AHMAD ALHADDAD

USE OF GLASS POWDER AND SAWDUST AS A PARTIAL REPLACEMENT OF FINE AGGREGATES IN CONCRETE PRODUCTION

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A THESIS SUBMITTED TO THE INSTITUTE OF GRADUATE STUDIES OF NEAR EAST UNIVERSITY

BY

AHMAD ALHADDAD

In Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil Engineering

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Approval of Director of Institute of Graduate Studies

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All praises and thanks to Allah. It is by His grace that I have been able to access this point in my life.

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To my family…

ABSTRACT

Concrete consumption volume increased year by year due to the growing urbanization, which increased the demand for building materials. Around 15 billion tons of sand consumed yearly all over the world, which poses a threat to natural resources.

In light of the massive depletion of natural resources on the planet, the need arose for many techniques that reduce the use of these resources, such as using of waste materials as an alternative of concrete materials. Waste materials increase tremendously and most of these wastes end up in the landfills causing environmental pollution. Despite of the existence of recycling projects but in fact it doesn't meet the target due to the difficulties of recycling process representing by high cost and the slowness of the recycling operation.

This study examined the effects of replacing fine aggregates with different percentages of waste glass of (10%, 20%, and 30%) with sawdust of 5% on the workability, the mechanical properties, and the permeability. It was found that the increasing of the glass powder content increases the workability of concrete, and increase the compressive strength value. In addition, it increases the resistance of concrete against penetration by water. Among the three glass powder percentages (10%, 20%, and 30%) with 5% sawdust, the maximum compressive strength was achieved with a 30% glass powder and 5% sawdust, the lowest with a 10% glass powder and 5% sawdust.

Keywords: Glass waste; sawdust; fine aggregates; workability; compressive strength; permeability; splitting tensile strength.

ÖZET

Artan şehirleşme ve yapı malzemelerine olan talebin artması nedeniyle beton tüketim hacmi her geçen yıl arttı. Tüm dünyada her yıl tüketilen yaklaşık 15 milyar ton kum, doğal kaynaklar için tehdit oluşturuyor.

Gezegendeki doğal kaynakların büyük ölçüde tükenmesi ışığında, atık malzemelerin beton malzemelere alternatif olarak kullanılması gibi bu kaynakların kullanımını azaltan birçok tekniğe ihtiyaç duyuldu. Atık maddeler büyük oranda artmakta ve bu atıkların çoğu çöplüklere giderek çevre kirliliğine neden olmaktadır. Geri dönüşüm projeleri olmasına rağmen, geri dönüşüm sürecinin yüksek maliyetle temsil edilen zorlukları ve geri dönüşüm işleminin yavaşlığı nedeniyle aslında hedefi tutturamamaktadır.

Bu çalışmada, ince agregaların farklı oranlarda atık cam (10%, 20% ve 30%) ile 5% talaş ile değiştirilmesinin işlenebilirlik, mekanik özellikler ve geçirgenlik üzerindeki etkileri incelenmiştir. Cam tozu içeriğinin artmasının betonun işlenebilirliğini arttırdığı ve basınç dayanımı değerini arttırdığı tespit edilmiştir. Ayrıca betonun su penetrasyonuna karşı direncini arttırır. 5% talaş içeren üç cam tozu yüzdesi (10%, 20% ve 30%) arasında maksimum basınç dayanımı 30% cam tozu ve 5% talaş ile elde edilmiştir, en düşük 10% cam tozu ve 5% ile elde edilmiştir talaş.

Anahtar Kelimeler: Cam atığı; talaş; ince agrega; işlenebilirlik; basınç dayanımı; geçirgenlik; yarmada çekme dayanımı.

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PC: Portland Cement

CaO: Calcium Oxide

SiO_2: Silicon Dioxide

Al_2O_3: Aluminium Oxide

Fe_2O_3: Iron Oxide

C_3S: Tricalcium Silicate

C_2S: Dicalcium Silicate

C_3A: Tricalcium Aluminate

C_4AF: Tetracalcium Aluminate Ferrite

ASTM: American Society for Testing and Materials

OPC: Ordinary Portland Cement

B.C.: Before Christ

Na_2O: Sodium Oxide

B_2O_3: Boron Oxide

K_2O: Potassium Oxide

MPa: Megapascal

C: Cement

W: Water

G: Gravel

S: Sand

gp: Glass Powder

sd: Sawdust

pl: Superplasticizer

EN: English Standards

ASR: Alkali Silica Reaction

ACI: American Concrete Institute

SSD: Saturated Surface Dry

d: Days

C-S-H: Calcium Silicate Hydrate

w/c: Water Cement Ratio

hr: Hour

min: Minute

CH: Portlandite

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is a widely used construction material for various type of structures due to its structural stability and strength (Meena et al., 2018). It consists of gravel, sand, cement, and water. The annual production of concrete is rapidly increasing, because of countries development and population growth, making the demand of construction greater than ever before (Kejela, 2020). Sand, which is an essential component for concrete is considered as the second most consumed natural resource on earth after water (Villioth, 2014). Statistics showed that the consumption of sand is around 15 billion tons annually in the world, with a trade volume of 70 billion dollars (Villioth, 2014). However, the river sand used for concrete production becomes insufficient, because of the excessive unscientific ways of extracting from river channels. The worldwide consumption of fine aggregates in concrete manufacturing is extremely high, and many developing countries have been facing difficulties to supply natural sand to meet the growing demand for construction projects. Several strategies are planned to make concrete without using sand, like sand-less concrete, and to use wastes as a substitute for sand.

Solid waste management is considered as one of the most difficult challenges that face governments in both developed and developing countries due to many reasons like rapid urbanization, population growth, rise in the standards of living, and hence the amount of the solid wastes produced (Abdul-Shafy and Mansour, 2018). However, the accumulation of uncontrolled wastes particularly in developing countries has led to a growing of concerns within the environment (Tilak et al., 2018). Recycling has become an indication of the progress of countries, where, the countries which benefit from their wastes are considered prosperous and civilized countries, it has many advantages on the environmental and economic levels (Schneider and Ragossnig, 2014).

Glass industry has constantly been evolving; as in 2016, world glass production was estimated at a total of around 209 million tons (International Commission on Glass, 2020). As the glass industry seeks new investment in the fields of telecommunications, medicine, electronics, and so on, the rapid changes in the glass industry will continue even in the future

(U.S.Department of Energy, 1996). Glass can be found in different forms: bottles, jars, cathode ray tubes, bulbs, windows, and many others. Some glass products have a restricted time period and should be recycled so as to avoid environmental issues regarding their storage or landfilling (Idir et al., 2015). According to Statistical study done in 2018, the amount of glass waste in landfills was 5% of the total glass production in 2016 globally, and this number increases annually (Kaza et al., 2018). Glass waste is progressively increasing and increasing the risk to public health because of the paucity of landfill's areas. Since glass is not biodegradable, it occupies most of the landfill. So it causes serious environmental pollutions on air, water, and soil (Siam, 2011). Some of glass forms are recyclable such as jars, glass bottles, soft drink bottles, and wine or beer bottles but heat treated glass as well as ceramics, glass sheet, and drink ware cannot be recycled like the glass bottles, because the heat treated glass need melting temperature beyond that of the glass bottles (Adebesi, 2015). In addition of that, recycling process needs to separate glass as colour to produce glass products of the same colour. However, mostly, the accumulated glass is mixed and become unsuitable for manufacturing bottles with the same colour (Idir et al., 2015). Consequently, this glass will either be reused for other purposes, or be sent to a landfill in the form of glass waste.

Wood is the most versatile and used natural material in the world, used in most of the items we use, such as houses, wooden furniture, newspapers, and books, and many others generate lots of unwanted waste materials which need to be dumped. The generation of wood wastes in sawmills inevitably pollutes the environment, because most of sawmills dump their wood wastes at landfills causing the landfills filled up and increased its volume day by day. Therefore, considerable efforts are made in the treatment of such wastes (Narayanan et al., 2017). Therefore, the scientists tried to reuse these wastes in many ways such as their use in concrete production as a replacement or additives.

