EXPERIMENTAL STUDY OF BUILDING MATERIALS MADE OF WASTE MATERIALS

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EXPERIMENTAL STUDY OF BUILDING MATERIALS MADE OF WASTE MATERIALS

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by giving explicit references.

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DEDICATION

This thesis dedicated to my families.

Thank you for all your support along the way.

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In the name of Allah, I would like to express my gratitude to Allah SWT for giving me the opportunity, strength, and ability to finish this Final Year Project satisfactorily. First and foremost, I would like to give special thanks to Universiti Sains Malaysia (USM), School of Civil Engineering, and School of Mechanical Engineering for giving me this opportunity and providing facilities to carry out this experimental study.

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LIST OF SYMBOLS

W	Load Applied
A	Area of the Surface
w_1	Weight of dry bricks (kg)
w_2	Weight of wet bricks after 24 hours (kg)

LIST OF ABBREVIATIONS

WG	Waste Glass
RCG	Recycled Crushed Glass
WGP	Waste Glass Powder
CSEB	Compressed Stabilized Earth Block
FG	Fine Glass
CG	Coarse Glass
FA	Fine Aggregate
CB	Control Brick
WGB	Waste Glass Brick
SEM	Scanning Electron Microscopy
EDX	Energy Dispersive X-Ray Analysis
USM	Universiti Sains Malaysia

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ABSTRAK

Terdapat banyak longgokan bahan terbuang di dalam dunia ini hingga mengganggu keadaaan persekitaran. Hal in kerana, terdapat bahan buangan yang tidak dapat dilupuskan dengan sempurna di samping kos untuk melupuskannya agak tinggi terutamanya sisa bahan buang kaca. Penggunaan bahan buangan dengan baik dapat mengurangkan pencemaran air, tanah, dan udara serta isu pembuangan sampah. Kajian ini adalah bagi menyelesaikan masalah persekitaran disebabkan bahan buangan kaca yang tidak dilupuskan dengan mengantikan sisa kaca sebagai bahan dalam pembuatan bata simen. Penggunaan sisa kaca dalam bahan binaan telah lama diperkenalkan dan telah membuktikan keberkesanannya. Matlamat kajian ini adalah untuk mengkaji keberkesanan sisa kaca bagi menggantikan tanah dalam pembuatan bata simen. Bata simen akan dibuat dengan menggantikan tanah dengan 10%, 20%, dan 30% sisa kaca yang berlaian saiz sisa kaca yang dihancurkan iaitu 0.5cm, 1.0cm dan 2.0cm. Hasil kajian menunjukkan nilai kekuatan mampatan meningkat apabila jumlah kaca sisa meningkat dalam campuran bata. Walau bagaimanapun, nilai maksimum mencapai pada 1.0cm saiz kaca buangan (23.67 MPa) berbanding dengan saiz kaca sisa 0.5cm, 2.0cm dan bata kawalan (6.76 MPa). Prestasi batu bata meningkat apabila ujian penyerapan air menunjukkan trend menurun apabila peratusan kaca sisa yang ditambah meningkat. Ini adalah salah satu kajian ke atas bata simen bagi langkah mengurangkan pembuangan sisa kaca di kawasasan terbuka.

ABSTRACT

Many piles of waste materials in this world disturb the environment. This is because there are waste materials that cannot be disposed of perfectly, and the cost of disposing of them is high especially glass waste. Using waste materials can reduce water, soil, air pollution, and garbage disposal issues. This study aims to solve the environmental problem caused by glass waste that is not disposed of by replacing glass waste as a material in manufacturing cement bricks. The use of glass waste in building materials has long been introduced and has proven its effectiveness. This study examines the effectiveness of glass waste as a replacement for soil in manufacturing cement bricks. Cement bricks will be made by replacing the natural sand with 10%, 20%, and 30% of glass waste that is different in size from the crushed glass waste, which is 0.5cm, 1.0cm, and 2.0cm. The study results show that the value of compressive strength increases when the percentage of waste glass increases in the brick mix. However, compressive strength reached the maximum value at 1.0cm waste glass size (23.67 MPa) compared to 0.5cm waste glass size, 2.0cm, and control brick (6.76 MPa). It also shows the increasing in compressive strength compared to the conventional brick (8.01MPa). The performance of the bricks increased as the water absorption test showed a decreasing trend as the percentage of waste glass added increased. This is one of the studies on cement bricks for measures to reduce the disposal of glass waste in open areas.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

For a long time, the waste material has been a problem that is difficult to solve in Malaysia or abroad. According to Malaysian Solid Waste Management, residents produce approximately 23,000 tonnes of waste per day. Waste prevention and recycling are essential components of a waste disposal system strategy because they conserve natural resources and reduce the need for dumping sites [1]. There are many types of municipal waste materials in Malaysia from easy to dispose of to difficult to dispose of such as paper, organic waste, aluminium, and glass. In many parts of the world, discarded waste glass is already a challenge at waste disposal sites. Glass bottles are typically used once or twice and then disposed of in most countries [1]. Municipal solid waste recycling began decades ago, but due to limitations and exorbitant prices, waste materials like glass were sent to landfills rather than being recycled. Because all commercial glass bottles are made of silica, which contains more than 70% SiO_2, it is presumed that waste glass can be crushed and managed to sort into the desired size of particles for use as aggregates or as a building material in the construction industry [1]. In this study, waste glass is used as a mixing material in the manufacture of sand-cement bricks in building materials.

