The Utilization of Crushed Waste Glass in Mortar

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ABSTRACT

Waste glass creates serious environmental problems, mainly due to the inconsistency of waste glass streams. There is increasing environmental pressure to reduce solid waste and to recycle as much as possible. On the other hand, it is known that all of the waste glass is not been used for recycling.

The properties of mortar containing waste glass as fine aggregate were investigated in this study. Produced mortar will be tested for fresh and hardened properties on specified ages.

Mortar produced will have two types of aggregates. These are crushed sand and crushed waste glass. A statistical analysis of flow table, unit weight, flexural and compressive strength, water absorption, drying shrinkage, porosity, dry density, freeze-thaw resistance and permeability test results are given.

Keywords: Waste glass, mortar, silica fume, unit weight, flow table, compressive strength, flexural strength, porosity, absorption, drying shrinkage, dry density, freeze-thaw resistance, permeability.

ÖZ

Atık cam ağırlıklı olarak içeriğinden dolayı çevre sorunları yaratmaktadır. Katı atıkların azaltılması ve mümkün olduğunca geri dönüşüm olması için çevreci kuruluşlardan baskı olmaktadır. Diğer taraftan ise tüm atık camın geri dönüşümde kullanılamadığı da bilinmektedir.

Bu çalışmada doğal kumdan ve atık camdan üretilen ve ince agrega olarak kullanılarak elde edilen harçların çeşitli özellikleri incelenmiştir. Üretilen harçların hem taze hem de kuru özelliklerini belirlemek için deneyler yapılmıştır. Birim ağırlığı, eğilme ve çekme dayanımı, emilim, kuruma büzülmesi, gözeneklik, kuru yoğunluk, donma-çözünme dayanımı ve geçirgenlik deneyleri üretilen harçlar üzerinde yapılmıştır. Elde edilen sonuçlar ise doğal kum miktarı ve atık camdan elde edilen kum miktarı ile ilişkilendirilmiştir.

Anahtar Kelimeler: atık cam, harç, silis dumanı, birim ağırlığı, akma tablası, basınç dayanımı, eğilme dayanımı, porosite, su emme, büzülme, kuru yoğunluk, donma-çözünme dayanımı, geçirgenlik.

To Everyone Who Trust Me

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ASR	Alkali silica reaction
ASTM	American Society for Testing and Materials
BS	British Standard
CRD	Different between comparator reading and reference bar
EN	European Standard
G	Gage length
p_g	Absorption
P_g	Porosity
SG	Specific Gravity
SSD	Saturated Surface Dry
TS	Turkish Standards

Chapter 1

INTRODUCTION

1.1 General

Many researchers have been studying new types of wastes to deeply investigate particular aspects. Taking advantage of wastes, apart from the environmental benefits, produces good effects on the properties of final products. One of the new waste materials used in the concrete industry is recycled glass. Moreover, the reuse of glass in concrete industry is considered as the most feasible application [1]. Glass is used in day to day life in various ways. It has a limited life and after use, it is going to be stockpiled or sent to landfills, because glass is not biodegradable. Landfills are not a solution because it's not helping the environment. Therefore, there is a strong need to use waste glass and utilize it. Many efforts try to use waste glass in concrete as a coarse aggregate, fine aggregate and cement. The present study aims to use waste glass powder as a filler or pozzolan to compare the performance with other materials like fly ash and aggregate.

The quantities of waste glass in Cyprus especially in Mağusa are increasing without being recycled. Waste glass is the cheapest of all the mortar ingredients and cheaper than aggregates and sand. So we save and clean the nature from wastes. There is increased interest to developing the utilizing of waste glass as part of the mortar. This interest has been bothered by the extensive measure of waste glass accessible from void jugs, trash windows glass and compartments. If such glass could be expended in solid, it would fundamentally diminish the transfer of waste glass and take care of some of the ecological issues. The utilization of waste glass as total in cement has been endeavored recently. Utilizing such glass as a development material is the most reasonable choice due to the possibility of decreasing the expense of glass transfer and robust creation. It is normal that marked contrasts happen in the structure between glass and mortar [2-3]. Typically glass does not hurt the earth at all since it doesn't emit poisons. The term glass contains a few compound diversities including pop lime silicate glass, salt silicate glass, and borosilicate glass. To date, these sorts of glass powder have generally been utilized as a part of the bond and total blend as pozzolana for popular works. The presentation of waste glass in the bond will build the soluble base substance in the mortar. It additionally helps in blocks production and it crude jam materials, diminishes vitality utilization and volume of waste sent to landfill. As helpful reused materials, glass powder are principally utilized as a part of fields identified with the structural building, for instance, in bond, as pozzolana (supplementary cementitious materials), and coarse aggregate. They are additionally utilized as a part of cement without antagonistic impacts in solid strength. In this manner, it is viewed as perfect for reusing [4].

1.2 Problem Statement

The waste glass constitutes approximately 3% of the total solid waste in the world and usually consists of carbon dioxide, potassium carbonate, calcium carbonate, sodium carbonate, silicon and other oxides for coloring glass [5]. The similarity of these components with raw material components in the cement industry encouraged the community on the experience of the use of glass as a partial substitute for the raw materials in the cement industry. The glass is a straightforward material created by liquefying a blend of materials, for example, silica, pop fiery remains, and CaCO3 at high temperature took after by cooling amid which hardening happens without crystallization. The glass is broadly utilized as a part of our lives through made items, for example, sheet glass, containers, crystal, and vacuum tubing. The glass is a perfect material for reusing. The utilization of reused glass in new compartment recoveries of vitality. It helps in block and clay assembling, and it monitors crude materials, lessens energy utilization, and the volume of waste sent to landfill. In Cyprus, the holder business can't devour the greater part of the reused compartment glass that will get to be accessible in the coming years, in the main because of the shading lopsidedness between that which is fabricated and that which is expended. The subsequent excess of green glass from imported jugs containing red wine might be sent out to make nations, or utilized locally as a part of the developing assorted qualities of auxiliary end uses for reused glass.

There are presently several methods of solid waste disposal in use, but many have serious disadvantages. The oldest method of disposal is the open dump. Open dumps pollute the air with strong odors, may pollute ground water, and clutter our countryside with appalling eyesores. Incinerators have the potential for handling the solid wastes; however, incinerators presently in use give off air pollutants and leave up to a 20 percent residue of ash which must still be disposed of. Sanitary landfills are perhaps the most promising means for solid waste disposal. However, required specifications such as minimum cover depths are seldom adhered to, thus resulting in a modified open dump. Even if they were built to specifications, they would be only a temporary solution since conveniently located sites for landfills are becoming scarcer in many areas. The search for new landfill sites in remote areas disturbs conservationists due to destruction of marsh habitats for wildlife, and the longer hauls increase cost and operational problems, especially in inclement weather [6, 7].

1.3 Aim and Objective

Especially in Cyprus, most of the waste glass is not recycled. This study will be focused on the production of mortars containing various proportions of waste glass as aggregate and fine aggregate. Produced mortar will be tested for fresh and hardened properties on specified ages.

The objectives of the thesis will be:

1) Determine the effect of waste glass on the properties of mortar mixes as a partial replacement of fine aggregate.
2) Determine the effects of waste glass on the fresh properties of mortar mixes such as unit weight and flow table
3) Determine the influence of waste glass on hardened properties of mortar mixes such as: dry bulk density, compressive strength, flexural strength, porosity, water absorption, freeze-thaw resistance, drying shrinkage and rapid chloride permeability.

1.4 Methodology of the study

1) Collecting the required documents related to usage of glass in concrete or mortar.
2) Collecting glass bottle.
3) Preparing the specimens according to standard specifications and testing.
4) Discussion of test results, conclusions and recommendations for future research.

1.5 Thesis Outline

This thesis consists of five chapters:

Chapter 1: Introduction

This chapter talks about general information and contains problem statement, aim and objective and methodology of the study.

Chapter 2: Literature Review

This chapter covers the previous studies of waste glass and previous research about the topic.