1.2 Definition of the Problem

The consumption of river sand worldwide is too high, due to the massive use of concrete. The increasing amount of glass waste and sawdust lead us to look for other ways to rid of these wastes. Many utilization channels exist already for recovery, and one of these channels

is to use these wastes in building as partial alternative to construction materials. Therefore, the idea is to reduce the depletion of natural resources and dispose of wastes in landfills.
The literature review has shown that there is a lack of information regarding the use of waste glass as a sand replacement in concrete together with waste sawdust added to the mixture. Using these commonly found wastes together in concrete and their effects on performances of concrete has not been investigated by systematical laboratory experiments in the previous works.

1.3 Objectives of the Research

This work examines the feasibility of using a combination of waste glass powder in different quantities with a certain percentage of sawdust as a partial replacement of sand.
The aims of this research are:

- To investigate the influence of the percentage of sand replacement with glass powder and sawdust in concrete mixtures.
- To compare the performances of conventional concrete and glass powder sawdust concrete at different mix proportions.
- To understand the effectiveness of glass powder and sawdust on the mechanical properties of concrete.

Four different mixes will be prepared, with waste glass content varying in between 0 and 30% replacement combined with constant sawdust contents of 5%.
The specimens will be tested for compressive strength at 7, 28 ,56, and 90 days curing ages, while the flexural strength will be done at 56 days curing age and permeability test will be done at 28 and 90 days curing ages.

1.4 Importance of the Research Study

The significance of this study is to provide experimental data and information to the officials, researchers, civil engineers, and contractors, with the detailed laboratory investigations described above. This information will contribute to the literature and it will increase the understanding of the researchers and engineers dealing with the use of glass and sawdust wastes' used in concrete, also helping them to determine the most effective concrete mixture design by utilizing those wastes. In addition to that, it will allow the economists to observe its influence on the cost of building and to designers to recognize its difference on the weight of building and their related concerns.

With the contribution of the results to be obtained from this study to the related literature, the depletion of natural resources (fine aggregates) and disposal of wastes is expected to reduce by using waste materials (waste glass and sawdust) as partial replacement. In addition, using of these wastes saves money on the factories to get rid of these wastes (Ganiron, 2013).

Waste glass and sawdust are considered as the least expensive materials, hence, reducing the total cost of construction and give the opportunity for low-income persons and marginalized sector of society to own houses with cheap prices, also it gives more profit for the contractors.

Concrete with glass powder and sawdust is lighter than the ordinary concrete because it is denser than the ordinary concrete, so we can use it to reduce the dead load and for providing thermal insulation for the building. By reducing the dead load, the weight of the structure is reduced and thus reducing the base shear force for the seismic design. Overall, it is expected that an understanding on the use of waste glass waste in concrete together with sawdust, would enable the researchers and engineers to work more efficiently on this topic both in practice and in their investigations.

1.5 Thesis Structure

This research composed of 5 chapters which are clarifying in details. A background about the concrete, solid waste management, waste glass, and sawdust, as well as a definition of the problem, objectives of the research, importance of the research, and the structure of the thesis will be explored in chapter 1.

Chapter 2 explores a historical background of the topic, including an information about the concrete materials, the origin and the types of glass used in this study.

The materials used and the methodology of preparing the samples and the tests will be presented in details in chapter three.

Chapter four explores the results and discussions of the tests done on the samples with scientific explanation.

Chapter five presents the conclusion and the future recommendations.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Introduction

Concrete is considered one in all the best inventions within the construction engineering field (Ede et al., 2015). It has many characteristics that make it distinguished from other materials. Beside of its high durability, it can be cast to desired shape, moreover it is resistance to fire due to its non-combustible nature, unlike, timber which considered nondurable and able to catch fire and burn easily, or steel that has very high cost and low compressive strength.

Concrete industry has been developing continuously, where the researchers still discovering a new mixture in order to improve its properties and make it more economical. Since waste materials are cheap and mostly free, the scientists tried adding these wastes to concrete mixture. Using waste materials in concrete production eliminates waste and adds positive properties to concrete, and it can be used as a cement or aggregate replacement (Tavakoli, 2018).

2.2 Concrete Materials

Concrete is a combination of cement, fine and coarse aggregate, and water, which blend together to obtain a specific strength. Cement and water react chemically with each other to make a paste that combines the coarse and fine aggregates particles. As a building material, concrete has several desirable properties, including wind and water resistance, economy, durability, and high compressive strength. However, as a low-ductility material, it has undesirable characteristics, including low tensile strength, and the unexpected cracks that make constructions collapse unpredictable, in addition, its huge weight. However, the internal reinforcement represented by iron can reduce these issues by its high tensile strength and the cracks can be controlled to some extent.

Concrete comprises of three main components which are aggregates, cement, and water.

2.2.1 Water

Water is a vital component in concrete. It reacts chemically with cement by a process called hydration to provide the desired properties of concrete. There should be an adequate amount of water available in concrete, and usually it is indicated by water cement ratio which refer to the weight of water to the weight of cement, where it is responsible for the plasticity of concrete which defined its workability.

If the mixture has insufficient water, the hydration process cannot take place sufficiently to complete the reaction, and that leaves some cement unreacted and lost its role as a binder, thus decreasing the workability at the fresh state and also reducing the strength at the hardened state of concrete. On the opposite hand, if an excessive amount of water added, the excessive water will evaporate causing voids in the concrete and that reduces its strength in the hardened concrete or cause segregation of aggregates during transportation and placement. In addition to the quantity, the quality of water utilized in concrete also plays a decisive role in the performance of fresh concrete and hardened concrete. In general, water used in concrete can be any water unless it contains harm impurities to concrete such as oils, grease, and dissolved salts.

2.2.2 Cement

Cement considered as the most essential component of concrete which is a fine grey powder reacts with water by the hydration process, it binds the aggregate together to form homogeneous and strong blend. The crucial compounds which considered the raw materials of cement production are calcium silicates which found as limestone or chalk that form the calcareous materials, and clay or shale which form the silicate materials.

Cement is produced by heating the raw materials in the rotary kiln to around 1500 °C temperature, then the burning product is cooled and grounded to a fine powder with adding some gypsum to form the Portland cement (Neville and Brooks, 2010).

Chemically, the raw materials used for PC manufacturing consist of number of oxides which are limestone CaO, silica SiO_2, alumina Al_2O_3, iron oxide Fe_2O_3, and some other oxides. These compounds react in the rotary kiln at high temperature to form the clinker compounds that are tricalcium silicate C_3S, dicalcium silicate C_2S, tricalcium aluminate C_3A, and tetracalcium aluminoferrite C_4AF.

Generally, American Society for Testing and Materials (ASTM) classified Portland cement by numbers to five different types in their standard specification C-150-94 as following:

- Ordinary Portland (type I) Cement ‘OPC’.
- Rapid - Hardening Portland (Type III) Cement.
- Low Heat Portland (Type IV) Cement.
- Sulphate – Resisting (Type V) Cement.

In addition to the standard ASTM types, there are other types of cement; these types are not affected by changes in clinker content, but rely on replacing cement with other materials that even have the properties of a binder. Binding materials are waste or by-products. These materials can in some ways improve the performance of cement; These substances are silica fume, ground granulated blast furnace slag and fly ash. Mixing these substances together produce various kinds of cement. These types are as follows:

- Portland Blast-Furnace (Type IS) Cement.
- Supersulphated (Slag) Cement.
- White and Coloured Portland Cement.

2.2.3 Aggregates

Aggregates are divided into 2 main classes, fine aggregates and coarse aggregates. The diameter of coarse aggregates is usually more than two millimetres, while the diameter of small aggregates is known to be smaller than two millimetres. Aggregates employed in concrete must comply with ASTM C33/C33M-18 standards. The economical aspect of concrete is to use the minimum amount of cement as possible while maintaining the specified strength. Thus, once concrete is formed, the large particles of coarse aggregates would compose an oversized part of the concrete. The fine aggregates minimize the needed cement by filling the voids formed by coarse aggregates.

