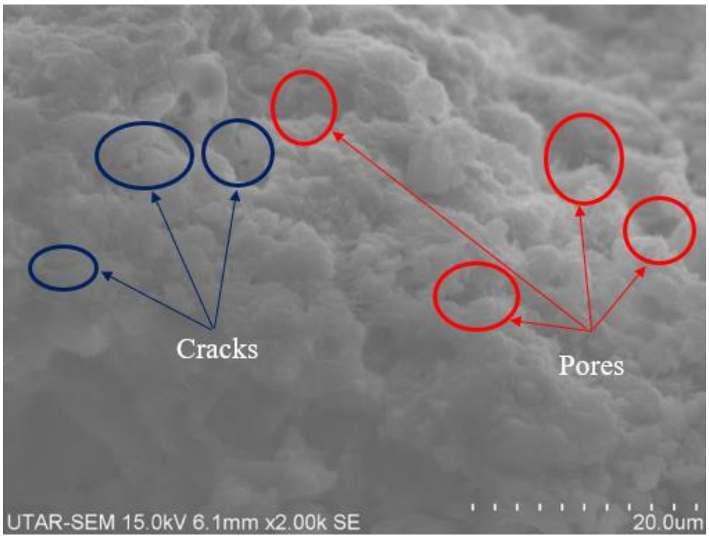


Figure 4.14: SEM Images of control mix treated with 0.05 M of $Ca(OH)_2$ at 28 days of Curing in 2000×.

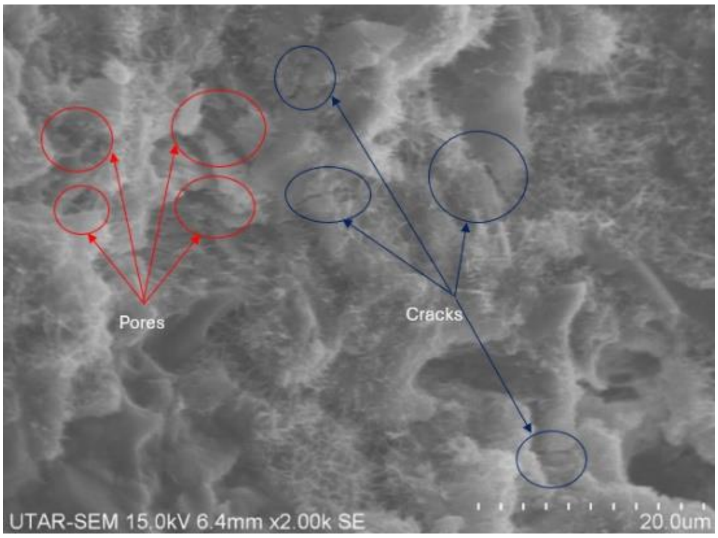


Figure 4.15: SEM Images of control mix treated with 0.1 M of $Ca(OH)_2$ at 28 days of Curing in 2000×.

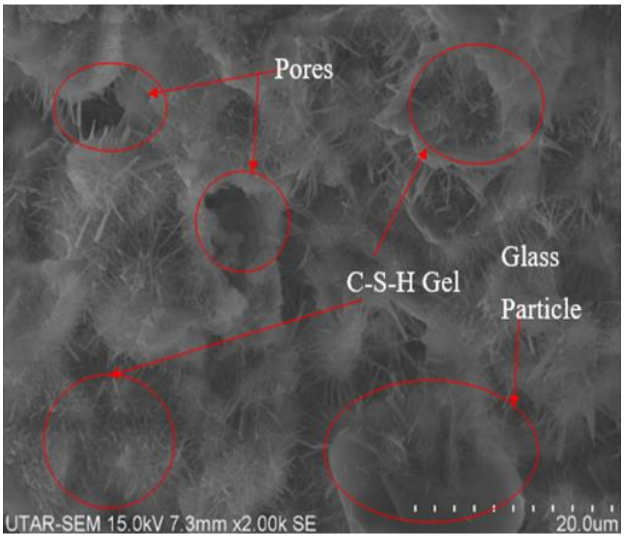


Figure 4.16: SEM Images of Mortar Containing 75 % Brown Colour Glass Powder treated with 0.05 M of $Ca(OH)_2$ at 28 days of Curing in 2000×.

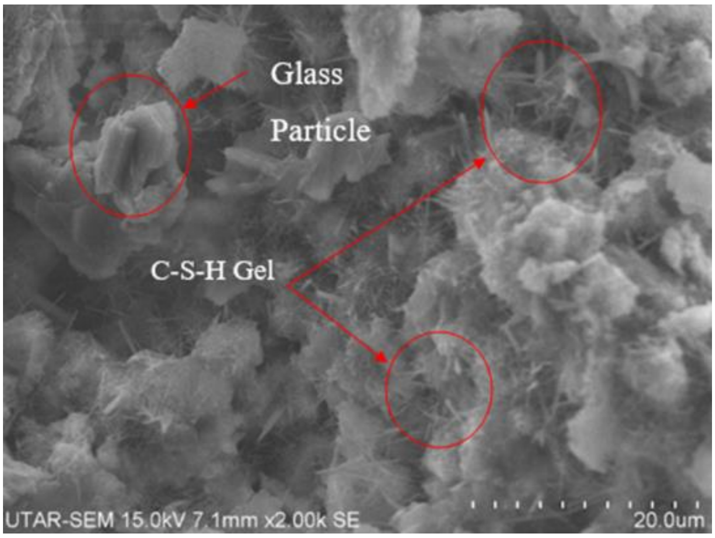


Figure 4.17: SEM Images of Mortar Containing 75 % Brown Colour Glass Powder treated with 0.1 M of $Ca(OH)_2$ at 28 days of Curing in 2000×.