Chapter 3: Materials and Experimental Works

This chapter contains two topics; the first one is about the properties of materials used for samples, the second is procedure of the tests and experimental work.

Chapter 4: Data Analysis and Results

This chapter talks about the result of the tests and the effects of adding waste glass in mortar.

Chapter 5: Conclusions and Recommendations

This chapter is about the final conclusion and the recommendation for future research.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Glass is one of the archaic human-made material. It is delivered in various structures, for example, packaging, container and bulb glasses, all of which have a restricted life in their fabricated designs, and consequently it must be recycled to be reclaimable to steer clear of environmental cases that should be made if they anyway happened to be stockpiled or sent to junkyard. The evolution business has demonstrated awesome additions in the reusing of materials, including waste glass. A number of waste glass have been rising quickly in the last ten years due to the high augmentation in industrialization and the comprehensive change in the styles of life. However shockingly, the majority of the waste glass are not being reused yet rather relinquished leading to certain complex cases, as an illustration, the misapply of normal assets and environmental contamination [8].

2.2 Waste Glass

Hypothetically, it is a completely recyclable material; it can be reused with no damage of value. There are a lot of numerous cases of effective reusing of waste glass: like cullet in glass manufacture, as unrefined material of the creation of abrasives, in soil-impacting, as a pozzolanic added substance, in street beds, asphalt and parking areas, like crude materials to deliver glass spherule or dabs utilized as a part of intelligent, to manufacture fiberglass. It can also be manufactured from vacant glass pitchers and jugs [9]. This is normally smashed into small pieces that look like the grading sizes of rocks and sands. Consequently, there is a possibility to replacement the aggregate with waste glass due to the absence of characteristic recourses in Cyprus. Table 2.1 records some of proximate compositions and the relating employments of different regular types of glass [10].

Table 2.1:Approximate compositions of different regular types of glasses

Type of Glasses	Composition	Uses
Boro - Silica	81% SiO_2, 12% B_2O_3, 4% Na_2O and 3% Al_2O_3	Laboratory instruments
Alumino - Silicate	65% SiO_2, 24% Al_2O_3, 10% MgO and 0.5% Na_2O	Fiber glass isolation
Soda - Lime glass	73% SiO_2, 14% Na_2O, 9% CaO and 4% MgO	Windows and bottles
Crystal	57% SiO_2, 30% PbO and 13% K_2O	Lead crystal

In any case of the verity that waste glass can be recycled endlessly and can be reused as, a variety of times to create different items. In this way, continuous residual amount of waste glass coming about due to development retrogression and should be area filled or reused in blends as fractional substitute for coarse aggregate sand and fine aggregates [11].

Actually, glasses are generally made as tubes, poles, void vessels and an assortment of exceptional shapes, as well as flat glass for use basically in science, research laboratory, pharmaceuticals, optoelectronics, and various domestic uses. For the intention of categorization, the large number of specialized glasses can be generally roughly arranged in four principle bunches, as indicated by their oxide arrangement.

Boro - silica glasses is the primary principle class with the significant measures of SiO_2 and B_2O_3 (>8%) as glass system formers. The measure of boric oxide influences the glass properties especially. Aside from the exceptionally safe assortments B_2O_3 (≤13%) there are others that, because of the distinctive route in which the boric oxide is fused into the basic system have just low chemical resistance B_2O_3 (>15%). Besides, the alkaline-earth aluminosilicate glasses are free of salt oxides and contain (15-25%) Al_2O_3, (52-60%) SiO_2, and around (15%) soluble earths. High change temperatures and softening focuses are normal components. Primary fields of utilization are glass globules for incandescent lights.

The last classification is the most seasoned glass sort and in principle, they are antacid earth silicate glasses (pop lime glasses). It includes level glasses (window glass) and holder glasses, which are created in vast clusters. Such glasses contain around (15%) soluble base normally Na_2O, (13-16%) basic earths CaO+MgO, (0-2%) Al_2O_3 and around (71%) SiO_2. Variations of the essential piece can likewise contain noteworthy measures of BaO and basic earth content [12].

2.3 Previous Studies

Meyer [1] talked about "the steps that need to gather the glass, detach the glass from other materials, clean and pulverize it to get the suitable size to meet the specifications for particular like aggregate in mortar, with the main target being to use glass as much as possible. It is normal that commercial production of glass affect the financial matters of glass reusing".

Topçu and Canbaz [13] wanted to see the impact of waste glass on firmness and workability of the concrete. So they added waste glass in the concrete mix as coarse aggregates. The results showed that it would lower the cost of the concrete production but it had no notable effect on the workability nor the firmness.

Kou and Poon [14] employed the recycled glass to replacement river sand in different percentage level (10, 20 and 30), and 10 mm granite in different percentage (5, 10 and 15). They reached that there is a positive relationship between the recycled glass content and air content, blocking ratio, slump flow of the recycled glass self-compacting concrete mixes. Plus, there is an inverse relationship between the waste glass and the drying shrinkage.

On the other hand, Federico and Chidiac [15] considered waste bottle glass an augmenting cementing material and came to an end that there is a relation between the pozzolanic ASR and the mote size. Plus, adding lithium can hold ASR increasing in size.

Caijun and Keren [16] had different studies and they concluded that waste glass cannot be used as concrete aggregates for its bad effect on workability, firmness, and most importantly the breaking of concrete consisting of waste glass. For the sake of stopping possible abrasion in concrete, Portland cement should be displaced with pozzolanic materials like fly ash, meta-kaolin. Waste glass can also be used as crude materials for the production of the cement.

Palmquist [17] made utilization of glass, in pulverized structure, as another kind of reused material, as an aggregate in mortar. This reused material has been examined in mortar work pieces, and tests on mortar with glass aggregate. At the end, the compressive strength of the mortar with waste glass is lower than the mortar with normal aggregate.

Karamanoğlu and Eren [37] [38] focused on the production of mortars containing various proportions of waste glass and limestone filler. Waste glass and limestone filler was replaced with cement by weight. The mixes were made by Ordinary Portland cement (PÇ52.5), crushed sand, waste glass and limestone filler. The waste glass passing 75 μm BS sieve was partially replaced with cement by weight at percentages of 0, 5, 10, 15, 20, 25, 30 and 40. Also, limestone filler passing 75 μm BS sieve was partially replaced with cement by weight at percentages of 0, 5, 10, 15, 20, 25, 30 and 40.

Produced mortars were tested against fresh and hardened properties on specified ages. The experimental study of unit weight, flow table, compressive strength, flexural strength, porosity, absorption and drying shrinkage test results are given. Different relations were found between the replacements of cement with waste glass and limestone.

Below results were obtained:

- In all mixes, unit weight decreases compared to control mix.
- The consistency of the mortar decreased as the cement is replaced with waste glass, when compare with control mix.
- The flexural strength of the mortar decreases compared to control mix.
- A significant reduction in compressive strength is observed for all mixes compared to the control mix.

- A significant increasing in apparent porosity is observed for all mixes compared to the control mix.
- A significant increase in absorption is observed for all mixes compared to the control mix.
- As the level of replacement of cement with waste glass increases, the drying shrinkage reduces

Chapter 3

EXPERIMENTAL WORK

3.1 Introduction

This chapter demonstrates the properties of materials used to make the mortar samples. Also, mixture properties are given together with test methods.

3.2 Materials Used

3.2.1 Aggregate

Aggregate is an inert, inexpensive material dispersed throughout the cement paste so as to produce a large volume of mortar and also give stability and durability to mortar. The physical properties of the aggregates (crushed sand and crushed waste glass) as given in Table 3.3. The sieve analysis of the crushed sand given in Table 3.1. Grain size distribution of aggregates is given in Figure 3.2 (ASTM C136) [20].