If coarse aggregates are only utilized, there will be spaces between the particles and therefore the resulting spaces will be stuffed with cement paste. So fine aggregates are utilized to stuff these spaces. Fundamentally, the purpose is to reduce the gaps in the concrete mixture by utilizing less amount of cement paste to fill the spaces between the particles. The fresh aggregates utilized in concrete mixture possess some moisture, which comes from condensation on the particles or the aggregates washed with water. Aggregates should achieve specific standards for optimum engineering use; they should be clean, hard, sturdy, durable, and free of chemical materials or any other fine materials in amounts that might affect hydration and the bond of the cement paste (Kosmatka, Kerkhoff, and Panarese, 2008). Consequently, there are four distinguished condition that the aggregates may be in:

- The oven dry aggregate, it is fully absorbent, and it absorbs water to stuff its spaces and thus, decrease the w/c ratio and therefore the hydration process is not allowable to persist and also the resistance of the concrete mixture is reduced by a substantial quantity.
- The air dry aggregate absorbs water, but the degree of water absorption is less than that of the oven dry aggregate, and the surface seems dry. thus due to the water absorbed, the w/c ratio decreased and the concrete strength decreases slightly.
- The saturated surfaces dry aggregates, are aggregates whose cavities are filled with water and therefore no longer absorb water. These aggregates maintain a constant water/cement ratio, and the concrete also maintains its strength.
- The damp or wet aggregates are containing an excess amount of free water on the surface. Unlike the other types of aggregates, it is not absorbing water, but these aggregates add water to the mixture, increasing the water-cement ratio and thus reducing the strength of the concrete.

2.3 Glass

2.3.1 Introduction

Glasses are produced by melting a balanced combination of limestone, sodium carbonate, silica, and dolomite at huge oven at high temperature around 1600 °C, then the combination is cooled down to about 650 °C without crystallization state to be shaped on request. Special additives are added to give the glass their colours and special properties (Hasanuzzaman et al., 2016).

2.3.2 Glass types

Glass are often categorized in several groups consistent with their required application or by their chemical structure. The following parts show the most common glass types, depending on their chemical composition**:**

- **Soda-lime glass**

  Soda-lime glass is that the commonest industrial glass, it's relatively cheap and able to recycling. Chemically this type has 70-75 percent of silica, 12-16 percent of sodium oxide, and 10-15 percent of lime. A little share of different regent is often added for special purposes and application needs. The main addition within this kind of glass except silica (SiO_2) is sodium oxide (Na_2O). Despite the fact that (Na_2O) contains (O) atoms, it is control along by ionic instead of covalent bonds. The (N) atoms within the mixture give electrons to the (O) atom, making a combination of (O^-) with negatively charged and (Na^+) with positively charged. The (O) atom with an additional electron binds to silica atom and does not compose a connection between couples of silicon atoms. So, the melting heat of the combined is significantly decreased. Comparatively high quantity of alkali amount within the glass causes a rise of the thermal extension constant by around twenty times. (Na^+) are too soluble in solution; therefore, (CaO) is added to enhance its quality. Soda-lime glass is made on oversized grade and may utilized for normal glass used such as drinking glasses and bottles because of its smooth and non-reactive surface. It's appropriate to be used as window glass thanks to their ability to transmit light through and its low melting temperature as well (Hasanuzzaman et al., 2016).

- **Lead glass**

  Lead glass is comparable to soda-lime glass wherever (CaO) is displaced by lead oxide. It usually contains silica oxide with 55-65%, lead oxide 18-38%, and sodium oxide 13-15%. It is utilized for ornamental tableware; it is additionally having high index of refraction so it can be used in special optical glasses. Lead glass is stronger and has less internal friction than soda-lime glass because the networks in lead one are more integral than the networks in soda-lime glass, also lead glass is appropriate to be used in radiation shielding thanks to lead oxide properties that make the glass dense, hard, and x-ray absorbing (Hasanuzzaman et al., 2016).

- **Aluminosilicate glass**

  This type of glass contains normally 52-58% of SiO_2, 15-25% of Al_2O_3, and 4-18% of CaO. This glass is able to sustain very high temperature compared with soda-lime glass thanks to its low thermal expansion and high softening temperature, thus it can be used for furnaces and fiber glass insulation, cookware, and combustion tubes (Hasanuzzaman et al., 2016).

- **Borosilicate glass**

  Borosilicate glass contains usually 70-80% SiO_2, 7-13% B_2O_3, 4-8% Na_2O or K_2O, and 2-8% Al_2O_3. Boron oxide percentage sometimes differs in this type of glass for example, if the B_2O_3 between 7-13% the glass known as low-borate borosilicate glass and used for lamps and chemical instruments, while if this percentage is 15-25% the glass known as high-borate borosilicate glass and can be used for cookware and for stationary phase in chromatography (Hasanuzzaman et al., 2016).

2.3.3 Glass production volume

The glass production in the global growing progressively, due to the rising of the glass consumption at most of life aspects. In 2015, a research paper written by Nora Wintour and published by the international labour office sectoral policies department shows that in 2007, the global glass production reached a volume of 115 megatons (Wintour, 2015). And with the progressive development this number is expected to increase significantly, where in Europe which considered one of the largest glass market in the world in both of production and consumption produced 32 megatons of glass in 2010, while the production increased in 2019 by 16.25% to reach a volume of 37.2 megatons (Glass Alliance Europe, 2020). China also considered as a large producer of glass and glass products, where in 2009, has more than 50% of worldwide glass production, it is expected that China’s impact will keep growing on the worldwide glass market. By talking about South America, Brazil considered an importer and exporter of glass, it imports glass mainly from China and USA around 29% and 13% respectively of total glass imports, also glass production in Brazil increases annually, where in 2007, the production of flat glass in Brazil was 992 kilotons, while in

2011, the production was 1516 kilotons. On the other side Africa imports glass from Europe, China, and South America, the demand in 2013 was estimated at 360 kilotons yearly, and at the same year the first glass manufacturing was established in Nigeria with designated production capacity 500 tons daily.

2.4 Sawdust

Sawdust is the tiny pieces that produced as a byproduct of ripping, swishing, drilling, cutting, mortising, shaping, grilling, or grinding the timber with saw, drilling machine, or any other tools, varies in size depending on the tool and the method used (Neymba et al., 2018; Abu James and Daniel, 2018).

The main components of sawdust include cellulose, Hemicellulose, lignin, and extractives (Tilak et al., 2018). It is used mainly for particleboard; also, it can be used as a fuel (Ganiron, 2014).

2.4.1 Sawdust production volume

The volume of sawdust has been increasing during last decades. In 2010, in Malaysia only, 1.5 cubic megametre of wood waste has been thrown at the landfills (Suliman et al., 2019). While in United States the total amount of wood wastes at landfills were around 12.2 megatons in 2018 (Zimmer et al., 2018). Also in Europe according to Eurostat data around 55 megatons of wood wastes were generated in 2016 (Borzecka, 2018).

2.5 Recent Studies

The seeking for new building materials remains one of the most prominent engineering research supported by construction companies in the world, within the perspective of responding to legislation and laws related to sustainability and environmental protection and in pursuit of savings on public and private sectors. Within this field, several researches have been emerged in different countries of the world to add glass waste or sawdust to the composition of concrete mixture. However, the results were different at times and consistent at times leaving the scoop opened for more studies and researches. Several studies and investigations have been carried out on the resources and properties of glass powder and sawdust, and the potential side impacts of improper handling and best solutions to improve the properties of fresh and hardened concrete.

2.5.1 Recent studies with glass waste

Najib et al., (2018) examined the effects of using different types and colours of recycled glass as coarse aggregates and fine aggregates with different percentages. The types were green glass bottles, clear glass bottles, brown glass bottles, and clear window glass. The specimens were with these percentages 33%, 50%, 67%, and 100% glass powder of coarse aggregates + 100% fine aggregates, and 100% glass powder of fine aggregates + 100% coarse aggregates, w/c ratio was 0.55. The results shown that the optimum value of glass powder as coarse aggregate was 33% which has compressive strength 90% of the control mix at 28 days. On the other side waste glass can be as a replacement of fine aggregates up to 100% without deleterious effects on concrete properties. Also changing the glass type does not have a noticeable effect on concrete properties. However, the concrete with glass at high percentage reduced the compressive strength due to the smoothness of glass particles leads to a weaker bonding between glass and cement.