When comparing mortar samples with 0% and 75% glass powder, it was observed that the higher percentage of brown glass resulted in fewer cracks and pores compared to the control specimen. This is likely because the smooth and angular surface of the waste glass particles improved the interlocking at the interfacial zone (ITZ) (Olofinnade et al., 2018). Researchers Tan & Du (2013) mentioned that this phenomenon may be due to the pozzolanic reaction, which occurs at a later stage as it reduces the porosity and increases the interlocking at the ITZ of the specimen. During the hydration of cement, $Ca(OH)_2$ is one of the primary products formed. It plays a crucial role in filling the microstructure of the mortar. When comparing the 0.05 M and 0.1 M concentrations of mortar treated with calcium hydroxide, the higher concentration of calcium hydroxide has fewer pores than the lower concentration. If $Ca(OH)_2$ is present in an optimal amount, it can help to fill in the pores that develop during the hydration process, leading to a denser and less porous mortar. This is in line with research conducted by Joener et al. (2023), which found that calcium hydroxide will develop the hydration process. The reaction between $Ca(OH)_2$ and glass could lead to secondary hydration products, such as calcium silicate hydrates (C-S-H), which may modify the pore structure differently across the replacement levels. this same reaction may create microcracks or leave behind a network of fine pores that enhance water absorption due to capillary action. This could also explain the higher water absorption for the 75% replacement despite lower pore visibility in the microstructure.

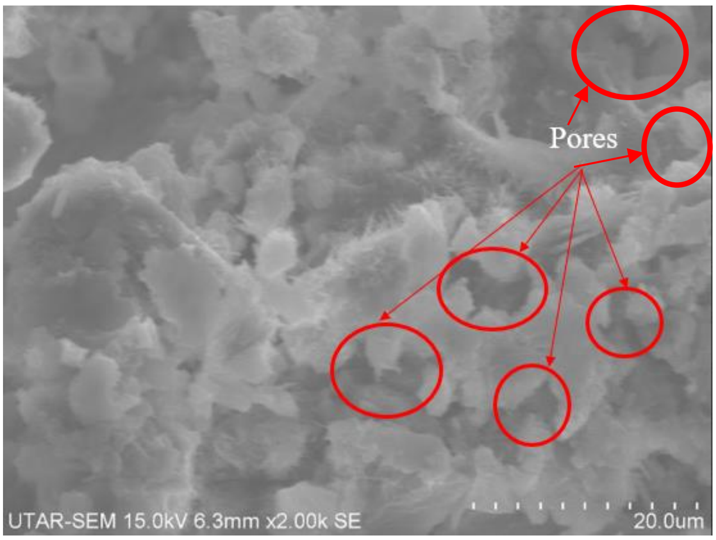


Figure 4.18: SEM Images of control mix treated with 0.05 M of $Ca(NO_3)_2$ at 28 days of Curing in 2000×.

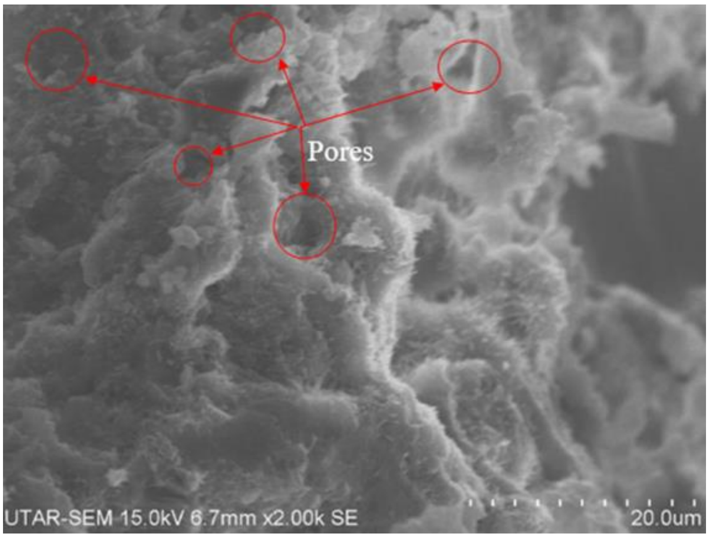


Figure 4.19: SEM Images of control mix treated with 0.1 M of $Ca(NO_3)_2$ at 28 days of Curing in 2000×.

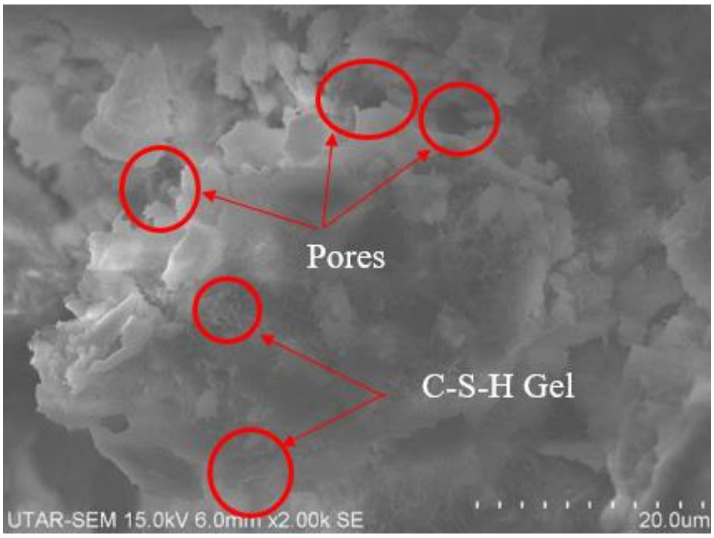


Figure 4.20: SEM Images of Mortar Containing 75 % Brown Colour Glass Powder treated with 0.05 M of $Ca(NO_3)_2$ at 28 days of Curing in 2000×.

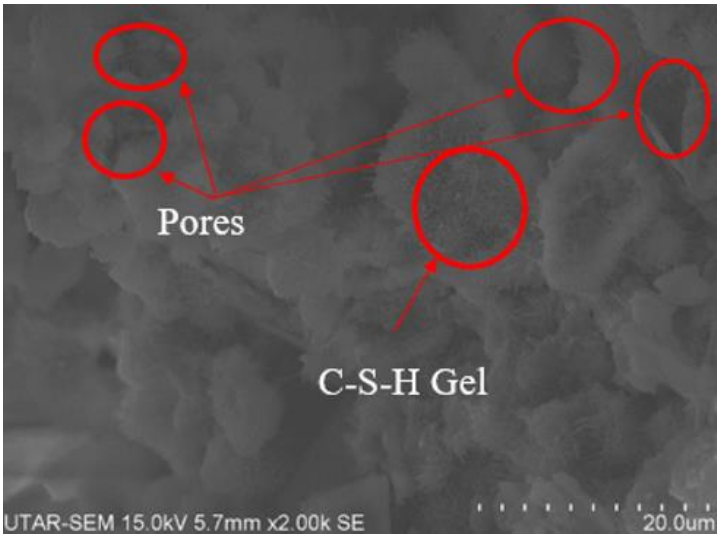


Figure 4.21: SEM Images of Mortar Containing 75 % Brown Colour Glass Powder treated with 0.1 M of $Ca(NO_3)_2$ at 28 days of Curing in 2000×.