Table 3.1: Crushed sand sieve analysis results

BS Sieve size (mm)	Weight retained (gr)	Total weight retained (gr)	Percentage retained	Cum. percentage retained	Cum. Percentage passing
4.75	**15.0**	**15.0**	**3.0**	**3.0**	**97.0**
2.36	**142.5**	**157.5**	**28.5**	**31.5**	**68.5**
1.18	**91.5**	**249.0**	**18.3**	**49.8**	**50.2**
0.6	**78.0**	**327.0**	**15.6**	**65.4**	**34.6**
0.425	**28.0**	**355.0**	**5.6**	**71.0**	**29.0**
0.3	**19.5**	**374.5**	**3.9**	**74.5**	**25.1**
0.15	**23.0**	**397.5**	**4.6**	**79.5**	**20.5**
0.075	**17.5**	**415.0**	**3.5**	**83.0**	**17.0**
Pan	**85.0**	**500.0**	**17.0**	**100**	**0**

3.2.2 Waste Glass

All of the glasses used for this study were obtained by crushing glass bottles consisting primarily of beer and soft drink bottles (green and white) collected from various places of Famagusta city. The initial treatment of the bottles consisted of a hot bath where labels and all other foreign materials were removed, after allowing the bottles to dry, crushed by hammer to get the required size to put in machine to get a powder glass for replacing with aggregate by weight at percentages of 0, 5, 15, 25, 35 and 45 see Table 3.8 and Figure 3.1 [37] [38]. The physical properties of the waste glass used in this research are given in Table 3.3. Table 3.2 shows the sieve analysis of the waste glass and the grain size distribution of waste glass is given in Figure 3.2.

Table 3.2: Sieve analysis results of crushed waste glass

Sieve size (mm)	Weight retained (gr)	Total weight retained (gr)	Percentage retained	Cum. percentage retained	Cum. Percentage passing
4.75	**0**	**0**	**0**	**0**	**100**
2.36	**0**	**0**	**0**	**0**	**100**
1.18	**0**	**0**	**0**	**0**	**100**
0.6	**2.5**	**2.5**	**0.5**	**0.5**	**99.5**
0.425	**28.5**	**31.0**	**5.7**	**6.2**	**93.8**
0.3	**28.0**	**59.0**	**5.6**	**11.8**	**88.2**
0.15	**241.0**	**300.0**	**48.2**	**60.0**	**40.0**
0.075	**65.0**	**365.0**	**13.0**	**73.0**	**27.0**
Pan	**135.0**	**500**	**27**	**100**	**0**

Figure 3.1**:** Waste glass powder

Table 3.3: Physical properties of crushed sand and crushed waste glass

Properties of Aggregate	Crushed Sand	Crushed Glass
Relative density SG (OD)	2.67	2.38
Relative density SG (SSD)	2.73	2.39
Apparent relative density SG	2.85	2.39
Absorption (%)	2.46	0

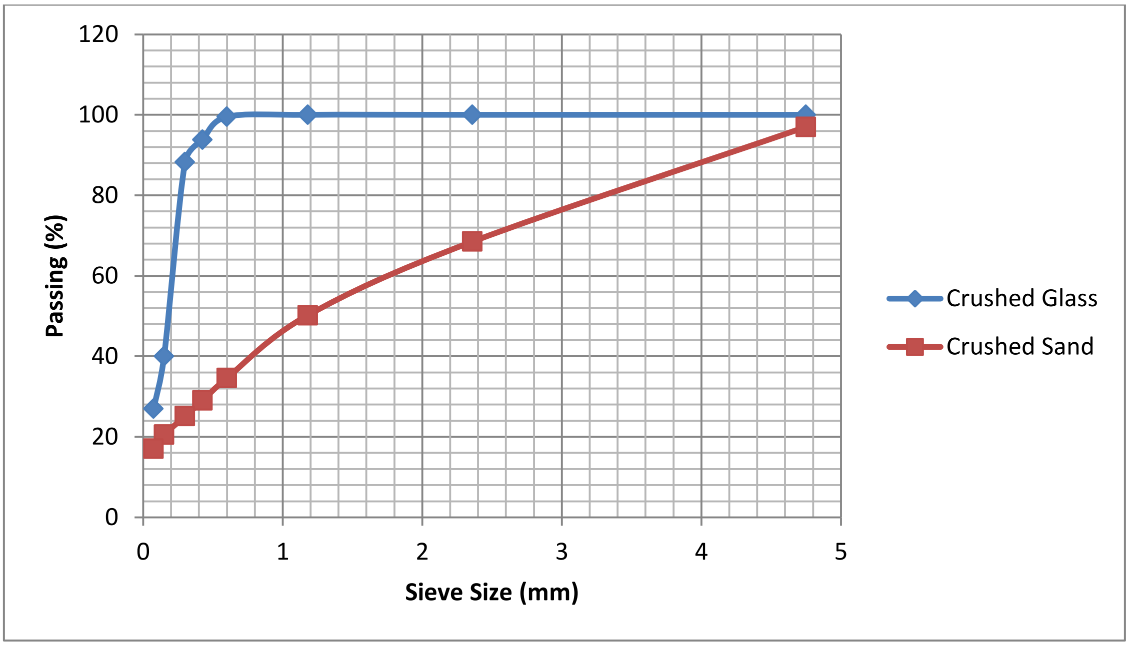

Figure 3.2: Grading curve of crushed sand and crushed glass

3.2.3 Cement

There are more than eight types of cement according to American standards (ASTM C150) [21] and cement is significant for mortar and it's the most important part for mortar mixture. For experimental part of this study Portland composite cement [CEM II/ B-M (S-L)] PO32.5R was used. Table 3.4 shows the chemical properties of cement and Table 3.5 shows the physical properties of cement used for this work [18-19].

Table 3.4: Chemical properties of cement

Oxide	Amount %
CaO	63.2
SiO_2	19.8
Al_2O_3	6.3
Fe_2O_3	3.2
MgO	1.5
K_2O	1.0
SO_3	2.5

Table 3.5: Physical properties of cement

Physical properties	Value
Initial Setting Time (min)	80
Final Setting Time (min)	520
Loss on ignition (%)	1.8
Fineness-Blaine (m^2/kg)	225
Compressive Strength (MPa)	
2 days	13
7 days	-
28 days	46

3.2.4 Water

Generally, cement needs water for hydration, because adding water will give flexibility for the mixture which gives the mortar workability. During the experiment, W/C ratio was (0.6). The drinking water was used for the mortar mix was satisfying (ASTM C94) [22].

3.2.5 Silica Fume

Silica fume is highly reactive pozzolanic material and used around 10% by mass of cement in the concrete. Silica fume is used for improving concrete performance also. However, silica fume is a very fine powder and the particles are about hundred time's smaller size than particle size of cement. Table 3.6 shows the chemical and physical properties of silica fume used for this study (ASTM C1240) [18-19-36].

Table 3.6: chemical and physical properties of silica fume

chemical and physical properties	Value
SiO_2	98.5%
CaO	0.25%
SO_3	0.25%
$Al_2O_3, Fe_2O_3, K_2O, MgO, Na_2O$	1%
PH – value	3.7 – 4.7
Bulk density	550 – 720 kg/m^3
Specific gravity	2.2
Specific surface	15000 – 30000 m^2/kg
Moisture	1.8%

3.3 Methodology

3.3.1 Preparation of Mortar Mixtures

Mixing completed by using weight-batching method according to ASTM C305 [23]. The mixtures were blended in a mortar mixer and the mixture components placed in the following order; put the water, cement and silica fume will be placed in bowl and mixed at slow speed for 30 seconds then sand and waste glass will be added slowly in same speed for another 30 seconds. After that, the speed of mixer will be changed to medium for 30 seconds then stopped. Then the mixer will be kept with mortar for

15 seconds. Finally, the mixer will be turned on for 60 seconds at medium speed. Therefore, total mixing time will be 165 seconds.

3.3.2 Compaction Method

Vibrator was used for compacting the fresh mortar. The compaction time for all mixes was 60 seconds during the test.

3.3.3 Curing Method

Specimens were kept in moulds for one day in the moisture room and after 24 hours, specimens were removed from the moulds and put in water curing tank until testing age. The temperature of water was kept around 20 ℃ according to (ASTM C109 M) [24], as shown in Table 3.7.