Parthiban and Thirugnanasambandam, (2018) studied the difference between the waste glass concrete and fine aggregates concrete. The used cement in this study was ordinary Portland cement with water cement ratio 0.5 and super-plasticizer 0.7% of cement. White colour clear glass was used in this study with maximum particle size 3 mm, while the coarse aggregates particle size was between 4.75 mm and 20 mm. The mechanical properties of concrete that has waste glass were higher in values than the river sand concrete, where the compressive strength of waste glass concrete increased with around 1% compared to conventional concrete, while the splitting tensile strength and flexural strength increased by 1.6% compared to conventional concrete.

To illustrate the mechanical and chemical properties of using glass powder instead of 100% river sand at different concrete grade, the researchers used three concretes of grade 20, 40, and 60 MPa. Three water cement ratios were selected for this purpose 0.5, 0.39 and 0.35 respectively. Ordinary Portland cement was used with a grade of 43 MPa. The superplasticizer Fosroc SP430 is used as an additive to maintain the required workability.

The superplasticizer content of the 20 MPa grade is 0.7%, and the cement content of the 40 and 60 MPa grade is 1%. Angular crushed stone was used as coarse aggregates with particle size between 20 mm and 4.75 mm. Recycled white glass was used to replace the sand with particle size less than 3 mm. The results revealed that the glass powder enhances the mechanical properties of all grades of concrete, where the compressive strength increased around 4% for all concrete grades due to the lower water absorption in glass aggregates concrete. Also the ultimate load carrying capacity for recycled glass concrete was higher than the sand concrete beam around 26% and 31% for grade M 40 and M 60 respectively. Moreover, the number and pattern of cracks were similar when compared to conventional concrete (Parthiban and Thirugnanasambandam, 2019).

Ganiron, (2013) investigated the performance of concrete by using recycled glass bottles from junk shops as fine aggregates in concrete mixture, the cement used was Portland Pozzolanic type IP with w/c ratio ranging between (0.55) and (0.65), the particle size of fine aggregates was between 0.0625 mm and 2 mm. The results showed that using of recycled glass bottles with the percentage 25%, 50%, 75%, and 100% of fine aggregates in concrete mixture decreases w/c ratio, the unit weight of concrete, and cost. Nevertheless, it was not recommended for structural members such as columns, beams, and suspended slabs, because it reduces the compressive strength value to the half of the control mixture.

Researchers also studied the effectiveness of using glass wastes in concrete as fine aggregate by studying the workability and the compressive strength of concrete using glass powder as a partial replacement of sand. 66 cube samples were cast with different replacement percentages 0%, 10%, 20%, 30%, 40%, and 50% of ground waste glass as fine aggregates. This study was prepared by using ordinary Portland cement grade 43 with specific gravity 2.96 and fineness 2800 cm^2/g with w/c ratio used of 0.5. For aggregates, crushed angular granite was used as gravel with maximum particle size 12.5 mm and specific gravity of 2.6 and fineness modulus 6.05, while for fine aggregates natural river sand was used with maximum particle size of 2.36 mm with specific gravity of 2.62. The results observed that waste glass can be used as fine aggregates up to 40% without a substantial change in strength and the optimum replacement was 10% which has a better compressive strength by 3% by compared with conventional concrete (Gautam et al., 2012).

A study undertaken by Adaway and Wang, (2015) demonstrated that concrete specimens containing glass as fine aggregates are workable, but its workability is low compared to concrete with full of fine aggregates. The mixes in this study were proportioned to achieve 40 MPa as compressive strength after 28 days. The cement used was ordinary Portland cement with corresponding water cement ratio of 0.42. The coarse aggregates were of angular nature with maximum particle size of 19 mm, while the fine aggregates were in the form of river sand with fineness modulus of 2.61, and maximum particle size 4.75 mm. The waste glass was collected from a company which collects mixed colour post-consumer container glass, and it used in the mixtures instead of fine aggregates with the proportions 0%, 15%, 20%, 25%, 30%, and 40%. They mentioned in their study that the optimum replacement of sand with glass powder was determined to be 30%, where at that point the compressive strength developed was 58.5 MPa at 28 days, which is 6% higher than that achieved by the control concrete.

Meddah, (2019) studied the feasibility of using windows waste flat glass in concrete mixture at different replacement proportions. For this study Portland cement type I with a specific gravity of 3.14 was used with a w/c ratio of 0.48. Polynaphthalene sulphonate-based super-plasticizer was used at different dosages to achieve targeted slump 50-70 mm. Crushed limestone were used as coarse aggregates with a specific gravity of 2.8 and water absorption of 0.92%, while natural sand was used as fine aggregates with a specific gravity of 2.49 and water absorption of 0.06%. The study considered the crushed recycled waste glass as natural sand in concrete mixture with proportions 0%, 10%, 20%, and 30%. In this study compressive strength, splitting tensile strength, flexural strength, and porosity and water absorption capacity tests of concrete mixtures were conducted. After analysing the test results, it was found that physical properties of the crushed glass aggregates obtained from glass wastes are convenient in terms of size, gradation, shape, and specific weight as a natural sand for concrete manufacturing. The angular grain shape of the crushed glass can influence the workability of the concrete but it was very beneficial in improving the strength. This conclusion was drawn after it was determined that the compressive strength, flexural strength, and splitting tensile strength have shown negligible reduction compared to the control concrete mixture. However, the porosity and water absorption of concrete with different glass waste contents increased slightly compared to the control mixture.

Du and Tan, (2014) examined the influences of concrete with 100% recycled glass instead of sand. They used glass beer bottles with particle size as sand with maximum of 4.75 mm, while the maximum size of coarse aggregates was 19 mm, the cement was ordinary Portland cement with water cement ratio ranging between 0.32 and 0.49. They did many tests as compressive strength, splitting tensile strength, flexural strength, and rapid chloride permeability test. The tests showed that up to 100% replacement ratio of sand is replaceable without any deleterious impacts on the properties of concrete, on the contrary, it increases the compressive strength, flexural strength, splitting tensile strength, and static modulus, furthermore, its high resistance to the chloride ion penetration of concrete.

Abbas et al., (2011) studied the effects of using of glass wastes as fine aggregates in concrete mixture on the cost of concrete materials and their impacts to mechanical properties of concrete. The cement used in this study was OPC with w/c ratio of 0.5. Coarse aggregates used have specific gravity of 2.65 and water absorption of 0.7% with maximum size of 14 mm, While natural sand is used for fine aggregate with specific gravity of 2.63 and water absorption of 1.75%. The glass proportions used in this study were 0.33%, 0.66%, and 100%. The cost analysis showed a decrease in cost by 18% by using concrete with waste glass with comparing to conventional concrete. However, the compressive strength test showed a reduction in strength by increasing the proportion of glass in concrete mixture, where the percentage of compressive strength decreased down to 40%, 48%, and 54% according to waste glass percentages 33%, 66%, and 100% respectively. The researchers attributed the decline in compressive strength due to the weak bond between the concrete mixture compounds and broken glass because of the fine surface of glass particles.

Suganya et al., (2014) performed the effects of adding glass powder with proportions 10%, 20%, and 30% to concrete mixture on the mechanical properties of concrete. The cement used was ordinary Portland cement with water cement ratio 0.35, the maximum particle size for glass powder was 2.36 mm. The study showed 30% of glass powder increased the compressive strength with 9% for 28 days compared to conventional concrete, also in increased the tensile strength by 23% and it increased the flexural strength by 74% for 28 days compared to conventional concrete.