The microstructure of mortar treated with 0.1 M $Ca(NO_3)_2$ shows a notable increase in the formation of calcium silicate hydrate (C-S-H) gel compared to mortar treated with 0.05 M $Ca(NO_3)_2$. This is attributed to the role of $Ca(NO_3)_2$ as an accelerator, which significantly enhances the hydration process of cement. By speeding up this reaction, more C-S-H gel, the primary binding phase responsible for strength in cementitious materials, is produced at an earlier stage. In the samples with 75% glass particles, glass can be observed embedded within the microstructure. These particles play a critical role in filling cracks and pores. Acting as a filler, the glass particles reduce the void space within the mortar, which further contributes to the overall densification of the matrix. The SEM test might show a lower number of visible pores, but it doesn't necessarily reflect the connectivity of the pores. If the pores in the 75% replacement sample are more interconnected, it could lead to higher water absorption.

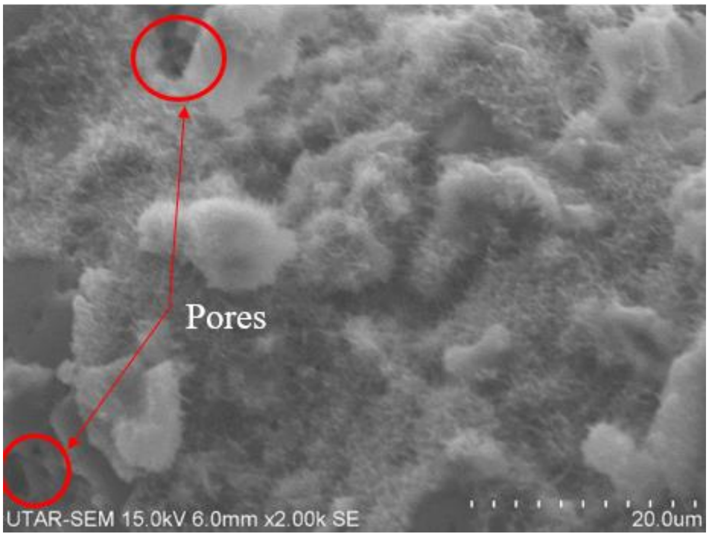


Figure 4.22: SEM Images of Control Mix treated with 0.05 M of HCl at 28 days of Curing in 2000×.

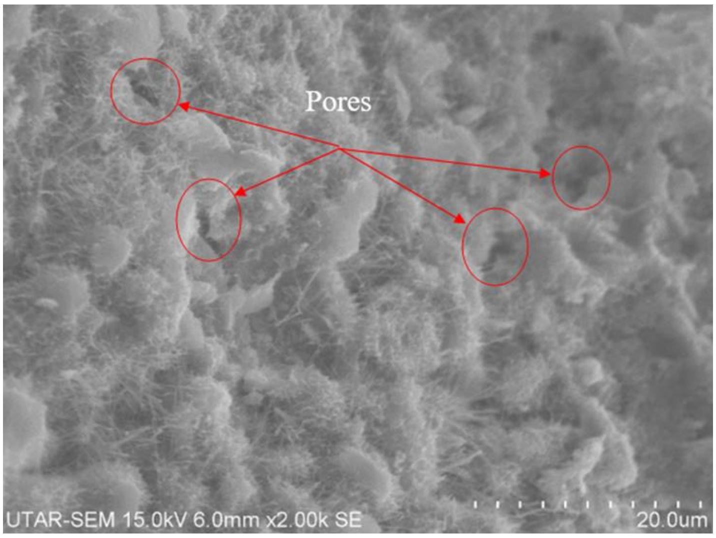


Figure 4.23: SEM Images of Control Mix treated with 0.1 M of HCl at 28 days of Curing in 2000×.

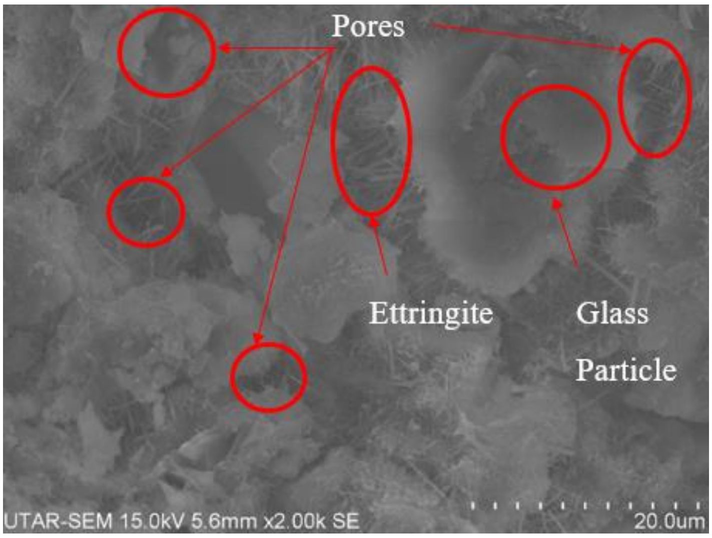


Figure 4.24: SEM Images of Mortar Containing 75 % of Brown Colour Glass Powder treated with 0.05 M of HCl at 28 days of Curing in 2000×.