Table 3.7: Average temperature of water curing

Time (Week)	Average temperature (℃)
1	18.4
2	18.8
3	18.5
4	18.9
5	19.1
6	19.5
7	19.7
8	19.4

3.3.4 Specimens

The specimen size was $40 \times 40 \times 160$ mm for flexural strength, compressive strength, absorption, dry bulk density, drying shrinkage, freeze – thaw resistance and porosity tests. The size of samples was 51 mm thick × 102 mm nominal diameter for rapid chloride permeability test.

Table 3.8: Proportioning of mortar mixes for 1 m^3

# of mix	Waste glass (%)	Waste glass content (kg/m^3)	Fine aggregate content (kg/m^3)	Cement content (kg/m^3)	Water content (kg/m^3)	Silica fume content (kg/m^3)
1	**0**	**0**	**1868**	**603**	**362**	**60**
2	**5**	**94**	**1774**	**603**	**362**	**60**
3	**15**	**280**	**1588**	**603**	**362**	**60**
4	**25**	**467**	**1400**	**603**	**362**	**60**
5	**35**	**654**	**1215**	**603**	**362**	**60**
6	**45**	**841**	**1027**	**603**	**362**	**60**

3.4 Testing Program

3.4.1 Testing of Fresh Mortar

3.4.1.1 Unit Weight

A sample of freshly mixed mortar was obtained according to ASTM C 138 [25] in the following order. The mass and volume of an empty vessel was recorded and three equal layers of mortar were added to the vessel. The first layer was filled and compacted. The second layer was added on top of the first layer and the same action was performed. Following this, the third layer was added to fill the entire vessel.

3.4.1.2 Flow Table

Consistency was measured according to ASTM C 1437 [26]. A sample of fresh mortar was obtained and placed in the flow table. Sequentially, the table was dropped 25 times on the sample in 15 sec time interval. Four measurements were taken and the average of them was recorded.

3.4.2 Testing of Hardened Mortar

3.4.2.1 Dry Bulk Density

Following the BS EN 1015-10 standard [27] a dry sample of mortar was obtained and placed in the oven for 24 hours. After removing the sample from the oven it was placed to cool down to room temperature. Subsequently, the sample was immersed in water (20 ± 2℃) for a period of 24 hours in order to be fully saturated. Two measurements were taken of the sample. Once while the sample was immersed in the water and the second when it was removed from the water.

3.4.2.2 Compressive Strength

According to ASTM C349 [28] compressive strength tested by three different ages of 3, 7 and 28 days. The testing machine was adjusted to have a rate of loading 0.5 MPa/sec.

3.4.2.3 Flexural Strength

According to ASTM C348 [29] the sample size is 40 × 40 × 160 mm and tested by three different ages of 3, 7 and 28 days. The rate of loading was adjusted to be 0.5 MPa/sec.

3.4.2.4 Porosity

According to standard test method TS 699 and ASTM C20 [30] the test specimens were put in oven for 24 hours and the weight recorded and then immersed in water (20 ± 2 ℃) for 24 hours to be fully saturated and the weight was also recorded.

3.4.2.5 Absorption

Two ways of calculation of absorption were performed. The first calculation used the weight of water absorption per unit area. According to BS EN 1015-18 [31] a sample of mortar was dried in the oven at 105 ± 5 ℃ for 24 hours then placed to cool down to room temperature. Subsequently, the sample was placed in a pan containing 5mm of deionized water. Furthermore, the weight of the sample was recorded at different time intervals. The second way to calculate the percentage of absorption by mass is according to TS 699.

3.4.2.6 Freeze – Thaw Resistance

A solution of sodium sulfate was prepared 48 hours prior to use according to ASTM D5240 [32]. A sample was dried at constant mass at (110°C) in the oven and the mass was immediately recorded. Subsequently the sample was immersed in the prepared solution of sodium sulfate that had a depth of 12.5 mm, for 17 hours and then removed. The process was repeated for a total of five cycles.

3.4.2.7 Drying Shrinkage

According to ASTM C596 [33] and ASTM C157 [34] the sample was removed after three days of being immersed in water and reading were recorded after 4, 11, 18, and 25 days in air storage.

3.4.2.8 Rapid Chloride Permeability

Specimens of 51 mm thick slices and 102 mm diameter according to ASTM C1202) [35] were obtained. Two separate solutions of sodium chloride and sodium hydroxide were prepared at temperature less than 90°C. The sample was placed in a vacuum desiccator for three hours at (6650 Pa) and then the water stopcock was opened to cover the specimen and not allow air to enter desiccator. Subsequently the desiccator was opened with the specimen immersed in water for 20 hours. The last step involved putting the permeability chamber for 6 hours and then the results were recorded.

Chapter 4

RESULTS AND DISCUSSION OF RESULTS

4.1 Introduction

The aim of this chapter is to discuss test results of fresh and hardened mortar.

4.2 Test Results of Fresh Mortar

4.2.1 Unit Weight Test

The effects of aggregate replacement with waste glass on unit weight are given in Table 4.1 and Figure 4.1.

Table 4.1: Results of Unit Weight Test

Mix #	% of waste glass	Unit weight (kg/m^3)
1	**0**	**2264**
2	**5**	**2319**
3	**15**	**2287**
4	**25**	**2244**
5	**35**	**2201**
6	**45**	**2145**

The unit weight of fresh mortar decreases compared to mortar mixture without glass. As Figure 4.1 shows, it can be observed that the unit weight of fresh mortar reaches its peak in the second mix (5% of waste glass) with an amount of 2319 kg/m^3. Also it is shown in figure that the unit weight was at its minimum amount (2145 kg/m^3) when the percentage of glass was at maximum level (45%). It can be seen that the replacement of aggregate with waste glass has no clear effect on unit weight.

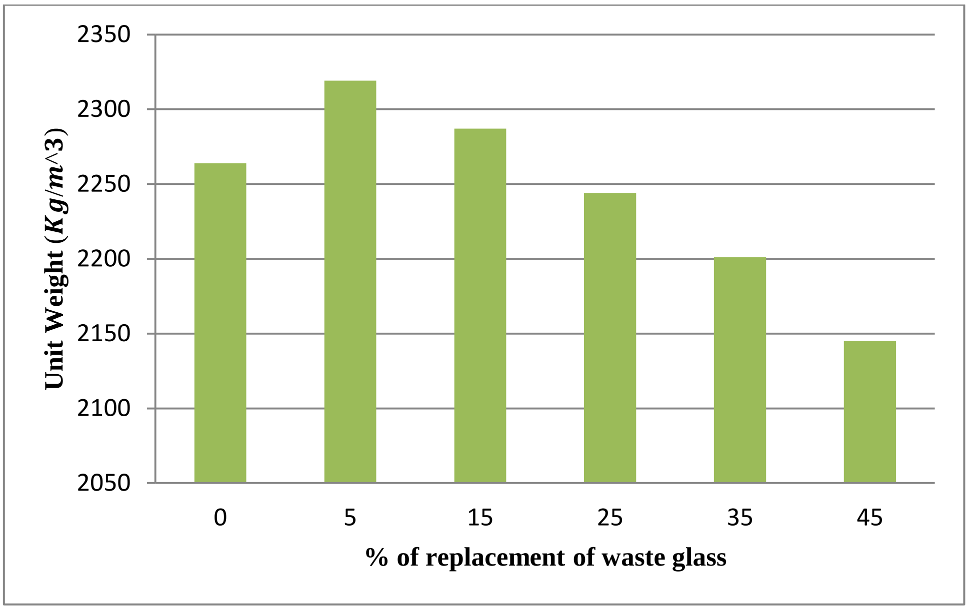

Figure 4.1: Effect of aggregate replacement level with waste glass on unit weight.

4.2.2 Flow Table Test

The effects of aggregate replacement with waste glass on flow table are given in Table 4.2 and Figure 4.2.