2.5.2 Recent studies with sawdust

In Narayanan et al., (2017), researchers adopted sawdust as a partial replacement of fine aggregates in order to investigate the performance of concrete in terms of workability, weight of concrete, and compressive strength. Several mixtures were prepared to produce concrete mixtures with grade M20 using ordinary Portland cement grade 43with w/c ratio of 0.5. The maximum particle size used for coarse aggregates was 20 mm with specific gravity of 2.69 and water absorption 0.5, while for fine aggregates the maximum particle size was 4.75 mm with specific gravity of 2.62 and water absorption 1. The sawdust used instead of fine aggregates with proportions of 0%, 10%, 20%, and 30%, and the maximum particle size was the same of fine aggregate 4.75 mm and 0.27 for specific gravity and 2 for water absorption. The results showed an increasing with compressive strength by increasing the replacement percentage, where the compressive strength of control mix was 20.33 MPa at 28 days of curing age, while it was 23.25 MPa, 23.72 MPa, and 25,25 MPa according to the proportions 10%, 20%, and 30% respectively. In addition, the weight of sawdust concrete decreased compared with normal concrete by increasing the replacement percentage thanks to its low specific gravity comparing to normal aggregates as the specific gravity of sawdust is less than the fine aggregate.

In another study, a researcher studied the effects of using sawdust as fine aggregates in concrete mixtures on both the compressive strength and split tensile strength of concrete as well. In this study, OPC was used with w/c ratio of 0.55 to achieve M20 conventional concrete mix with proportion as 1:1.5:3. 5%, 10%, 15%, and 20% of fine aggregate was replaced with sawdust, then the cubes and the cylinders were casted and the tests done on the cubic and the cylindrical samples to find out the compressive strength and split tensile strength after 7 and 28 days of curing ages. The results showed a decreasing in the values of compressive strength and split tensile strength with the increasing of the percentage of sawdust with around 5.5% reduction in compressive strength and split tensile strength values for each 5% increasing of sawdust. However, the concrete became environmental friendly and the cost was less than conventional concrete through the use of industrial waste (Vimala, 2018).

In the study undertaken by James and Daniel, 2018, it was aimed to clarifying the work method of sawdust in concrete mixture, which improves the understanding of the different between the sawdust concrete and the sand concrete. The study intended to prepare five concrete mixtures with different proportions of 0%, 5%, 10%, 15%, and 20%. For preparation these mixtures OPC was used with w/c 0.5. The coarse aggregates used were the retained on sieve 4 mm, while the fine aggregates and the sawdust were sieved through sieve 2 mm. test considered were compacting factor test, and compressive strength test for 7, 14, and 28 days of curing ages. Researchers found that the cost decreased due to the reduction in the fine aggregates amounts. However, they also found that sawdust works as an air-entraining agent, has no positive effect on the compressive strength of concrete, contrariwise, the compressive strength decreased by the increasing of the percentage of sawdust. The reduction in compressive strength of the concrete with 5% sawdust was 34.5% compared to normal concrete, while for concrete with 10% and 15% the reduction was around 50%. Whereas according to workability of the fresh concrete, the results showed that the workability decreases as the percentage of sawdust increases in the mixtures. Therefore, they detected that for this study the optimum value of sawdust replacement is 5%.

Tilak et al., (2018) reported a paper on experimental investigations on the effect of replacing partially or completely fine aggregates with sawdust on the properties of concrete. The percentages of sawdust replacement were 0, 10, 20, 50, and 100%. Ordinary Portland cement of grade 43 was used with specific gravity of 3.12 and water cement ratio 0.45. crushed granite of 20 mm maximum size were used as coarse aggregates with specific gravity and fineness of 2.64 and 6.816, respectively. While the fine aggregates used were river sand with2.7 for specific gravity and 2.71 for fineness. In their study they touched the effects of sawdust on concrete with the observed reduction in the compressive strength and density of concrete as the fraction of sawdust increased. Where the percentage reduction in density with respect to conventional concrete mixture was 4.02%, 5.54%, 9.15%, and 19.20% according to the replacements 10%, 20%, 50%, and 100% of sand by volume, respectively. And the corresponding percentage reduction in compressive strength with respect to conventional concrete mixture was 28.54%, 53.95%, 67.10% and 75.92%, respectively. However, according to its low cost they decided in their conclusion that the concrete with sawdust can be used at nonstructural concrete where the compressive strength is not major requirement.

Suliman et al., (2019) have investigated the effectiveness of concrete using sawdust partially to replace the river sand which may reduce the cost of the construction and the environmental problems as well. In their study, they replaced the river sand with sawdust by 5%, 10%, and 15% of the total sand volume with maximum particle size of sawdust 0.6 mm. The cement used was ordinary Portland cement with 0.4 water cement ratio to produce concrete of grade C30. In their results, they found that adding of sawdust to concrete mixture has many benefits on environment and this this type of concrete is free from any pollutants harmful to the environment, but the compressive strength decreased with the replacement increased. The compressive strength recorded a reduction 13.22% when the sawdust percentage was 5%, while it was 28% and 40% when the sawdust percentage was 10% and 15%, respectively. However, the optimum replacement of fine aggregates has obtained to be 5%.

In another study, researchers adopted two different types of concrete. The first type was normal concrete and the second type was coconut shell concrete, which has the same material of the normal concrete but with coconut shell as full replacement to coarse aggregates. In both concrete types, sawdust was used as partial replacement of fine aggregates as 0%, 5%, 10%, and 15%. Ordinary Portland cement grade 53 was selected for the preparation of the specimens with specific gravity 3.05 and w/c ratio of (0.5) for normal concrete and (0.42) for coconut shell concrete. The fine aggregates used were river sand with particle size less than 4.75 mm and specific gravity and fineness modulus 2.72, and 2.73, respectively. While coarse aggregates were angular in shape and had maximum particle size 12.5 mm with specific gravity 2.7. The coconut shell was collected and the upper surface of the shell was smoothed after removing the fibers on the top surface of the shell, then it crushed to small parts by hummer and soaked in water for 24 hours and then putted in sun for one hour to be dry. The maximum particle size for coconut shell was 12.5 mm and specific gravity 1.3. Sawdust also collected from sawmill and sieved through 4.75 mm sieve and then soaked in water for 12 hours, the specific gravity was 0.35. The tests done on samples were compressive strength, split tensile strength, flexure test, and impact test. The tests results showed that the soaking of the sawdust in water for 10-12 hours may eliminates the heavy water absorption of sawdust. However, it is suitable to use in hot conditions (less amount of moisture). The mechanical properties decreased by increasing the percentage of sawdust. The optimum percentage that adopted in this study was 5% for both types of concrete that has a small reduction in compressive strength value by 11% compared with the normal concrete, while it was the same value for coconut shell concrete. However, split tensile strength and flexural strength were almost had the same values for both types without a quite effect of sawdust (Nurulla et al., 2019).

Ganiron, (2014) examined the effect of sawdust as fine aggregate in concrete mixture. In his study, he tried to explore the differences between the curing ways of concrete specimens. He prepared two types of specimens, one of them sand concrete which contains gravel, sand, cement, and water, and the other one sawdust concrete which contains gravel, sawdust, cement, and water. For each type he choose three ways of curing, so he prepared six cubic concrete specimens, three for sand concrete and three for sawdust concrete. Then he applied the curing process as follows: the first specimen received no curing for seven days, the second specimen was soaked in water for fourteen days, and the third one was splashed with water every morning for 28 days. Of all three specimens, the seven-day specimen which was not even cured was the sample that showed the highest early compressive strength. He attributed that due to the presence of sawdust within the concrete which absorbed water during mixing helping the hydration process at the center part of concrete resulting to stimulate the concrete to reach early high compressive strength at early time period. The specimen which soaked in water for 14 days was lower than the 7 days specimen by 9.8 MPa, and the sample which cured with water every morning stabilized at about 21.53 MPa. In addition, the threshold for w/c ratio was defined to be 0.45 which under this value the sawdust concrete will not be workable. In his conclusion, he mentioned that the sawdust concrete has less cost and less weight than sand concrete where it was a reduction in weight between the two types of concrete by around 7% at the same volume.