1.2 Research Background

Brick construction process is one of the important criteria in our building in term of the strength and durability of that materials used. Glass wastes have a good physical property that can increase the performance of existing sand-cement bricks. Because of recent massive global consumption, single-use glass bottles are now one of the major waste sources developing as a serious environmental issue. Even though waste glass recycling can produce new products, a considerable amount ends up in landfill containing impurities and the high expense of the recycling process. This experimental project investigates the effect of waste glass added on different sizes of glass particles, which are 0.1cm, 1.0cm, and 2.0cm in a handmade brick manufacturing process. The results produced will be compared with the existing sand-cement bricks. The use of waste glass in the creation of building materials has been pursued effectively because it may minimise both the consumption of natural resources and the expense of waste disposal while also preserving the environment from negative consequences.

1.3 Problem Statement

Waste glass is the most difficult waste material to dispose of compared to other materials. Rather than stacking it in an open area, it is better to use it as a mixture in the building material, such as bricks, tiles. There is much literature focusing on the making of clay fired bricks made of waste glass in various percentages ranging from 10% to 30% in increments and different size of waste glass particles [2]. Currently, they are using fired clay bricks and concrete as the experimental material for the mixing with waste glass for the water absorption, compressive strength test and Scanning Electron Microscopy (SEM) Analysis. This approach to multiply the study of the use of cement bricks with a mixture of waste glass with different glass content and sizes. In addition, the size of waste glass particles also affects the mechanical properties of bricks.

Most experiments, however, use small glass particles that are difficult to isolate and crush. Thus, the aim is to investigate the use of glass waste as a mixing proportion in sand-cement bricks with the different sizes of glass particles.

1.4 Experimental Objectives

There are two main objectives of the study, which are:

I. To study the effects of waste glass in the mixing of sand-cement bricks using different sizes of waste glass particles and percentage of waste glass

II. To investigate the performance of ordinary waste glass bricks with the conventional sand-cement brick in terms of mechanical properties.

III. Identify the effects of adding waste glass material on the properties of sand-cement bricks mixes such as, water absorption, and compressive strength.

1.5 Scope of Research

In this study, it focuses more on the experimental methods which require skills in using experimental equipment and materials. Also, the making of a manual glass crusher design to be used as a glass crusher using the SolidWorks Software. The experimental study includes preparing brick samples for study and testing the performance of waste glass bricks. The activities involved in conducting this project are research, designing, and prototyping for the materials.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review chapter begins with a brief overview of key aspects of making sand-cement bricks made of waste glass. There are a few steps and materials that will be used to investigate the mechanical properties of the bricks. This chapter provides the current existing handmade bricks made of bricks from different sizes of glass particles. A review of previous research on the inclusion of waste glass into building materials is also provided.

2.2 Municipal Solid Waste (Glass)

Glass has become indispensable in daily existence due to its properties, such as its ability to do any shape, its colourful surface and wear resistance, and its strength and reliability. As the number of uses for glass expands, so does the quantity of waste glass. The United Nations assumed that 200 million tons of solid waste are discarded each year globally, with glass accounting for 7% of that total. This amount approaches 120 000 tons in Turkey, with 80 000 tons recycled, and it has been mentioned that 3 million tons of waste glass are recycled in Germany [3]. In 2018, approximately 27 million tons of waste recycling was observed in global recycling volumes, representing only 21% of glass output. Glass causes pollution in the surrounding environment, including the air, water, and land, due to its non-biodegradable nature [4]. Dumping glass in the open environment endangers animal and human safety, is unsightly, and takes up a large amount of land.

The daily removal of more than 300 tons of waste glass deduced from post-consumer glass bottles is one of Hong Kong's biggest environmental problems, and this challenge is only getting worse as limited recycling streams are recognised and useful landfill space is being depleted at an alarming rate. Post-consumer waste glass is a large element of Hong Kong's solid waste stream. In 2010, 96.7% of waste glass in Hong Kong (131,864 tons) was disposed of directly in landfills [1]. The waste glass material replacement in the bricks mix was suggested as a solution for the waste collection company Zanrec's monthly delivery of 15500 kg of waste glass to the beverage workshop, of which only 160 kg is used to produce things for the Trending Terrazzo collection [5].