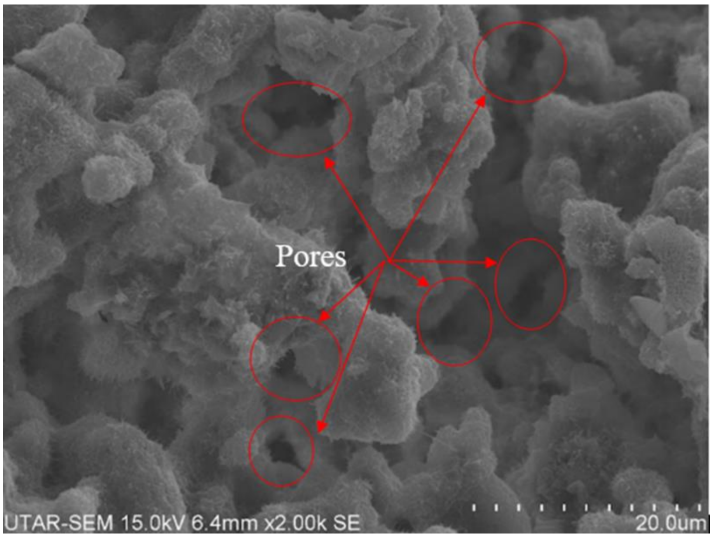


Figure 4.25: SEM Images of Mortar Containing 75 % of Brown Colour Glass Powder treated with 0.1 M of HCl at 28 days of Curing in 2000×.

From the microstructure from Figure 4.22 to 4.25, the rough surface was observed primarily due to the chemical reactions that occur when the acid interacts with the components of the mortar. When comparing mortars treated with 0.05 M and 0.1 M HCl, the microstructure reveals that the higher concentration of acid leads to the formation of more pores. This is likely due to the more aggressive reaction of HCl with the calcium hydroxide present in the mortar. The acid dissolves calcium hydroxide in the mortar, leaving behind voids that increase the porosity. This increased porosity results in a more porous and less compact structure. The loss of binding material around the aggregates increases surface roughness and exposes underlying particles, contributing to the observed texture (Hilbig, Gutberlet and Beddoe, 2024).

Other than that, the needle-like structures observed in Figure 4.24 are commonly associated with ettringite, a mineral that forms during the hydration of cement. Ettringite is a calcium-aluminium-sulphate compound that precipitates from the reaction between calcium hydroxide, aluminate, and sulphate in the presence of water (Christensen, Jensen and Hanson, 2004). This is formed due to HCl introduces chloride ions (Cl^-) that can compete with sulphate ions for reaction with calcium aluminates in cement, potentially affecting the formation of ettringite. The presence of ettringite can affect the dimensional stability of the mortar, and excessive formation could lead to expansion and cracking over time (Mohr, M. Shariful Islam and Bryant, 2024).

4.7 Energy-Dispersive X-ray Analysis (EDX)

Figures 4.26 to 4.37 show the EDX analysis of the mortar specimen containing 0%, and 75% brown waste glass powder treated with 0.05 M and 0.1 M Calcium Hydroxide, Calcium Nitrate and Hydrochloric Acid at 28 days.

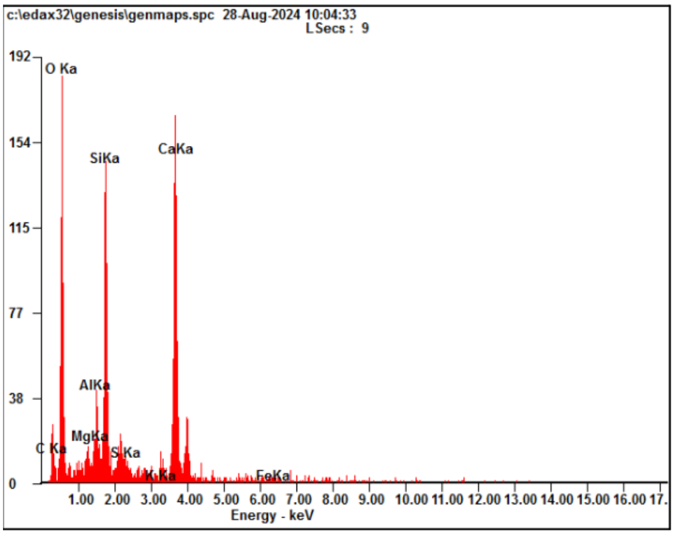


Figure 4.26: EDX for Control Mix treated with 0.05 M of $Ca(OH)_2$ at 28 days of Curing.

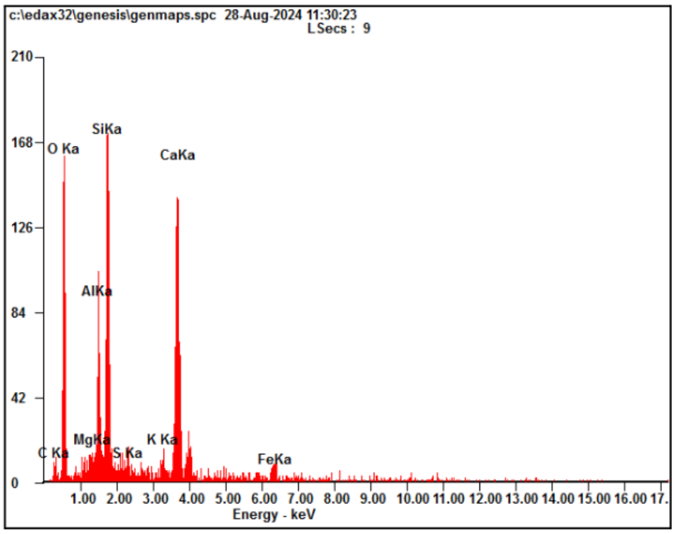


Figure 4.27: EDX for Control Mix treated with 0.1 M of $Ca(OH)_2$ at 28 days of Curing.