Kumar and Nagi, (2019) studied the strength evaluation of self-compacting concrete with sawdust as a partial replacement of fine aggregates. The fine aggregates were supplanted with four rates 0%, 10%, 15%, and 20% of sawdust in concrete mixture with particle size less than 4.75 mm. The cement used in this study was ordinary Portland cement with water cement ratio 0.5, and by using self-curing agent (PEG-400) as 2% of cement weight which reduce the vapor weight and that led to lessening the rate of dissipation from the surface. The results showed that utilization of PEG-400 gives high compressive strength around 36 MPa for 15% sawdust replacement, but its rate should not be exceed 2% otherwise cement quality decreased. In addition of that, using of PEG-400 allowed to increase the rate of sawdust replacement to 15%, while most of the other studies agreed that the optimum replacement of sawdust was 5%.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 General Aspects

Using waste materials as a substitute for fine aggregate in concrete can reduce the cost of concrete materials because it is easily available in landfills (Ganiron, 2013). The use of glass waste and sawdust reduces the quarries consumption, thereby reducing the amount of waste in landfills and eliminating the need for new landfills (Parthiban and Thirugnanasambandam, 2018).

The study will examine the change of concrete performance related to compressive strength, tensile splitting strength and permeability properties with and without using glass powder and sawdust instead of fine aggregate.

In this research four mixes were prepared. The first mixture was the control mixture, while in the other three mixtures the sand was partially replaced by glass powder and sawdust The glass powder was gradually increased from trial to another by an increment of 10% of sand's weight, from a rate of 10% up to 30% with a stable percentage of sawdust by 5%. Superplasticizer was added to the last three mixtures in order to improve the consistency of the mixes (Table 3.1).

Table 3.1: Mix design proportions of specimens prepared

Mix No	Components
Mix 1 (control mix)	C + W + G + (100% S)
Mix 2	C + W + G + (85% S + 10%gp + 5% sd) + pl
Mix 3	C + W + G + (75% S + 20%gp + 5% sd) + pl
Mix 4	C + W + G + (65% S + 30%gp + 5% sd) + pl

Where

C: Cement, W: Water, G: Gravel, S: Sand,

gp: glass powder, sd: sawdust, pl: superplasticizer.

Twelve cubes and one cylinder samples were prepared. 10 cubes were used for compressive strength at different curing ages of 7, 28, 56, and 90 days, and 2 cubes were used for permeability at 28, and 90 days of curing ages. In tensile splitting test the cylindrical sample were tested at 56 days of curing age (Table 3.2).

Table 3.2: Organization and distribution of test samples

	Mix 1	**Mix 2**	**Mix 3**	**Mix 4**
No of cubes compressive (7 days)	3	3	3	3
No of cubes compressive (28 days)	2	2	2	2
No of cubes compressive (56 days)	3	3	3	3
No of cubes compressive (90 days)	2	2	2	2
No of cubes permeability (28 days)	1	1	1	1
No of cubes permeability (90 days)	1	1	1	1
No of cylinder tensile (56 days)	1	1	1	1
Total of samples	13	13	13	13

3.2 Materials

3.2.1 Cement

In this study CEM III/A 42.5 N was used (Figure 3.1.). It was provided from Kale Çimento Beton company, complying with the European standard EN 197-1: 2011, which is blast furnace cement made by blending of cement clinker with granulated blast-furnace slag. It provides low heat of hydration making it used in mass concrete, furthermore its high sulphate resistance due to the low content of C_3A which makes it suitable for sea-water construction. The chemical properties of this cement are listed in Table 3.3 (Yıldırım et al., 2011).

Figure 3.1: Sample of the cement used CEM III/A 42.5 N

Table 3.3: Chemical properties of CEM III/A 42.5 N

Compound	Contents (%)
SiO_2	25.38
Fe_2O_3	2.72
Al_2O_3	7.65
CaO	55.29
MgO	2.99
SO_3	1.7
Cl^-	0.01
Na_2O+0.658 K_2O	0.79
Loss on Ignition	2.55
Slag content	37.5
Blain fineness, cm^2/g	3593
Moisture content	0.04%

3.2.2 Aggregates

In this study the aggregates extracted from Beşparmak mountain quarries in North Cyprus and provided by Tufekçi Group Company. Coarse aggregates size divided into two ranges, the first range is between 4.75 mm and 12.5 mm (Figure 3.2), and the other is between 12.5 mm and 19 mm (Figure 3.3). The percentage used in this study for coarse aggregate is 60% of (4.75 mm-12.5 mm), and 40% of (12.5 mm-19 mm). While fine aggregates used was natural sand with size range less than 4.75 mm (Figure 3.4). The properties of the aggregates used in the study is illustrated in Table 3.4.

Figure 3.2: Sample of the coarse aggregates used size (4.75 mm-12.5 mm)

(NEU Lab, 2021)

Figure 3.3: Sample of the coarse aggregates used size (12.5 mm-19 mm)

(NEU Lab, 2021)

Figure 3.4: Sample of the fine aggregates used

(NEU Lab, 2021)

Table 3.4: The properties of the aggregates

	Coarse aggregate(mm)		**Fine aggregate(mm)**
	19-12.5	**12.5-4.75**	**4-0**
Absorption capacity (%)	0.5	0.7	1.4
Bulk density (g/cm3)	1.412	1.412	1.845
Specific gravity	2.7	2.78	2.64
Humidity	1	0.8	0.5
Los Angeles	34	34	-
Moisture content (%)	0.02	0.02	0.04

For this study, the moisture content for the aggregates was adopted for the SSD state to avert any potential excess amount of water during the mixing the proess, and to ensure the preferable performance of the various w/c ratios used for making the concrete mixtures.

3.2.3 Water

Water is considered a vital factor in concrete where without water the hydration reaction does not begin. Potable water was used in this study to ensure the quality of the concrete produced in accordance with EN 1008 standards.

3.2.4 Glass powder

The collected waste glass green bottles were grounded down to particle size less than 2 mm (Figure 3.5).

Figure 3.5: Sample of the glass powder used

(NEU Lab, 2021)

3.2.5 Sawdust

The sawdust used in this study were collected from sawmill in Gönyeli in North Cyprus and were prepared in the NEU laboratory. The sawdust was sieved at sieve number 2 mm, where the retained particles were discarded and the passed were used in the mixtures (Figure 3.6).

Figure 3.6: Sieving of the sawdust

(NEU Lab, 2021)

3.2.6 Superplasticizer

Superplasticizer are used to enhance the workability of the concrete and to reduce the water in the mixture, which yields increase in the performance of concrete in terms of strength and durability. Superplasticizer was mixed with water and stirred manually to obtained homogeneous mix. The proportion of superplasticizer was 1.5% of cement content.

3.3 Methodology

3.3.1 Glass powder preparation

The empty green glass soda bottles were collected and transported to the NEU laboratory where were cleaned out by water to remove all impurities and were placed in the room to dry in the ambient temperature (Figure 3.7).

Figure 3.7: Preparation of the glass bottles

(NEU Lab, 2021)

The dried bottles were put in Loss Angeles machine with 11 steel balls for crushing and milling process in order to get the fine aggregates size as in (Figure 3.8) and (Figure 3.9), respectively.

Figure 3.8: The Los Angeles machine

(NEU Lab, 2021)

Figure 3.9: The crushed glass inside the Los Angeles machine and the steel balls

(NEU Lab, 2021)

After 1000 rotation the machine was stopped and the crushed glass were removed. After removing the glass particles, they were sieved at sieve number 2 mm (Figure 3.10). The glass particles retained on 2 mm sieve were discarded in order to avoid excessive ASR where, the smaller the particle size of the remaining glass powder, the better effect on ASR expansion (Ke et al., 2018). It also allows for the removal of organic contaminants that are separated at the top during the screening process, while the passed glass particles were used in the mixtures.

Figure 3.10: Sieving of the glass particles

(NEU Lab, 2021)

3.3.2 Concrete mix design

The concrete mix design was undertaken according to American Concrete Institute ACI 211.1, the American method (Neville and Brooks, 2010). The mix design was aiming to achieve grade concrete C20 with a slump of 50-80 mm. The mix design calculation was done according to one-meter cube of concrete. The proportions for each mix are illustrated in Table 3.5.