Resources such as clay and silt are the primary raw materials for clay bricks, but with the principle of sustainable development and increased environmental awareness, the extraction or acquirement of these raw materials has become increasingly more difficult in Taiwan [2]. The vessel industry in the United Kingdom will be unable to consume all the recycled glass bottle that becomes available in the early years, owing to a colour disparity between produced and consumed. The excess green glass from imported red wine bottles may be exported to producing countries or used domestically in the growing number of secondary close uses for recycled glass [6].

2.2.1 Glass in Building Materials

Making a combination of blocks alongside glass sections has for quite some time been concentrated on by different foundations since glass is one of the most troublesome waste materials to discard. Various methods and experiments were carried out in the manufacture of building materials from this waste glass. It includes the particle size and type of glass used as a substitute material in the building material mix. This study also found that replacing 20% of fine aggregate with < 1.18 mm fine glass increased the compressive strength of paving bricks by 69%, respectively [6] . Even so, when the rough glass (4.75 mm) was used rather than the fine glass, the improvement was reduced. The compressive strength of bricks fired at 900°C, 1000°C, and 1100°C was slightly different after the waste glass was increased in another study. At 900°C of fired bricks the strength increases about 23% when 10% waste glass is added to samples. At 1000°C, the strength increases to 43.17 MPa when 40% of waste glass addition. At 1100°C, the compressive strength reaches a maximum at 30% waste glass addition, accompanied by expansion of the brick samples and a significant decrease [2].

According to Gupta, [4] the percentage of soda-lime glass substituted for cement and sand has a major impact on the qualities of cement mortar. Mortars made of glass waste powder at 15% cement replacement and glass sand at 25% natural sand replacement have the maximum mechanical properties. Yixin Shao [7] investigated the performance of mortars made with glass as a partial replacement for cement. They indicated that particle size has a significant impact on mortar achievement. Finer glass particles increased glass reaction with lime, improved compressive strength, and decreased shrinkage. From the previous study, [8] the use of glass as a 50% substitute for fine aggregate results in lower levels of growth. Indeed, the magnitude of expansion in the case of refraction containing green and carnelian glass would be less than half that of those containing 100 % substitutions.

2.3 Fired Clay Bricks

Clay bricks are made by combusting them at a high temperature. They have a pleasing appearance and deliver excellent results, such as high strength and toughness, high fire, and weather resistance, and good in thermal insulation. Fired clay bricks are considerably longer than twice their width and could be held in one hand [2]. Much of the experimental literature on more fired clay bricks sample. The clay shown in this experiment was collected from one of the local concrete block plants in Turkey's Afyon region. Brick clay's major crystalline structures are calcite, clinichlore, muscovite, and quartz, whereas waste glass only have a glassy phase [3]. All materials used for fired clay brick are clay as the main raw material. After the clay brick has been finished mixing and drying, burning is an important process in the manufacturing of ceramic products because it effects many important qualities of the product for examples mechanical properties, and chemical resistance [9] . Figure 2.1 shows an overview of the procedure for manufacturing fired clay bricks. Clay blocks are high quality in Mexico utilizing a strategy of blending, projecting, drying, and sintering. The last stage is led out in conventional broilers made out of heaped dirt blocks shaping a chamber; be that as it may, no protection is given, so heat is lost during sintering [10].

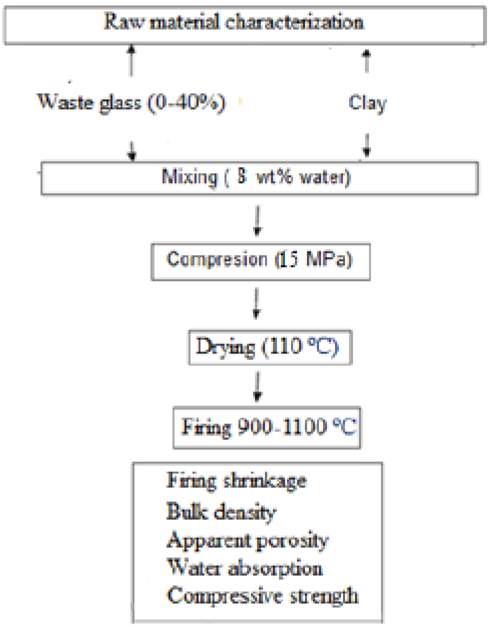

Figure 2.1: Flowchart the making of fired clay brick [2]

Masonry concrete blocks emerged as a viable alternative to fired clay bricks with the introduction of Portland cement in the twentieth century, and they are still widely used today. Concrete blocks, for example, account for only about 5% of total masonry unit production in the United Kingdom. Combining cullet and clay in this regard is a very promising method of lowering the processing temperature in order to produce high-quality bricks for modern building structures [11].