Table 4.2: Result of Flow Table

Mix #	% of waste glass	Flow table (cm)
1	0	14.18
2	5	15.23
3	15	14.97
4	25	15.05
5	35	14.58
6	45	13.15

Figure 4.2 describes the consistency of the mortar with respect to the percentage of waste glass. It can be seen that consistency dramatically changes among different mixes. The following graph shows an increase from mix 1 to mix 2, which reaches 15.23cm. It then begins to steadily decrease from mix number 3 to mix number 6, eventually reaching a reading of 13.15cm. In general, the mortar workability rises slightly when waste glass is added.

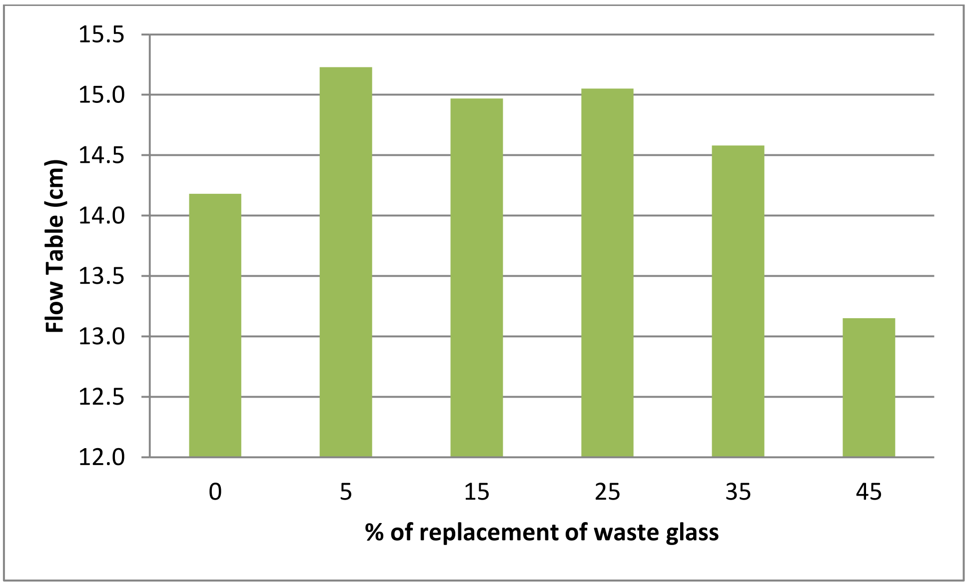

Figure 4.2: Flow table test results with aggregate replacement level with waste glass

4.3 Test Results of Hardened Mortar

4.3.1 Dry Bulk Density

Results of dry bulk density test are given in Table 4.3 and Figure 4.3.

Table 4.3**:** Result of dry bulk density

Mix #	% of waste glass	Dry Bulk Density (kg/m^3)
1	**0**	**2165**
2	**5**	**2168**
3	**15**	**2147**
4	**25**	**2113**
5	**35**	**2055**
6	**45**	**2014**

It can be seen that 45% replacement of aggregate with waste glass dropped the dry bulk density by 7% compared to control mix. It is important to say that 0% and 5% waste glass replacement shows slight difference in the density. Moreover, the relative density of crushed glass is less than relative density of crushed sand and also glass powder is lighter compare to sand.

Figure 4.3: Effect of aggregate replacement with waste glass on dry bulk density.

4.3.2 Compressive Strength

The results of compressive strength tests at 3, 7 and 28 days are given in Table 4.4, Figure 4.4 and Figure 4.5.

Table 4.4: Results of Compressive Strength Test

Mix #	Percentage of waste glass	Compressive strength (MPa)		
		3 days	***7 days***	***28 days***
1	**0**	**1.89**	**13.00**	**20.29**
2	**5**	**1.84**	**12.42**	**20.84**
3	**15**	**1.84**	**11.27**	**19.80**
4	**25**	**1.90**	**9.22**	**14.10**
5	**35**	**2.85**	**7.19**	**14.50**
6	**45**	**2.77**	**6.24**	**10.26**

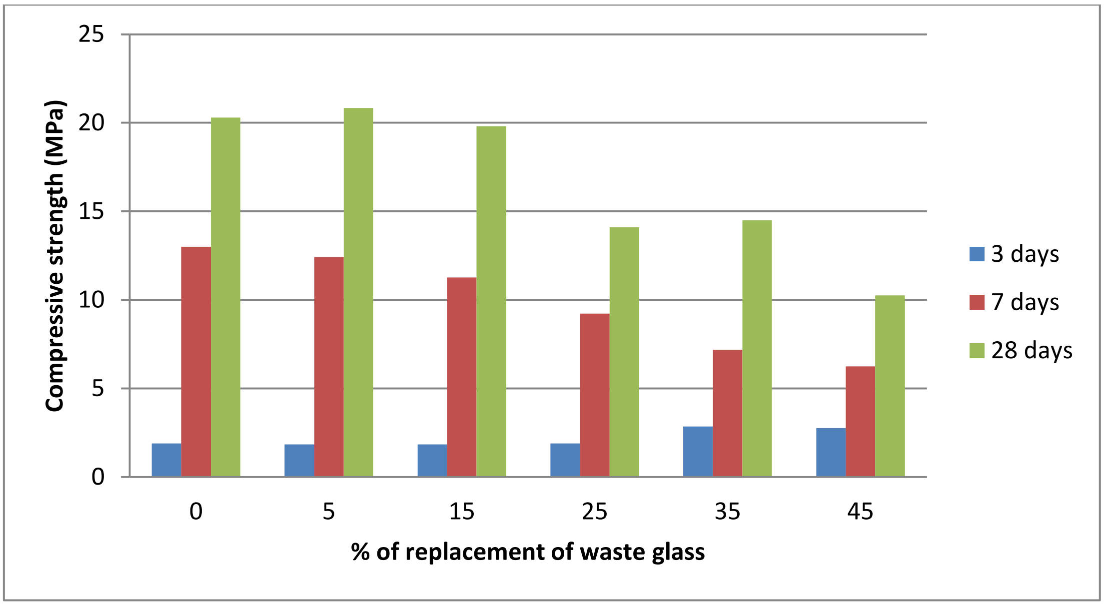

Figure 4.4: Effect of fine aggregate replacement with waste glass on compressive strength at different ages.

The following chart indicates the effect of aggregates with waste glass in compressive strength at 3 different time stages (3 days, 7 days and 28 days, respectively). The compressive strength of the samples at 3 days showed a slight difference with the differing percentages of waste glass, eventually reaching it's maximum strength of 2.85 MPa at 35% of waste glass. Unlike the 3 day sample, the sample at 7 days observed a decrease in strength with the increasing percentage of waste glass, albeit having a higher compressive strength than the 3 day sample. Tests done after 28 days showed also a decrease in compressive strength with the increasing percentage of waste glass, yet a higher compressive strength then the 3 and 7 day sample tests. The strength reduces as percentage of waste glass increases due to the weak bonding between the cement paste and the glass aggregate.

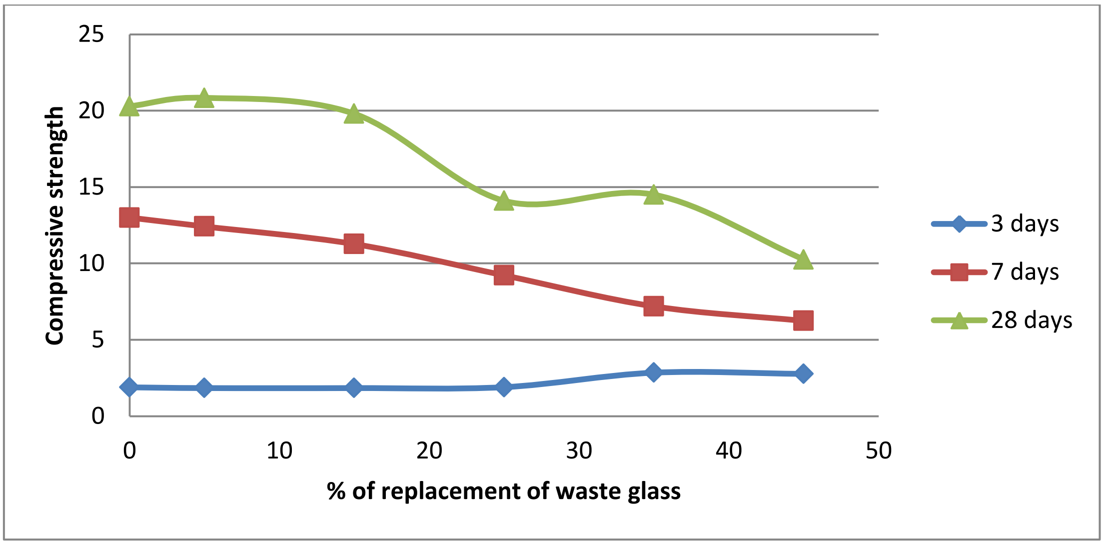

Figure 4.5: Effect of fine aggregate replacement with waste glass on compressive strength at different ages.