Table 3.5: Concrete mixtures proportions

Constituents	**Proportion(kg/m^3)**			
	Mix 1 (control Mix)	**Mix 2**	**Mix 3**	**Mix 4**
Cement	361	361	361	361
Water	270	270	270	270
W/C	0.62	0.75	0.75	0.75
Coarse agg (12.5-19) mm	410	410	410	410
Coarse aggreg (4.75-12.5) mm	614	614	614	614
Fine agg	746	634	560	485
Glass powder	-	74.4	149	224
Sawdust	-	37.3	37.3	37.3
Superplasticizer	-	5.4	5.4	5.4

3.3.2.1 Water cement ratio (w/c)

The hydration process of concrete begins with the addition of water. The water cement ratio is usually calculated based on the mix design. However, for actual work, the trial mix is necessary to be done to achieve acceptable workability and low permeability. The w/c ratio is decided according to slump test, for all four mixes, slump test was done and according to its values trial mixes were used to adjust water cement ratio for all the four mixtures until obtaining the target slump value 50–80 mm.

3.3.3 Casting and curing

All four mixtures were prepared according to American Society for Testing and Materials ASTM C31 following the same mixing and casting procedures using electrical concrete mixing machine. All dry constituents were added to the mixer and then the mixer was started and the water and the superplasticizer were added gradually. The mixing period started from the moment of water addition and it was between 2–3 minutes until obtaining a homogeneous consistent and the mixture was ready for casting and testing on fresh concrete (Figure 3.11).

Figure 3.11: The concrete mixture

(NEU Lab, 2021)

12 cubic and 1 cylindrical moulds were cleared and painted with a thin layer of oil, the concrete mixture was placed in the mould by three levels, and each level is a one third of the mould, each one third was roded with uniformly distribution by 25 strokes with tamping rod, and each side of the mould was tapped four times with rubber hummer to extract the voids and obtain the maximum bulk density (Figure 3.12).

Figure 3.12: Extracting the voids from the cubic sample by the tamping rod and the rubber hummer

(NEU Lab, 2021)

After filling the other two level of the mould with the same process a trowel was used to smooth the surface of the sample (Figure 3.13).

Figure 3.13: Levelling the surface of the sample by the trowel

(NEU Lab, 2021)

After the filling process was completed, the samples were placed for 24 hours at room temperature for setting to release it from the mould (Figure 3.14).

Figure 3.14: The cubic and the cylindrical samples in the mould

(NEU Lab, 2021)

The prepared samples then were numbered and were submerged in a tank that was already filled with potable water until the test date (Figure 3.15).

Figure 3.15: The samples in the curing tank

(NEU Lab, 2021)

3.4 Tests

3.4.1 Tests on material

3.4.1.1 Sieve analysis test for fine aggregates

Sieve analysis test for fine aggregates was done according to ASTM C136 to determine the grading of the fine aggregate particles in order to check the particle size weather if it is homogeneous or not and to make the particle size of glass similar to the most size in the fine aggregates. 900g were weighted from fine aggregates and were sieved in automatic mixer (Figure 3.16).

Figure 3.16: Sieving of the fine aggregates

(NEU Lab, 2021)

3.4.1.2 Absorption capacity test for gravel

The test was conducted as stated in ASTM C127-04. This test determines the moisture content in the mix which absorbed by the aggregates, which has an impact on the workability of the concrete mixture. A batch of coarse aggregate was weighed and were dried in the oven for 24 hours at 105°, then the dried aggregates were soaked in water for 24 hours, and were weighed again. Water absorption calculations were made as the formula 3.1.

$$\text{water absorption} = \frac{weight\ of\ the\ dry\ agg - weight\ of\ the\ SSD\ agg}{weight\ of\ the\ SSD\ agg} \times 100\% \qquad (3.1)$$

3.4.1.3 Moisture content

The test was done according to ASTM C566 and it was used to determine the water content for materials used in the mixture. This method requires a known amount of coarse aggregates, fine aggregates, cement, and glass powder as well. The materials were weighed and were heated in the oven for 48 hours and by 105 ^{o}C to remove moisture (Figure 3.16). Then the materials were weighed again and the percentage of moisture content was determined by the formula 3.2.

$$moisture\ content\ \% = \frac{(wet\ weight - dry\ weight)}{dry\ weight} \times 100\% \quad (3.2)$$

Figure 3.17: The sample inside the oven

(NEU Lab, 2021)

3.4.1.4 Bulk density

This test was performed according to ASTM C29/C29M, used to determine the voids between particles in aggregates. The test was done using a cylindrical metal measure has known volume and weight, and filled with coarse aggregates and then by fine aggregates and also the test was done on cement, glass powder, and sawdust as well.

The cylindrical measure was filled completely with all materials separately and then was weighed again with the materials. The bulk density or unit weight then was determined by the formula 3.3.

$$unit\ weight = \frac{W_2 - W_1}{V} \quad (3.3)$$

Where;

W_2: the weight of material and cylindrical measure

W_1: the weight of cylindrical measure

V: volume of cylindrical measure

3.4.2 Tests on fresh concrete

3.4.2.1 Slump test

Slump test was done using Abrams cone which the radius of its bottom and top bases are 200 mm and 100 mm, respectively, while its height is 300 mm. The cone was placed on metal plate with the small plate to the down side and the fresh concrete was filled inside the cone from the bigger base in three layers. Tamping rode was used with 25 tamps to extract the voids. This process was repeated for the next two layers. After filling the cone, a trowel was used to make the surface levelled, then the cone immediately was raised vertically. Then, the vertical difference between the top of the cone and the centre of the concrete sample was measured and the resulted value is the slump value (Figure 3.18).

Figure 3.18: Slump test

(NEU Lab, 2021)

3.4.2.2 Initial setting time test

The initial setting time is the time between the addition of water to the mixture and the beginning of the paste to lose its plasticity. ASTM C403 procedures were used to determine the initial setting time. Vicat's apparatus was used to determine the initial setting time with 1 mm needle. The concrete sample were sieved on sieve number 4.75 to extract the coarse aggregates and the passed sample was filled on a circular mould resting on a non-porous plate and then the surface of the sample was levelled by small gauging trowel. The plate was placed inside the Vicat apparatus and the needle was lowered till the surface of the sample and released to penetrate the sample. The period elapsed between the time when water added to the mix and the needle penetrate the sample where the needle indicator refers to 5 cm is the initial setting time (Figure 3.19).

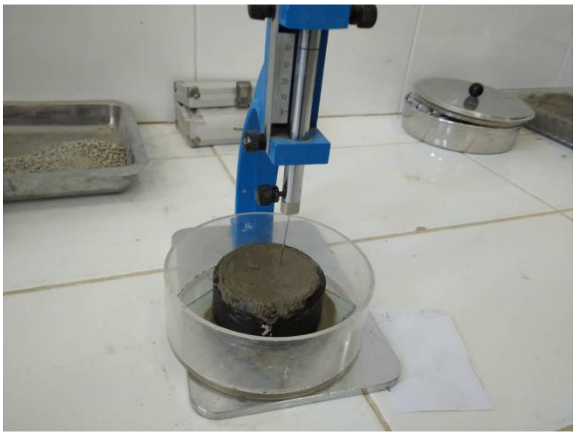

Figure 3.19: Initial setting time test

(NEU Lab, 2021)

3.4.2.3 Final setting time test

The final setting time is the time between adding water to the cement until the paste completely loses its plasticity and reaches a hardness sufficient to withstand a certain pressure. ASTM C403 was used to determine the final setting time, and it was applied using the same apparatus and the same sample of the initial setting time but the needle of Vicat's apparatus was replaced by a thicker needle with 5 mm in diameter. The time from adding water to the mixture to when the needle leaves a mark on the surface of the sample but the attached tool does not do so is the final setting time (Figure 3.20).