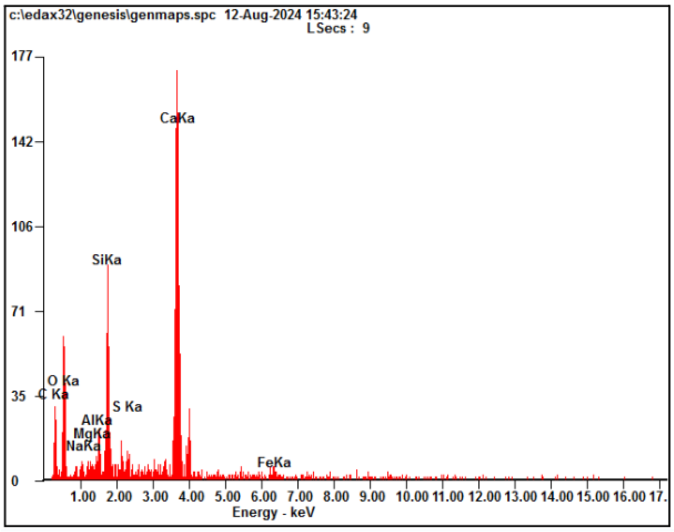


Figure 4.28: EDX for mortar with 75 % Brown Colour Glass Powder treated with 0.05 M of $Ca(OH)_2$ at 28 days of Curing.

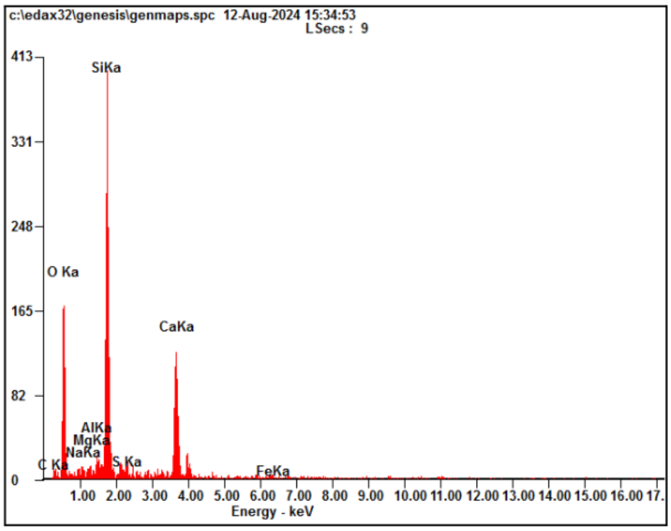


Figure 4.29: EDX for mortar with 75 % Brown Colour Glass Powder treated with 0.1 M of $Ca(OH)_2$ at 28 days of Curing.

Table 4.3: EDX Results for Control Mix, and 75% Brown Glass Powder with 0.05 M and 0.1 M of $Ca(OH)_2$ as Partial Replacement of Sand.

Element	**Specimen**			
	Control Mix treated with 0.05 M of $Ca(OH)_2$ at 28 days of Curing (At%).	Control Mix treated with 0.1 M of $Ca(OH)_2$ at 28 days of Curing (At%).	Mortar with 75 % Brown Colour Glass Powder treated with 0.05 M of $Ca(OH)_2$ at 28 days of Curing (At%).	Mortar with 75 % Brown Colour Glass Powder treated with 0.1 M of $Ca(OH)_2$ at 28 days of Curing (At%).
C	10.24	09.05	28.62	10.58
O	56.28	57.15	38.62	54.95
Na	-	-	01.58	00.89
Mg	00.67	00.51	01.05	00.66
Al	02.71	05.78	01.92	01.16
Si	11.47	12.77	07.70	21.66
Nb	-	-	-	-
S	00.71	00.81	01.05	00.73
K	00.68	00.63	-	-
Ca	16.71	11.95	18.83	09.09
Fe	00.53	01.35	00.64	00.28

The Control Mix treated with 0.05 M $Ca(OH)_2$ has moderate amounts of calcium and silicon important for forming calcium silicate hydrate. The calcium silicate hydrate which gives strength to the mortar. When treated with

0.1 M $Ca(OH)_2$, the silicon increases to 12.77%, but calcium decreases to 11.95%. This may be due to more calcium consumed, which can affect C-S-H formation.

When 75% brown glass powder is added and treated with 0.05 M $Ca(OH)_2$, the silicon content rises to 17.70%, and calcium remains relatively high at 18.83%. The carbon content increases significantly to 28.62%. This may be due to the carbon in the glass powder. In the mortar treated with 0.1 M $Ca(OH)_2$, silicon increases to 21.66%, but calcium drops significantly to 9.09%. This is due to its consumption in silica reactions.

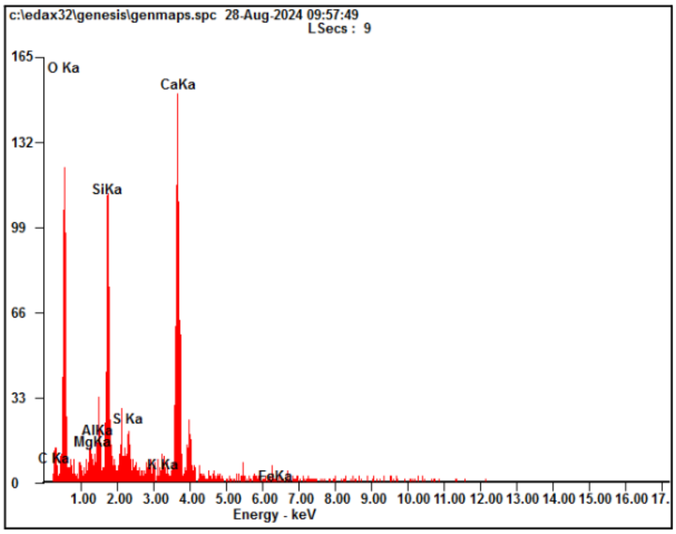


Figure 4.30: EDX for Control Mix treated with 0.05 M of $Ca(NO_3)_2$ at 28 days of Curing.

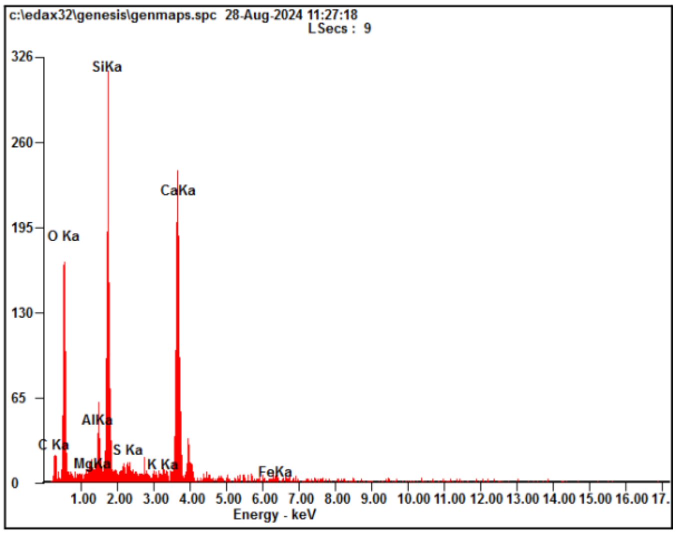


Figure 4.31: EDX for Control Mix treated with 0.1 M of $Ca(NO_3)_2$ at 28 days of Curing.