2.3.1 Effect on Size of Glass Particles

The mechanical strength improvement and sturdiness of earth items are affected by molecule size in light of the fact that the mechanical strength increments as the normal molecule size increments [12]. The crushed waste glass is made by ball-milling. The crushed waste glass was passed through a 74 µm sieve (200 mesh). All the materials were placed in an oven at a temperature of 105°C for 24 hours [13]. Following the washing and sanitising process, the recycled crushed glass (RCG) was completely dry for three days. The glass bottles were then crushed into particles ranging in size from 0.05mm to 1.6 mm [14]. Saraswathy [15] performed a sieve analysis on the ground glass powder to determine their particle size proportion, which is depicted in Figure 2.2 alongside that of sand. The particle size is in the range of 0.1mm to 10mm.

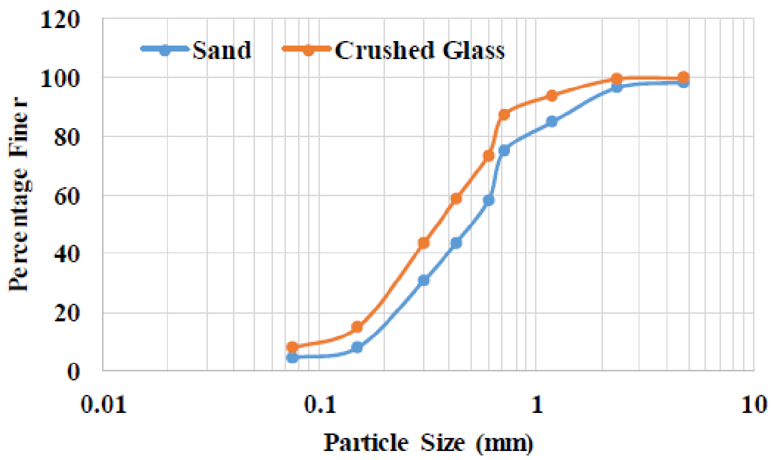

Figure 2.2: Particle size distribution of crushed waste glass [15]

The waste glass was collected and washed at Dimako Aluminium off Iyin-Ekiti road, Bashiri, Ado Ekiti, Ekiti State, Nigeria, before being crushed into smaller pieces of 5 mm size manually using a mortar and pestle. This had been wet grind with a ball milling process, and the particle sizes were sieved to less than 150µm and 75µm, respectively.

It was discovered that cement with WGP particle size less than 75 μm in CSEB should be used for obvious reasons, as opposed to cement with WGP particle size 150 μm. Overall, the results indicate that there is no discernible difference between using 150 or 75 μm WGP [16]. Abdeen, [2] discovered that the compressive strength of a fired clay brick sample with a waste glass particle size less than 150 μm differs by approximately 52.4 % from the control brick at 43.17 MPa..

2.3.2 Mechanical Properties of Bricks

Based on the Ponce Penã, [10] findings also show that compressive strengths ranged from 1.8 MPa to 6.8 MPa and increased with material particle size. Glass melting is improved when the particle size is reduced, allowing the material to fill empty spaces. At 850 °C, the minimum strength improvements were acquired because clay particles maintain their original structures and start contributing only slightly to vitrification. In contrast, the use of waste glass significantly contributes to vitrification and improves strength gain by filling the interior pores with a glassy phase, particularly at firing temperatures of 950 and 1050 °C [3]. The brick specimens were examined for compressive strength tests, as shown in Table 2.1.

According to Akinyele, [9] the first class of clay bricks has a compressive strength of about 14 MPa and the second class has not less than 7 MPa. The third and fourth samples of bricks have an average compressive strength of 7 MPa until 15 MPa which is not suitable for building bricks.

Table 2.1: Compressive strength test with different waste glass content [3]

Waste glass content (%)	Compressive strength (MPa)		
	850 °C	950 °C	1050 °C
0	16.45	19.50	20.37
2.5	18.75	22.65	24.50
5	20.15	25.13	27.15
10	20.62	27.56	29.35

According to one study, replacing fine aggregate with crushed spent fire bricks at 20% tends to increase the compressive strength of the concrete by 1.16 % compared to conventional concrete. When glass powder replaces cement by 20%, the strength increases by 3.82 % compared to conventional concrete, but it reduces about 20%. [17]. The strength development trend suggests a proclivity for additional strength gain as curing age increases. The results also show that a 20% replacement of cement with WGP with the sizes less than 150 µm but greater than 75 µm can be used in CSEB because the advanced strength at 28 days was approximately 71.33 % than the minimum suggested strength for CSEB at this level [16].