* Flow chart in Figure 4.5 shows the behavior of the mortar at three different ages.

4.3.3 Flexural Strength

The results of flexural strength tests at 3, 7 and 28 days are given in Table 4.5, Figure 4.6 and Figure 4.7.

Table 4.5: Result of Flexural Strength.

Mix #	Percentage of waste glass	Flexural strength (MPa)		
		3 days	***7 days***	***28 days***
1	**0**	**1.62**	**8.30**	**12.79**
2	**5**	**1.67**	**8.37**	**13.57**
3	**15**	**1.69**	**7.59**	**13.49**
4	**25**	**1.89**	**6.91**	**12.25**
5	**35**	**2.24**	**4.95**	**11.26**
6	**45**	**2.29**	**4.23**	**9.20**

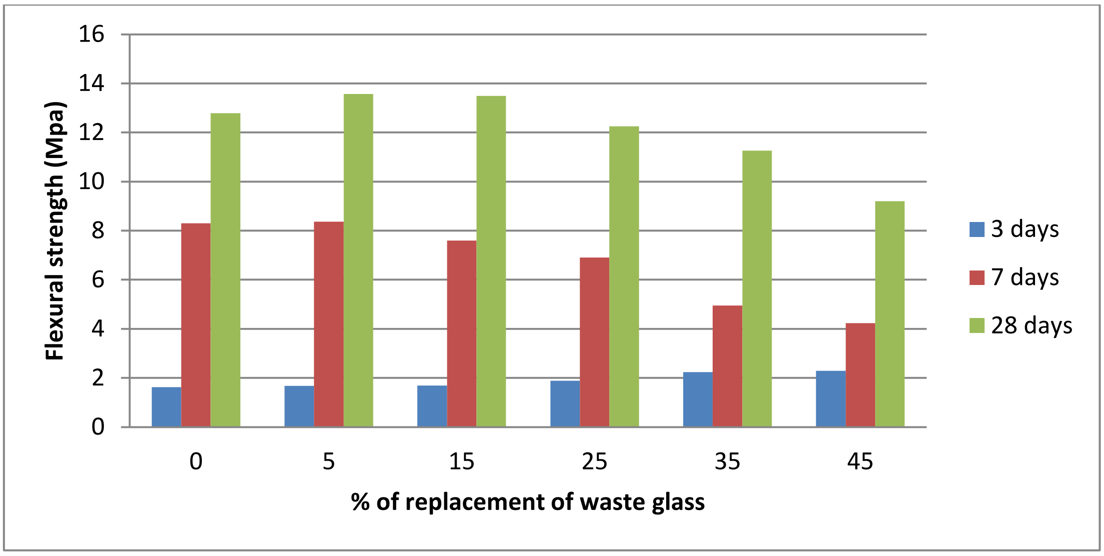

Figure 4.6: Effect of aggregate replacement with waste glass on flexural strength

Figure 4.6 exhibits the flexural strength of the mortar at three different ages. The test at 3 days indicates a minor increase up to 15% then a gradual increase up until it reaches 45% waste glass. At 7 days the flexural showed an slight uptick, reaching its highest flexural strength at 5%, and then gradually decreasing strength with increasing percentage of waste glass. A similar trend was observed at 28 days sample test, aside from having an overall higher flexural strength than both sample tests at 3 and 7 days. It's highest flexural strength value also occurred at 5% waste glass, afterwards decreasing in strength value with increasing waste glass percentage. The flexural strength decreased because of the weak bonding between the cement paste and the glass aggregate.

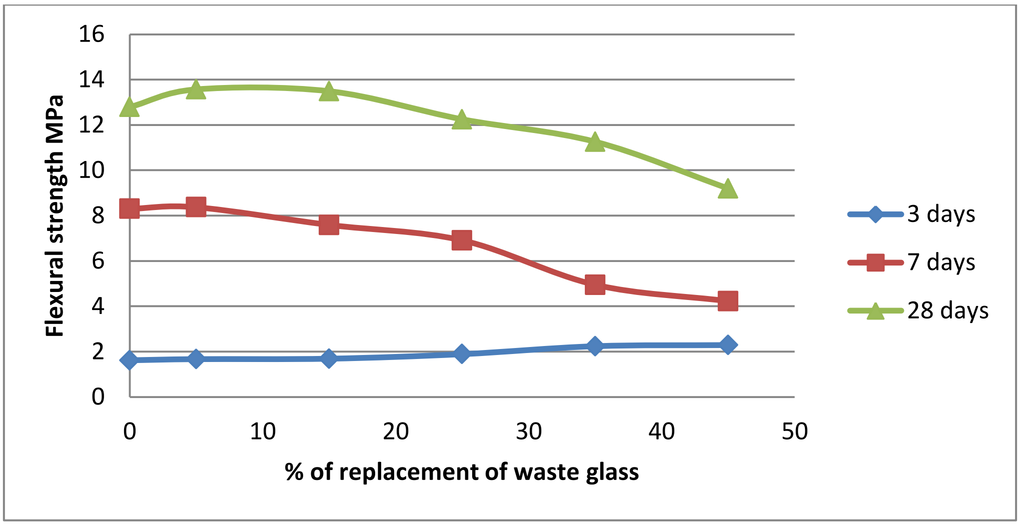

Figure 4.7: Effect of aggregate replacement with waste glass in flexural strength.

4.3.4 Porosity

Porosity tests were done on mortar samples after 28 days of curing. The results are shown in Table 4.6 and Figure 4.8.

Table 4.6: Results of porosity test

Mix #	% of waste glass	Porosity (%)
1	**0**	**13.70**
2	**5**	**12.45**
3	**15**	**12.04**
4	**25**	**12.51**
5	**35**	**14.02**
6	**45**	**14.23**

The bar chart in Figure 4.8 exhibits the results of the porosity tests taken of the samples. A decreasing trend in porosity percentage from mix number 1 to 3 is noted, and then an increasing trend from mix 3 to 6 is observed. Therefore, the highest porosity was found to be 14.23% at 45% of waste glass.