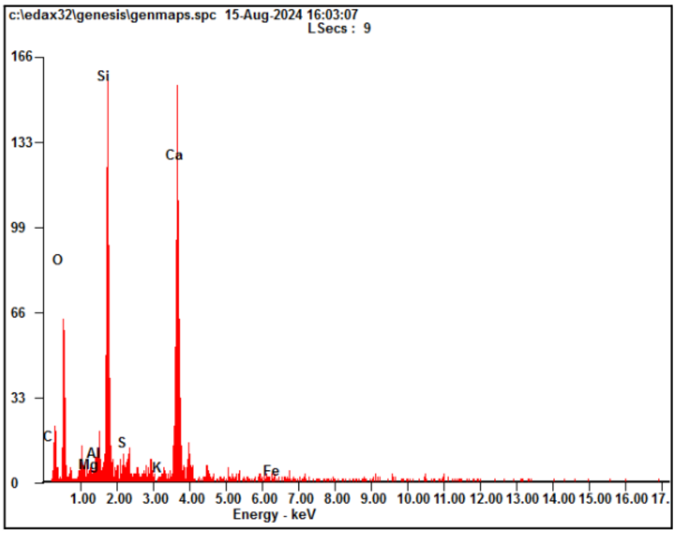


Figure 4.32: EDX for Mortar with 75 % Brown Colour Glass Powder treated with 0.05 M of $Ca(NO_3)_2$ at 28 days of Curing.

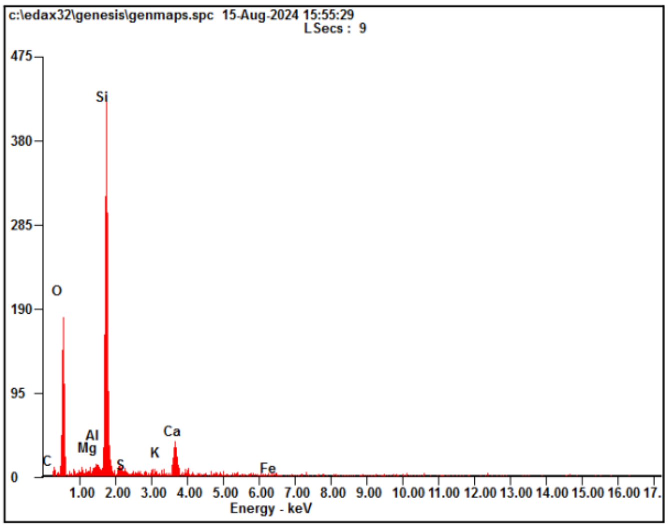


Figure 4.33: EDX for Mortar with 75 % Brown Colour Glass Powder treated with 0.1 M of $Ca(NO_3)_2$ at 28 days of Curing.

Table 4.4: EDX Results for Control Mix, and 75% Brown Glass Powder with 0.05 M and 0.1 M of $Ca(NO_3)_2$ as Partial Replacement of Sand.

Element	**Specimen**			
	Control Mix treated with 0.05 M of $Ca(NO_3)_2$ at 28 days of Curing (At%).	Control Mix treated with 0.1 M of $Ca(NO_3)_2$ at 28 days of Curing (At%).	Mortar with 75 % Brown Colour Glass Powder treated with 0.05 M of $Ca(NO_3)_2$ at 28 days of Curing (At%).	Mortar with 75 % Brown Colour Glass Powder treated with 0.1 M of $Ca(NO_3)_2$ at 28 days of Curing (At%).
C	07.93	12.59	24.73	13.22
O	56.21	55.36	44.12	54.17
Na	-	-	-	-
Mg	00.82	00.92	00.55	00.24
Al	01.94	02.61	01.37	00.85
Si	11.06	13.63	14.02	27.02
Nb	-	-	-	-
S	01.60	00.69	00.68	00.37
K	00.76	00.42	00.29	00.27
Ca	19.36	13.33	13.82	03.63
Fe	00.33	00.45	00.42	00.22

The Control Mix treated with 0.05 M $Ca(NO_3)_2$ shows high oxygen and calcium levels, which are essential for forming calcium silicate hydrate and improving the strength of the mortar. In contrast, the Control Mix with 0.1 M $Ca(NO_3)_2$ shows a slight decrease in oxygen to 55.36 % and calcium to 13.33 %, while silicon content increases to 13.63 %. This may be due to higher $Ca(NO_3)_2$ concentrations promote silica reactions which can more calcium in the process.

When 75 % brown glass powder is added and treated with 0.05 M $Ca(NO_3)_2$, the silicon content rises to 14.02 %, and calcium drops to 13.82 %. The carbon content increases significantly to 24.73 %, which may likely be due to the carbon in the glass powder. In the mortar treated with 0.1 M $Ca(NO_3)_2$, silicon increases at 27.02 %, but calcium drops sharply to 3.63 %. This may reflect its consumption in silica reactions. The carbon and oxygen levels also show changes due to the glass powder and calcium nitrate treatment.

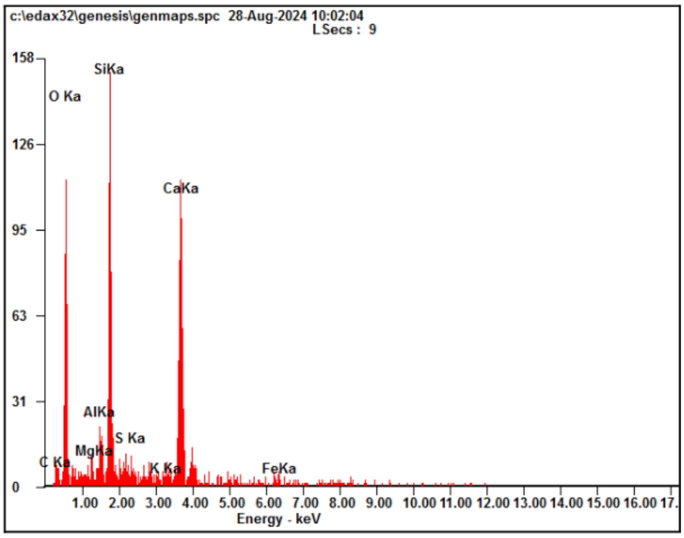


Figure 4.34: EDX for Control Mix treated with 0.05 M of HCl at 28 days of Curing.