2.4 Mixture Proportion

According to Mao, [13] approximately 10% galvanised sludge was added to the fired clay brick mixture, and different waste glass contents of 5, 10, 15, 20, 25, and 30% have been added as a replacement for clay. To enhance the elastic properties of the raw materials, 10% water will be added during the moulding process. The fired clay bricks have been tested in term of physical and mechanical properties for example water absorption test where the brick will be soaked in boiling water for 2 hours before calculating its weight gain. As a result, water absorption decreased by 50 % when up to 30% waste glass was added.

In this study, the mix proportion for mortar and concrete were glass powder replaced in cement with the percentage of 0% (control brick), 10%, 15%, 20%, and 25%. The following percentage of glass powder is about 30g, 45g, 60g, and 75g as replacement of cement. The results revealed that the maximum glass content is 20% when considering mortar and concrete compressive strength at 90 days [18].

The cement and water proportions in the mixes were kept constant in this study [6], but FA was replaced with FG and CG at levels ranging from 10% to 30% by weight. For instance, FG replacement of 20% means that FG replaces 20% of the corresponding FA weight in FG-20 samples. The mix proportion is shown in Table 2.2.

Table 2.2: Mixture Proportions [6]

Mixture no	Cement (kg/m^3)	Water (kg/m^3)	Aggregates (kg/m^3)		Waste glasses (kg/m^3)	Pressure applied (MPa)
			Fine (0-4.75)	Coarse (4.75-12.5)		
Control	350	121	1100	900	0	17
FG-10	350	121	990	900	110	17
FG-20	350	121	880	900	220	17
FG-30	350	121	770	900	330	17
CG-10	350	121	990	900	110	17
CG-20	350	121	880	900	220	17
CG-30	350	121	770	900	330	17

Ponce Penã, [10] investigated the effect of clear waste glass from bottles added in amounts ranging from 20 to 30 wt.% and with variable sizes of waste glass particles. In this manner, each group of tests was physically blended until homogeneity was accomplished, and afterward 20-25 wt.% water was added to the combination to shape a plastic glue. The outcomes showed that rising the glass content and diminishing the molecule size further developed the block properties of water absorption and compressive strength.

A. Nisha Dev, [17] was investigated when the concrete was replaced with fine aggregates in different percentage of 0%, 10%, 15%, 20%, and 25%, and glass powder was replaced by cement in varying proportions of 10%, 20%, and 30% . The study to determine the strength parameters of M30 grade concrete. As the results, the maximum compressive strength when percentage of replacement was found to be 20% crushed spent fire bricks with 20% glass powder.

2.5 Chemical Composition of Waste Glass

A municipal recycling company in Cairo, Egypt supplied the soda-lime glass waste generated by the lapping machine. A comprehensive elemental analysis of this industrial waste was introduced in the past study, and it was mostly made up of SiO_2 (71.6 wt.%), Na_2O (13.5 wt.%), CaO (9 wt.%), and MgO (3.87 wt.%), with a trace of Al_2O_3, Fe_2O_3, SO_3, and K_2O (about 1.71 wt.%) [19]. Chemical analysis revealed that WG contains a high concentration of SiO_2 (72.56 %), CaO (9.81 %), and Na_2O (12.41 %). WG powder acts as a fluxing agent due to its high sodium oxide (Na_2O) content and non-crystalline structure. Furthermore, the fluxing agent reduces the temperature needed for sintering bricks [12].

Table 2.3 shows the results of SEM and EDX assessment of the grain structural and chemical composition of waste glass aggregates, with SiO_2 had the highest composition followed by Na_2O and K_2O. The chemical composition of the different waste glasses differed significantly and can be defined by their colour [20].

Table 2.3: Chemical Composition of Waste Glass [20]

Type	Chemical composition		
	Emerald green glass (%)	Amber glass (%)	Flint glass (%)
SiO_2	71.30	72.10	73.04
Al_2SO_3	2.18	1.74	1.81
Na_2O+K_2O	13.07	14.11	13.94
$CaO+MgO$	12.18	11.52	10.75
SO_3	0.053	0.13	0.22
Fe_2O_3	0.596	0.31	0.04
Cr_2O_3	0.44	0.01	–
Grain shape	Angular	Angular	Angular

Because glass has chemical properties comparable to sand and cement, the construction sector, notably the construction materials industries, might provide a very effective and critical solution to the environmental impact of waste glass. The reuse of crushed waste glass in the construction materials such as production of brick and concrete conserves the earth's natural resources, saves energy and money, and reduces CO_2 gases and other greenhouse emissions. Yixin Shao, [7] was reported while glass has a higher silica content than fly ash, its equivalent reactive components (SiO_2+ Al_2O_3+ Fe_2O_3) are significantly small. The silica fume contained the most reactive silica of the three. Soda lime has the second highest SiO_2 component. According to ASTM C618 [21], the glass meets the basic chemical requirements for a pozzolan and has a preferred white colour.