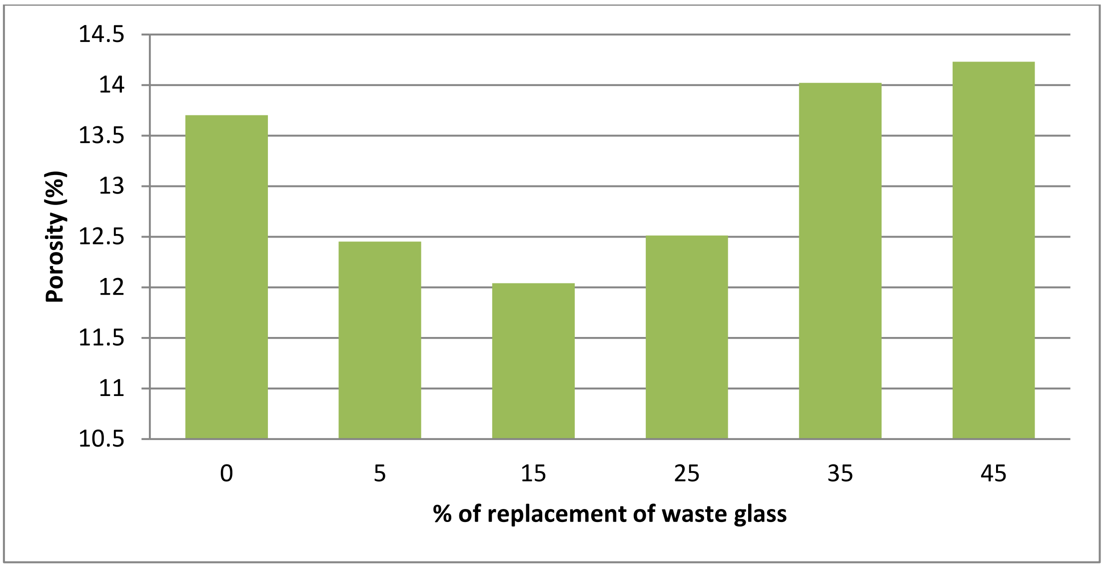

Figure 4.8: Effect of aggregate replacement with waste glass on porosity.

The results showed that adding 15% of glass powder decreased the porosity due to, a low porosity of glass.

4.3.5 Absorption

Absorption tests were done on mortar samples after 28 days of curing. The results are shown in Table 4.7, Table 4.8 and Figure 4.9, Figure 4.10.

Table 4.7: Results of water absorption test per unit area

% of waste glass	$m_{0.5\,min}$	m_1	m_2	m_{10}	m_{15}	m_{60}	m_{120}	$m_{180\,min}$	m_{20h}	m_{24h}
					kg/m^2					
0	**0.60**	**0.60**	**1.19**	**1.79**	**1.79**	**2.38**	**2.97**	**3.57**	**4.16**	**4.76**
5	**1.19**	**1.19**	**1.19**	**1.19**	**1.19**	**2.38**	**2.97**	**2.97**	**4.76**	**4.76**
15	**0.63**	**0.63**	**0.63**	**1.25**	**1.88**	**2.50**	**2.50**	**3.13**	**5.00**	**5.63**
25	**0**	**0**	**0.64**	**0.64**	**0.64**	**1.92**	**2.56**	**3.20**	**5.77**	**5.77**
35	**0**	**0**	**0**	**0.63**	**1.25**	**1.88**	**1.88**	**2.50**	**4.38**	**5.00**
45	**0**	**0**	**0.60**	**0.60**	**1.19**	**2.97**	**3.57**	**3.57**	**5.36**	**5.95**

The following flow chart shows the weight of absorbed water per unit area with respect to time (seconds). It was observed that the absorption showed a marked increase with increasing waste glass percentage. It can be noted from the chart that the last three mixes showed no absorption in the first two minutes due to the presence of waste glass particles. In addition, the acceleration of the absorption increase in the last three mixes was larger after the second minute (5.77 kg/m^2, 500 kg/m^2 and 5.95kg/m^2 respectively) than in the first three mixes (4.76 kg/m^2, 4.76 kg/m^2 and 5.00 kg/m^2) because of the absorption to water for the glass was very low.

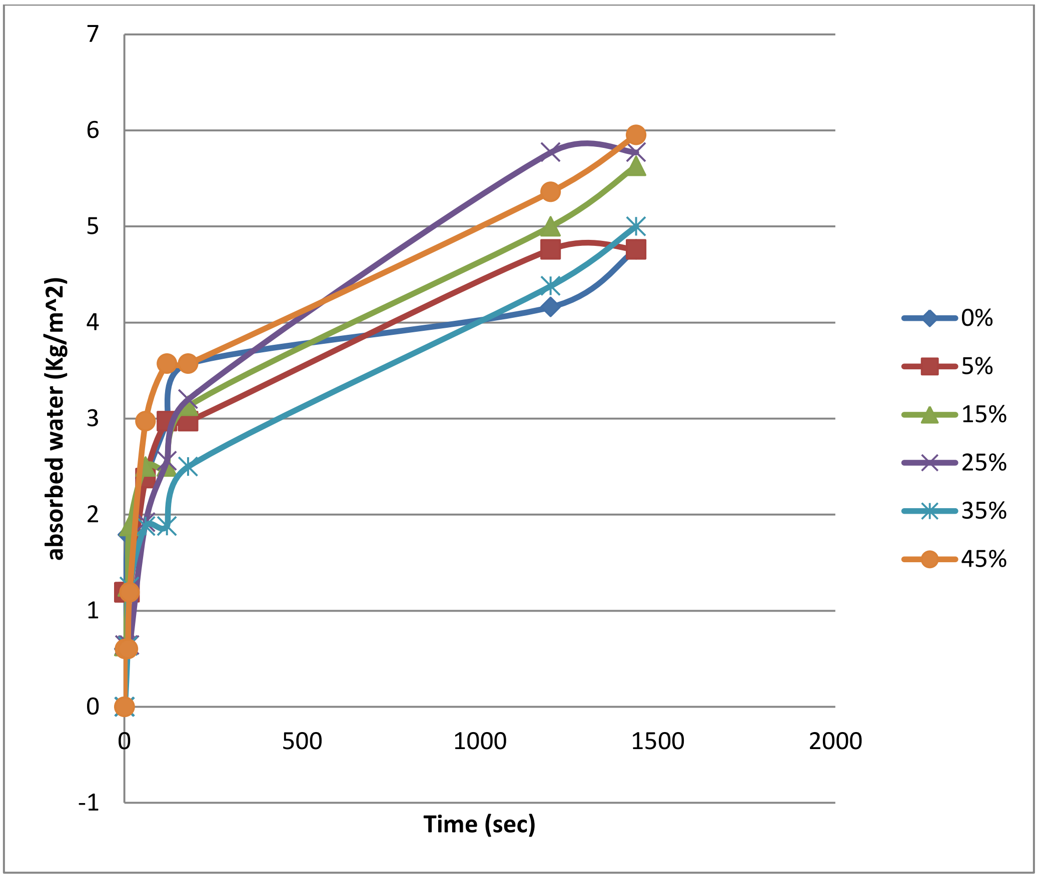

Figure 4.9: The effect of time on water absorption.

Table 4.8: Results of water absorption.

Mix #	% of waste glass	Water Absorption (%)
1	**0**	**5.92**
2	**5**	**5.76**
3	**15**	**5.68**
4	**25**	**5.88**
5	**35**	**6.44**
6	**45**	**7.04**

The bar chart below shows the absorption percentage of the mortar at different waste glass percentages and it can be observed that percentage of absorption reached its highest point (7.04%), at a waste glass percentage of 45%. This is due to higher porosity of mortar when glass is at its highest amount.

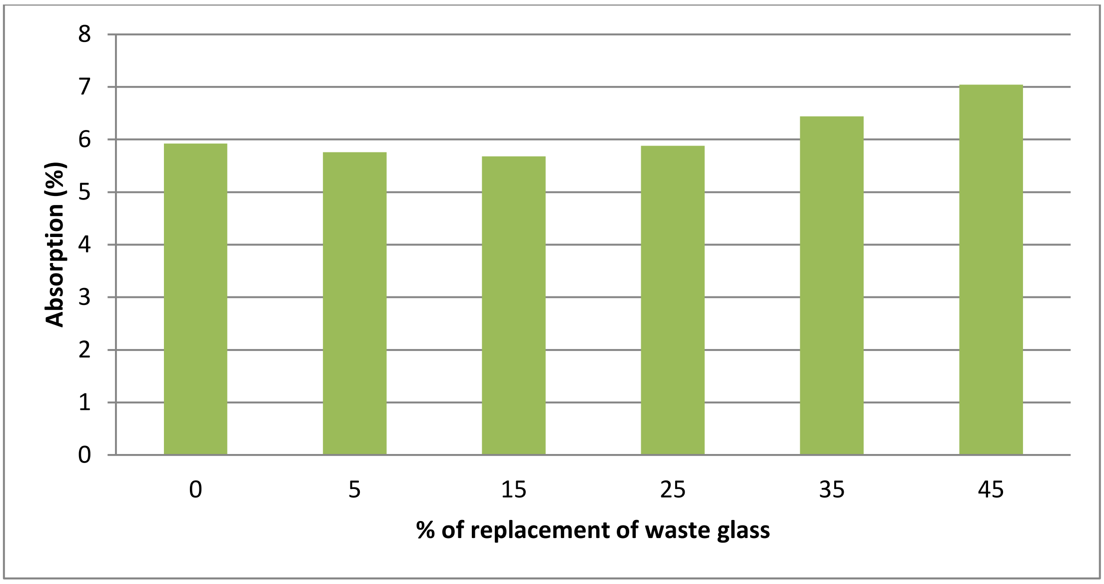

Figure 4.10: Effect of aggregate replacement with waste glass on water absorption.