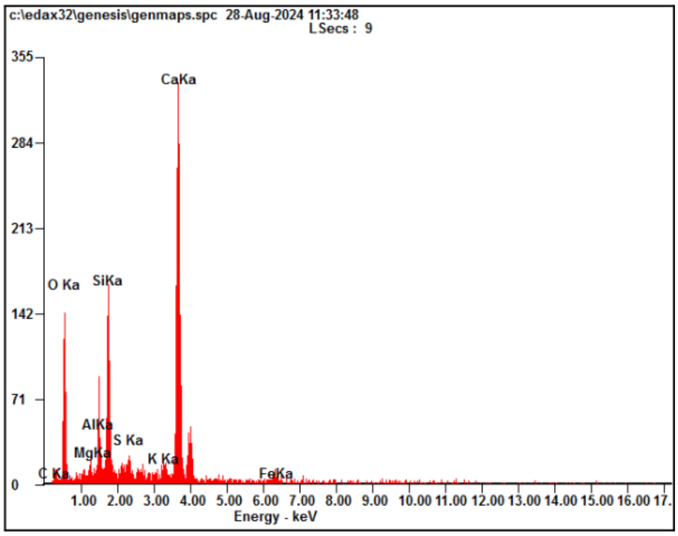


Figure 4.35: EDX for Control Mix treated with 0.1 M of HCl at 28 days of Curing.

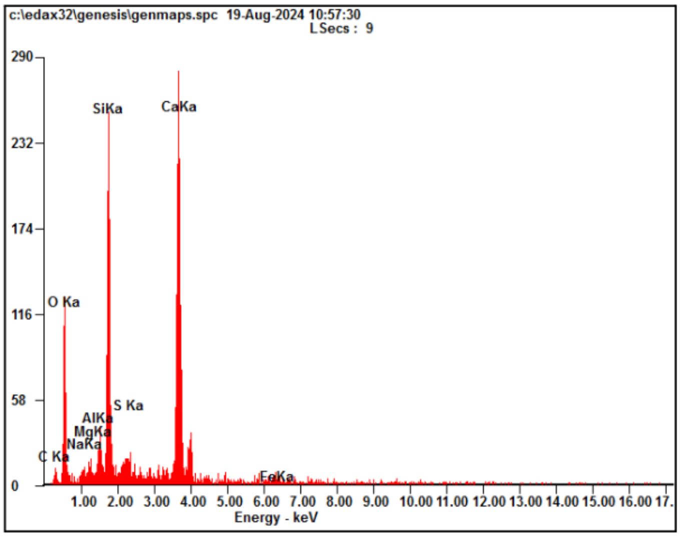


Figure 4.36: EDX for Mortar with 75 % Brown Colour Glass Powder treated with 0.05 M of HCl at 28 days of Curing.

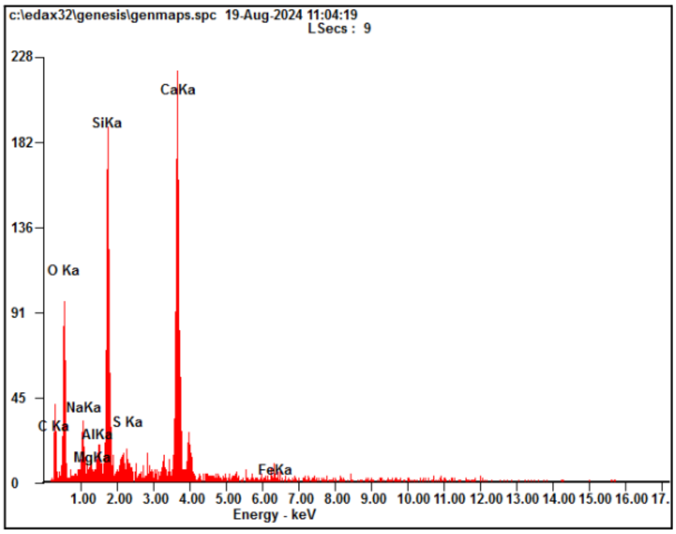


Figure 4.37: EDX for Mortar with 75 % Brown Colour Glass Powder treated with 0.1 M of HCl at 28 days of Curing.

Table 4.5: EDX Results for Control Mix, and 75% Brown Glass Powder with 0.05 M and 0.1 M of HCl as Partial Replacement of Sand.

Element	**Specimen**			
	Control Mix treated with 0.05 M of HCl at 28 days of Curing (At%).	Control Mix treated with 0.1 M of HCl at 28 days of Curing (At%).	Mortar with 75 % Brown Colour Glass Powder treated with 0.05 M of HCl at 28 days of Curing (At%).	Mortar with 75 % Brown Colour Glass Powder treated with 0.1 M of HCl at 28 days of Curing (At%).
C	06.43	06.60	08.09	25.33
O	54.82	55.21	52.07	41.85
Na	-	-	01.18	03.41
Mg	00.99	01.12	00.93	01.00
Al	02.79	03.73	02.10	01.37
Si	14.94	09.73	15.59	12.45
Nb	-	-	-	-
S	01.25	01.44	01.15	00.48
K	00.65	00.87	-	-
Ca	17.50	20.44	17.84	13.57
Fe	00.62	00.86	01.04	00.54

The Control Mix treated with 0.05 M HCl has high oxygen and calcium, which are 54.82% and 17.50%, respectively. It also has a moderate amount of silicon, which is 14.94%, that contributes to strength through the formation of calcium silicate hydrate (C-S-H). The carbon content is low compared to other mixes. When treated with 0.1 M HCl, the Control Mix shows a slight increase in calcium to 20.44% but a decrease in silicon, with carbon remaining nearly the same at 6.60%. This suggests that higher HCl concentration increases calcium availability but reduces silica, which can lower pozzolanic activity.