2.6 Benefits of Waste Glass in Building Materials

The performance of brick with the mix of waste glass was reviewed from a previous study. The use of glass waste in building materials has many advantages, especially in disposal costs and also in avoiding soil pollution. One significant benefit of using waste glass in construction materials is that it is environmentally friendly, resulting in fewer garbage being thrown away in landfills. Even though the impact of this procedure is not immediately apparent, the researchers believe that it will be beneficial not only to the environment but also to the building industry in the future [22]. As reported by Ling, [1] the effect of waste glass in the building materials can improve the durability of the brick because of the increased resistance to abrasion and acid. According to Koli Nishikant [23] , there are various advantages to using crushed waste glass in the production of construction materials and bricks:

a) Glass is one of the most durable materials since it absorbs almost no water.

b) The excellent tensile strength of glass could provide enhanced wear resistance to the building material, reducing the raw materials used.

c) Glass aggregates could enhance the flow characteristics of concrete, such as the strength of building materials, which can reduce weight when compared to conventional concrete mixtures.

d) The aesthetic potential of colour-sorted, post-consumer glass is still to be fully explored, but it offers numerous architecture design applications.

e) The reuse of waste glass can reduce the cost of raw materials in the building construction thus reducing the construction cost and increasing the company's profit.

2.7 Previous Studies on Concrete

The effect of glass bottle bricks in cement mortar was evaluated in a previous experiment. Cubes of standard size 150 mm x150 mm x150 mm have been cast tested for 7,14, and 28 days. The compressive strength values for 14 days have increased by 25% compared to 7 days strength (9 MPa), and the compressive strength values for 28 days have increased by 9% compared to 14 days strength (12.5 MPa) [24].

This study looked into the respond of waste glass admixtures on the physical and mechanical properties of the brick. In place of natural clay, bricks were made with 2 %, 4 %, 10%, 16%, 30%, and 40% waste glass. There has been no substantial increase in the characteristics of the brick with the addition of 2% and 4% WG. The pattern of strength development became more visible as WG content increased. With increasing WG content in the replacement of clay, compressive strength increased while water absorption decreased [12].

Based on Vandhiyan, [25] glass powder was tested in combination with concrete and mortar. Glass powder was used to replace cement in the following proportions: 5%, 10%, and 15%. The compressive strength results for cement mortar at 7 days show an increase in early strength gain, especially at specimen 15%. GP provided a 29% increase in strength on the 7th day over the control sample. All glass powder replacements improve strength. Whereas the values for compressive strength of concrete cubes are reduced at 15% replacement. When the strength gain is compared to the cement mortar strength development, it is clear that even with 15% glass powder replacement, there is an increase in performance. This is most likely due to the dilution effect, which causes the strength to decrease.

In another experiment, at the age of 28 days, a 15 cm x 15cm x 15cm mould is used in the concrete 5 %, 10%, and 15% substitution of cement and coarse aggregate. The compressive strength of the sample of M25 ratio with the addition amount of glass powder and brick aggregate has more strength when compared to normal concrete mixture because of the glass powder. Because fibre is taken with the weight of cement, the compressive strength decreases after the addition of brick aggregate content. Glass powder and brick aggregate-based concretes have shown an increase in strength for a 15% replacement of cement and coarse aggregate [26].

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research methodology provides the procedure and methods used to make a brick made of waste glass with different particle sizes and percentages. The methodology includes the raw materials and the mixture design for sand-cement bricks. At last, this chapter describes in detail the chosen mode of experimental and data collection method for the materials.

3.2 Materials

All the materials used in this experiment are readily available in the area. In this study, sand-cement bricks will be used with 10%, 20%, and 30% of waste glass as a partial replacement for sand and different sizes of waste glass particles.

3.2.1 Type of Glass

Most of the glass bottles are soda-lime glass. Soda-lime glass is lighter and more porous, with an easy-to-clean and perfectly alright surface. Soda-lime glass proliferates when heated, so use caution when filling a soda-lime glass container with hot water. It was highly corrosive and reactive. As a result, it cannot be kept open. It should be kept out of the reach of children, and when used in an experiment, it must wear protective equipment. Soda-lime glass can be produced in large quantities because the cost is cheap compared to other glass, such as bottles, drinking glasses, and windows. Figure 3.1 shows the glass bottles that will be used for the sand-cement brick mixture. According to Gupta, [4] soda-lime glass has been tested and approved for use as pozzolanic Portland cement and fine aggregate in cement mortar mixes. Waste glass particles improve the compressive strength of cement mortar by up to 25% when natural sand is replaced. Glass powder improves mortar flow due to its delicate texture and low water absorption. Because of the finer particles required to wet their texture, the use of glass sand reduces the flow properties of mortar. Sharp edges, particle contact pressure, and an irregularly shaped with a high aspect ratio all contribute to decreased mortar flow.