The result showed that adding glass powder in a certain percentage (15%) to decrease the absorption because the absorption of water for the glass was very low.

4.3.6 Freeze – Thaw Resistance

Freeze - thaw resistance tests were done on mortar samples after 28 days of curing. The results are shown in Table 4.9 and Figure 4.11.

Table 4.9: Results of freeze-thaw test

Mix #	% of waste glass	**Mass loss** (%)
1	**0**	**74.5**
2	**5**	**66.0**
3	**15**	**60.3**
4	**25**	**58.7**
5	**35**	**49.0**
6	**45**	**15.0**

In the figure below there is a bar chart showing the percentage of soundness loss of the mortar that varies from 15% at 45% of glass and 74.5% at 0% of glass.

This means that, the resistance of waste glass against freeze – thaw damage is good. Thats why the amount of waste glass increases, the mass loss reduces.

Figure 4.11: Effect of aggregate replacement with waste glass on mass loss after freeze-thaw test.

4.3.7 Drying Shrinkage

Drying shrinkage tests were done on mortar samples after 28 days of curing. The results are shown in Table 4.10 and Figure 4.12.

Table 4.10: Results of drying shrinkage test.

Mix #	% of waste glass	**Drying Shrinkage** (mm/mm)
1	**0**	**0.128**
2	**5**	**0.124**
3	**15**	**0.112**
4	**25**	**0.093**
5	**35**	**0.070**
6	**45**	**0.060**

The following bar chart indicates the calculated drying shrinkage percentage of the mortar. It was observed that the drying shrinkage percentage of the mortar decreased gradually from mix number 1 through 6, eventually reaching its lowest value of 6% in mix number 6 which had 45% of waste glass.

Replacing glass powder with crushed aggregate (sand) improved the resistance of drying shrinkage. The crushed sand has a high density and a high modulus of elasticity more than crushed glass.

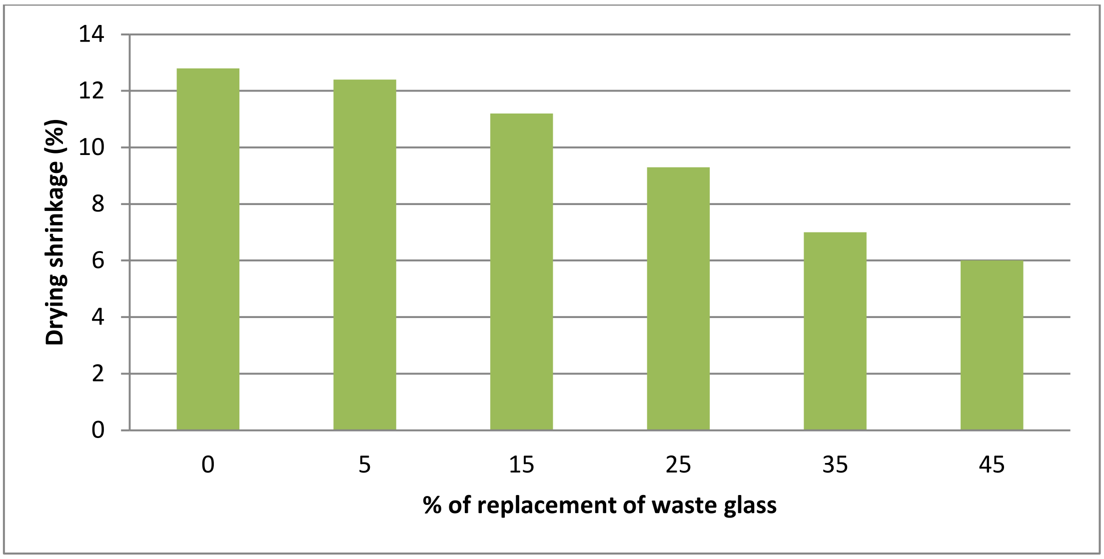

Figure 4.12: Effect of aggregate replacement with waste glass on drying shrinkage.

4.3.8 Rapid Chloride Permeability test

Permeability tests were done on mortar samples after 28 days of curing. The results are shown in Table 4.11 and Figure 4.13.

Table 4.11: Results of rapid chloride permeability test.

Mix #	%of waste glass	Permeability(coulombs)	Permeability class
1	**0**	**1420**	**low**
2	**5**	**1395**	**Low**
3	**15**	**1098**	**Low**
4	**25**	**1144**	**Low**
5	**35**	**1019**	**Low**
6	**45**	**769**	**Very low**

The bar chart below shows the permeability of the mortar, and it is clearly shown that the permeability class is very low at 45% of waste glass with a value of 769 Coulombs. Also with the increasing percentage of waste glass a gradual decrease in permeability is observed. According to ASTM C1202, the chloride Ion Penetrability (Permeability class) based on Charge Passed. So if the charge passed is between 1000 – 2000 the permeability class is low but if it is between 100 – 1000 the permeability class is very low as shown in Figure 4.13.

Figure 4.13: Effect of aggregate replacement with waste glass on permeability.

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The following conclusions can be drawn based on the experimental results reported in this study:

1) The results showed that it is possible to dispensing on little quantities of aggregate with waste glass and there is no difference in resistance at all tests.

2) The consistency of fresh mortar decreased generally with increasing the waste glass content, because of the edge and the shape of the waste glass powder are different than fine aggregate.

3) The unit weight of mortar decreased with increasing the waste glass percentage, because of the difference between the density of the glass and the aggregate.

4) The increases in compressive strength and flexural strength at 28 days age were 2.7% and 6.1% compared to control mixture, respectively.

5) The results showed that the addition of waste glass (45% waste glass) decreased the compressive strength by 50.7% at 28 days.

6) The results showed that the addition of waste glass (45% waste glass) decreased the flexural strength by 32.2% at 28 days.

7) The decline in the compressive and flexural strength due to, the lack of coherence between the components of the mortar mixture with powder glass, because the bonds between cement paste and waste glass is weak.

8) There was a significant increase in the porosity of mortar produced with waste glass additives. The result showed the addition of 15% waste glass dropped by 12.1% compared to control mixture and the addition of 45% waste glass increased by 4% compared to control mixture.

9) The results showed that, adding waste glass powder in different percentages (5, 15, 25, 35 and 45%) increased the water absorption in the samples.

10) The results showed that, adding waste glass powder decreased weight loss. This decrease in soundness loss arrived to (80%) when glass powder percentage is 45% waste glass.

11) The addition of waste glass as a partial replacement of fine aggregate leads to decrease the drying shrinkage of mortar. Up to 45% of waste glass, the reduction at 28 days age is about 50%.

12) The permeability of mortar decreased with increasing the waste glass percentage, because the soft surfaces of glass particles are dielectric.

5.2 Recommendations

The uses of recycled glass in mortars are new development in the world. More research work should be done, because of the different types, shapes and color of recycled glass.

Below subjects could be studied in the future:

1) Thermal conductivity of mixes,
2) Abrasion resistance of mixes,
3) Statistical modeling for strength or durability,
4) Microstructural scanning electron microscopy of each mix type.

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