For the 75% Brown glass powder mix treated with 0.05 M HCl, the silicon content is higher, which is 15.59%, while carbon increases to 8.09%, which can show the presence of glass powder. Calcium content is similar to the Control Mix, and the increased silicon enhances pozzolanic activity. However, when treated with 0.1 M HCl, the silicon content drops to 12.45% along with calcium, while carbon rises sharply to 25.33%. This may be due to interactions between the glass powder and the higher HCl concentration.

4.8 Summary

For the flow table cone test, the highest flow was observed with 75% glass powder and 0.05 M $Ca(OH)_2$, while increasing the chemical concentration generally reduced workability. This may be due to $Ca(OH)_2$, absorbed free water. Mortar with $Ca(NO_3)_2$ had optimal workability at 50% glass powder, with reduced flow beyond this due to higher surface area absorbing more water. Mortar with HCl showed the best workability at 25% glass powder, with higher concentrations slightly decreasing flow due to more aggressive chemical reactions with the glass.

The result for the compressive strength showed that the mortar with 50% glass powder with 0.1 M concentration of $Ca(OH)_2$ yielded the highest strength at 7.63 MPa after 28 days. Mortar with $Ca(NO_3)_2$ showed the highest strength at 25% glass powder with 0.05 M concentration, reaching 8.15 MPa. The mortar with HCl had the best performance in the control mix which achieved 9.81 MPa with 0.05 M concentration.

The SEM analysis showed that mortars with higher glass powder content, particularly at 75%, had fewer microstructural cracks and pores, leading to denser structures. The mortar treatment with $Ca(OH)_2$ and $Ca(NO_3)_2$ improved the overall density and reduced voids, while HCl treatments led to more microstructural disruptions. The mortar treated with 0.1 M $Ca(OH)_2$ showed the most compact microstructure with fewer cracks. This is due to glass particles acted as effective fillers which improved the microstructure of mortar and durability.

The EDX analysis showed that mortars with higher glass powder content, especially those treated with $Ca(OH)_2$ and $Ca(NO_3)_2$, showed an increased presence of silicon which indicates enhanced pozzolanic reactions from the glass powder. Higher chemical concentrations generally led to higher silicon and lower calcium content which can help in stronger glass-cement bonding. The mortar with 75% brown glass with 0.05 M $Ca(OH)_2$ had the highest silicon content which reflects the improved microstructure and strength of the mortar. However, HCl-treated mortars showed reduced calcium levels and less favourable element distribution which can contribute to weaker bonding and compromised durability.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

According to the experimental results, a conclusion can be made that the different proportions of waste glass powder with different chemical additives can affect the fresh and hardened properties of mortar containing chemical additives and brown waste glass particles as a partial substitution for sand.

The objectives have been achieved by investigating the fresh and hardened properties of mortar incorporating different chemical additives, which are 0.05 M and 0.1 M of Calcium Hydroxide ($Ca(OH)_2$), Calcium Nitrate ($Ca(NO_3)_2$), and Hydrochloric Acid (HCl) and brown glass waste as 0%, 25%, 50%, 75% and 100% sand replacement with flow table test for fresh properties and compressive test for hardened properties. For fresh properties, the mortars with 75% brown glass with $Ca(OH)_2$, 25% brown glass with $Ca(NO_3)_2$ and 50% replacement with HCl achieved the highest workability. Additionally, all the chemical treatments helped maintain better workability compared to 0.1 M concentration. For the hardened properties, the optimal replacement percentage of brown glass, which is 50% has resulted in enhanced compressive strength, which is a 38.48% increment compared to the control mix when incorporating 0.1 M $Ca(OH)_2$. 25% of brown glass is the optimal replacement percentage when incorporating 0.05 M $Ca(NO_3)_2$ to the mortar, which can increase compressive strength by 60.75%. However, incorporating HCl into mortar negatively affects compressive strength regardless of replacement percentages.

The incorporation of brown glass waste at optimal replacement levels significantly improved the microstructure of the cement mortar. Scanning Electron Microscope (SEM) analysis showed reduced pore sizes and fewer micro-cracks in the mortar with brown glass waste. $Ca(OH)_2$, particularly at 0.1 M concentration, has promoted the formation of more calcium silicate hydrate (C-S-H) gel, which filled the pores and increased the compactness of the mortar. $Ca(NO_3)_2$ also accelerates hydration, though its effects are slightly less apparent than those of $Ca(OH)_2$. On the other hand, higher concentrations of 0.1 M HCl led to increased porosity and potential micro-cracking due to its acidic condition, which can degrade the cement matrix.

The 0.05 M concentration of $Ca(NO_3)_2$ provided the best results across various performance metrics. Mortar treated with this concentration showed the highest compressive strength, optimal workability, and lower water absorption which indicates better durability. The higher concentration enhanced hydration, reduced porosity, and contributed to a more compact mortar matrix. The optimal performance was achieved with a 25% brown glass powder replacement combined with 0.05 M $Ca(NO_3)_2$.

5.2 Recommendations

According to the research, incorporating chemical additives and brown glass powder into mortar shows potential as a viable alternative to conventional mortar, indicating a shift towards a more sustainable future. To drive further progress in this area, a few recommendations can be suggested.

(i) Conduct the use of alternative additives such as sodium silicate or pozzolanic materials in mortar containing brown glass powder as a sand replacement. This investigation would focus on the effects of these additives on the strength, durability, and microstructural properties of the mortar which can provide insights into how different chemical treatments may influence performance.

(ii) Investigate the mortar on Long-term durability to understand the durability of mortar mixtures incorporating chemical additives and brown glass powder. Extending the study period to 90 or 180 days would provide a more comprehensive understanding of the long-term mechanical properties and durability, ensuring the suitability of the material for prolonged use.

(iii) Investigate the effects of different curing conditions, such as water curing, and steam curing on the mechanical and microstructural properties of mortar incorporating brown glass powder. This can help identify optimal curing conditions for improved performance.

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