Figure 3.1: Soda-lime glass

3.2.2 Raw Materials

This experiment used cement and sand as the primary raw materials to make the bricks. The WG was collected from the drink bottles. In this brick manufacture, CASTLE is a bagged Portland Composite Cement, with the certified requirement to MS EN 197-1: 2014 used. Fine aggregate is formed by the natural dissolution of rock and placed by streams or glacial agencies as materials in a concrete mixture. The sand from the river was used in its natural form and differed in terms of particle size from crushed rock. Sands that have been sifted and separated from organic material in dry environments by the action of running water are often of uniform grain size.

The waste glass was crushed using a manual hand crusher that had been fabricated. The crushed waste glass will go through three different mesh sizes. The main objectives are to divide the crushed waste glass into other particles of 0.5 cm, 1.0 cm, and 2.0 cm. Figure 3.2 (a) shows the sand, cement, and Figure 3.2 (b) crushed waste glass to make the brick.

a) b)

Figure 3.2: Raw materials for brick manufacture a) Sand and Cement b) Crushed glass

3.2.3 Glass Crusher

A manual glass crusher is intended to crush drink glass bottles before separating them to the desired particle size. The materials used to make the glass crusher are mild steel with a few manufacturing processes. The processes include cutting, welding, and lathing the circular solid steel. The inside diameter of hollow circular steel is about 70mm, which is where to fix the glass bottle. The manual glass crusher finds fine glass particles that can be recycled for the formation of new glass particles, requiring 60% less energy, and its use in building materials as a partial replacement for fine aggregate (sand). Figure 3.3 shows the final product of the manual glass crusher.

Figure 3.3: Manual Glass Crusher

3.3 Mixture Design

In order to achieve comparable results, three groups of sand-cement bricks were prepared for different mix proportions and particle sizes. The viability of using waste glass as a sand replacement in bricks is being investigated to determine its impact on performance and mechanical strength.

3.3.1 Moulding of Bricks

The moulds were made of fine-surfaced wood (pine wood) and measured 210mm x 100mm x 65mm, as shown in Figure 3.4. These moulds were lubricated before use to prevent the bricks from sticking to the mould wall. The number of brick samples for this experiment is 30, which contains 27 of WGB and 3 of CB and the bricks were dried for three days. All the mixture proportions were manually compacted in this mould to reduce the porosity of the brick.

Figure 3.4: Brick Mould

3.3.2 Size of Waste Glass Particle

The produced crushed waste glass is divided into 0.1 cm, 1.0 cm, and 2.0 cm, as shown in Figure 3.5. The particle size distribution uses mesh sizes with different sizes. In a study, when used in the proper proportions, crushed glass increases the strength and durability of concrete. Glass is a material that can be recycled and reused numerous times without losing its chemical properties. The crushed glass properties should match those of the cement[17]. Glass is crushed to specific sizes for use as aggregate in sand replacement in construction materials.

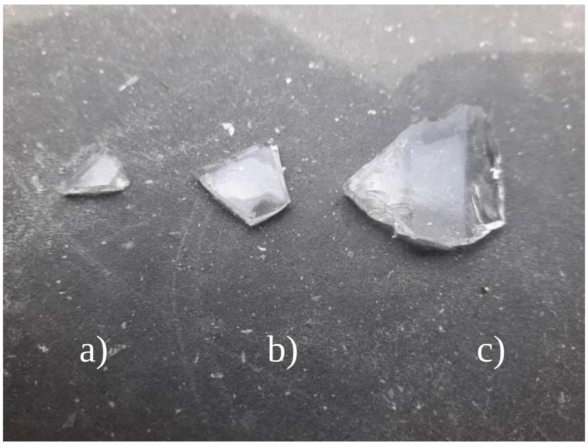

Figure 3.5: Size of Crushed Waste Glass a) 0.5cm waste glass b) 1.0cm waste glass c) 2.0cm waste glass

3.3.3 Mixture Proportion

The crushed waste glass bottle was used as a partial substitute for sand in the glass concrete mixes at 10%, 20%, and 30% by weight. This is shown in Tables 3.1, 3.2, and 3.3. The first part of the study looked into the effect of using waste glass aggregate (0.5cm, 1.0cm, and 2.0 cm) as an aggregate replacement with the same volume. It prepared concrete mixes with three samples of WGB in the proportions specified for each combination. There are three CB samples with no waste glass

Table 3.1: Mixture proportion for 0.5cm of waste glass

	Cement (wt.%)	Sand (wt.%)	Waste Glass (wt.%)	Quantity (Pcs)
A1	20	70	10	3
B1	20	60	20	3
C1	20	50	30	3

Table 3.2: Mixture proportion for 1.0cm of waste glass

	Cement (wt.%)	Sand (wt.%)	Waste Glass (wt.%)	Quantity (Pcs)
A2	20	70	10	3
B2	20	60	20	3
C2	20	50	30	3

Table 3.3: Mixture proportion for 2.0cm of waste glass

	Cement (wt.%)	Sand (wt.%)	Waste Glass (wt.%)	Quantity (Pcs)
A3	20	70	10	3
B3	20	60	20	3
C3	20	50	30	3

3.4 Sample Preparation

Sand-cement brick samples were made by mixing all the raw materials (sand and glass) as specified in Table 3.1, Table 3.2, and Table 3.3. The raw materials were manually mixed in each batch of samples until uniformity was achieved. Then about 20–25 wt.% water was added to the mixture to produce a sand-cement brick paste, which was cast into rectangular moulds measuring 210mm ×100mm× 65mm. The percentages of materials are calculated by weight for each brick. The procedure used was weighing the material, where this type of method is more effective than the volumetric method. To conduct the experimental studies, 30 samples were prepared, with three samples manufactured from each mixture. The samples were sun-dried for three days in an open area before being tested after 28 days. The experiment will investigate the effects of using recycled glass bottles as a fine aggregate alternative. These bottles were cleaned to prevent external materials or chemicals from contaminating the specimens. After cleaning, they were manually crushed and sieved to maintain consistency in particle size. The compressive strength was tested using a universal testing machine on full brick, according to ASTM specifications. For the microstructure analysis, the brick fragments sample is present for CB and WGB with different sizes of waste glass for examination under scanning electron microscopy (Hitachi S-3400N Variable Pressure SEM). The sample size was reduced by using the cone and quartering method. The sample was discharged onto a flat surface, forming a conical shape. The conical shape's top was flattened. The cone is cut into quarters. The remaining two quarters were merged after discarding two opposite quarters. The process is repeated until the sample size desired is acquired. [27].

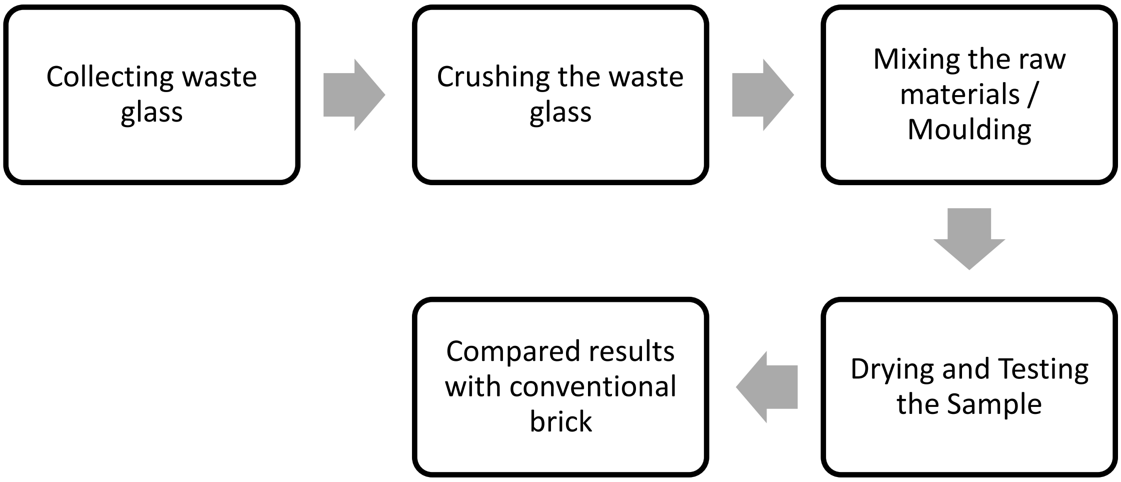

Figure 3.6: Experimental Design

Figure 3.6 depicts the experimental design used to recycle soda lime from drink bottles until it is formed into waste glass bricks and compared with control bricks and existing sand-cement bricks. In this project, the glass waste material used is transparent in color, which gives consistency to the brick mixture. The waste glass will be crushed using a manual crusher. The mixing processes are based on the proposed mix proportions and the WGB paste is moulded into the mould and manually compacted.

3.5 Sample Testing

The brick samples were then subjected to a variety of tests, including water absorption and compressive strength, to establish their quality in contrast to ASTM Standards.

3.5.1 Compressive Strength

The compressive strength of a material is the uniaxial compressive stress attained when the specimen totally fails. In each waste glass ratio, 3 brick specimens were examined, and the mean of these three different values was recorded [18]. The compressive strength variation of control bricks and waste glass bricks for curing periods of 28 days. Figure 4.1 shows the compressive strength machine for the brick testing. Determine each brick sample's compressive strength as described in the following:

$$Compressive\ Strength = \frac{W}{A}$$

$$W = Maximum\ load, N$$

$$A = Surface\ area\ of\ the\ brick\ sample, mm^2$$