Figure 3.20: Final setting time test (NEU Lab, 2021)

3.4.3 Tests on Hardened Concrete

3.4.3.1 Compressive Strength Test

This test was conducted to determine the compressive strength of the cubic samples using EN 12390-3 procedures. The machine was used to apply the load on the surface of the cubic sample with dimension of 150 mm*150 mm*150 mm, the load gradually increased until the failure of the cube, and the maximum applied load on the cubic sample was recorded. The test was done in the age of 7, 28, 56, and 90 days of curing (Figure 3.21).

Figure 3.21: Compressive strength test

(NEU Lab, 2021)

3.4.3.2 Splitting tensile strength

En 12390-6 was adopted to determine the splitting tensile strength. The method involves applying a longitudinal compressive force along the cylindrical concrete sample with dimension of 150 mm*300 mm. The load increasing stopped at the failure of the cylindrical sample and the maximum applied load on the cylindrical sample was recorded. The test were done after immediately 56 days of curing (Figure 3.22).

Figure 3.22: Splitting tensile strength test

(NEU Lab, 2021)

3.4.3.3 Concrete permeability

This test was performed to determine permeability of cubic concrete samples using EN12390-8 procedures. The cubic samples were with dimension of 150 mm*150 mm*150 mm and in the age of 28 and 56 days of curing. The test was carried out by placing three cubic samples for 72 hours within the machine, which was connected to compressor which provide pressure for five bars on the machine. After 72 hours the specimens were split into two parts and the maximum water penetration level was measured (Figure 3.23).

Figure 3.23: Permeability test

(NEU Lab, 2021)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General Aspects

In this research absorption capacity, moisture content, bulk density, and grain size distribution tests were applied on the materials used. Four mixes were prepared, all four mixes were tested for concrete consistency and setting time when the concrete was in the fresh state. 52 concrete samples were prepared, compressive strength test was applied on cubic samples for 7, 28, 56, and 90 days, splitting tensile strength test was applied on cylindrical samples for 56 days, and concrete permeability test was applied on cubic samples for 28, and 56 days.

4.2 Materials Tests

4.2.1 Grain size distribution of fine aggregates

Grain size distribution of fine aggregates in this study is important for controlling the homogeneity of the particles size distribution. In addition, it is important to know the volume of the particles with size less than 2 mm which is the range used for glass powder and sawdust. 900 g of fine aggregates were sieved and the results achieved are shown in Table 4.1

Table 4.1: The sieve analysis for fine aggregates

Sieve size (mm)	Retained%	Passed%
4.75	0	100
2.36	90	90
2	75	82
1.18	150	65
0.6	225	40
0.3	225	15
0.15	135	0

Table 4.1 shows that 82% of the fine aggregates passed through the sieve 2 mm which is the standard sieve that adopted in this study for sieving the glass powder and sawdust.

4.2.2 Absorption capacity

The absorption capacity test is an important factor in order to maintain the required workability. The aggregates absorption rate affects the determination of the water requirements of the concrete mixture. The test results show that the absorption capacity of the coarse aggregates used in this study were 0.7% for the aggregates that have size range between 4.75 mm and 12.5 mm, and 0.5% for the aggregates that have size range between 12.5 mm and 19 mm.

4.2.3 Moisture content

Materials used in concrete can contains water. The moisture content is important to know if the used materials have excessive water or will absorb water. In both cases, they have influences on the hydration process, which has impacts on the properties of concrete. Table 4.2 shows the moisture content of the materials used

Table 4.2: Moisture content of the material used

Material	Normal State (gr)	Oven Dry State (gr)	Moisture Content (%)
Coarse Aggregate	500	499.9	0.02
Fine Aggregate	500	499.8	0.04
Cement	500	494.8	1.0714
Glass Powder	500	499.8	0.04

4.2.4 Bulk density

Bulk density measures the volume of the materials in concrete including the granular shapes of the particles and the voids between them. In addition, the bulk density is also required for the batch volume method of the mixture. The bulk density of the materials used is shown in Table 4.3

Table 4.3: Bulk density of the materials used

	Bulk Density
Coarse Aggregate	1.412
Fine Aggregate	1.845
Glass Powder	1.737
Sawdust	0.229

4.3 Fresh Concrete Tests

4.3.1 Concrete consistency

Consistency of concrete is a major factor in concrete mixture, where it gives an indication about the workability degree of concrete mixture and it is measured by slump test. Table 4.4 illustrates the slump values for the four mixes investigated.

Table 4.4: Slump values for the concrete mixtures

Mix No	W/c	Superplasticizer	Slump(cm)
Mix 1	0.62	0	6
Mix 2	0.75	1.5% of cement content (5.4 kg/m^3)	3
Mix 3	0.75	1.5% of cement content (5.4 kg/m^3)	4
Mix 4	0.75	1.5% of cement content (5.4 kg/m^3)	7

The slump values shown in Table 4.4 refers to 6 cm for Mix 1 which is the control mix. With starting the replacing process of fine aggregates by glass powder and sawdust, the slump value was 3 cm for Mix 2 despite of the increasing of water content and in the presence of the water reducer. That is attributed to the existence of sawdust which has a great ability to absorb water, unlike glass powder which has lower ability to absorb water than sawdust and fine aggregate. By increasing the glass powder percentage in Mix 3 and Mix 4, the slump value increases to reach 4 cm for Mix 3 and 7 cm for Mix 4. This is explained by the reduction in fine aggregates amount which has higher ability to absorb water than the glass powder.

4.3.2 Setting time

The initial and final setting time are important factors to understand the behaviour of the concrete in relation to its plasticity and starting the stage of the hardening state. Table 4.5 illustrates the results for initial and final setting time for the four concrete mixtures.

Table 4.5: Initial and final setting time for the concrete mixtures

	Mix 1	**Mix 2**	**Mix 3**	**Mix 4**
Initial setting time	2hr 35 min	7hr 25 min	5hr 23min	4 hr 22min
Final setting time	5hr 20 min	9 hr 25 min	9 hr 6 min	8 hr 48 min

According to Table4.5, the presence of glass powder and sawdust has an effect on the setting time of concrete. The initial and final setting time for the last three mixes were close to each other but they are quite different from the time of the control mixture. However, the values of initial and final setting time for all mixes are within the allowable range according to the standards values of the ASTM which is 60 mins for the initial setting time and 10 hr for the final setting time (Neville and Brooks, 2010).

4.4 Hardened Concrete Tests

4.4.1 Compressive strength test

Table 4.6 illustrates the compressive strength values for the cubic samples for the four studied mixtures at different days of curing ages. As shown in Table 4.6, at 7 days, in case of Mix 2 and Mix 3 that have 10% and 20% of glass powder with 5% of sawdust, it was noticed a big drop in compressive strength value as compared by the control mix.

Table 4.6: Compressive strength of the cubic samples

	Day7	**Day28**	**Day 56**	**Day 90**
Mix 1	14	26.45	32.3	37
Mix 2	3.1	12.6	9.2	6.35
Mix 3	3	14.2	11.8	13.25
Mix 4	10.4	21.3	22.1	25.7

By increasing the glass powder percentage to 30% and maintain the sawdust percentage at 5% (as in case of Mix 4), it is noticed an increasing in the compressive strength value to reach 75% of the compressive strength of the control mix, and around 3.5 times the compressive strength value of Mix 2 and Mix 3. These explained by the high glass powder content in Mix 4 in comparison with the sawdust content in the same mixture, unlike the others mixes that has glass powder and sawdust percentage relatively close, where glass powder has a higher resistance to compressive strength as compared to sawdust resistance. Thus, the increasing of glass powder content, the increasing of the compressive strength value. These findings support Adaway and Wang, 2015 research, which said that the increasing of fine aggregates replacement to 30% of glass powder increases the compressive strength value. And also support the research of Suliman et al. 2019, who found that the compressive strength for the seven days samples reduced at the percentage 5% of sawdust replacement.

At 28 days, the values of compressive strength were almost with the same increasing that shown at 7 days. The compressive strength value for the Mix 4 was around 85% of the control mix value, and it was 69% and 66% higher than Mix 2 and Mix 3 respectively. It can be assumed that the angular nature and rough surface of the glass particles contribute to these strength characteristics and provide a strong adhesion between the cement paste and the glass particles. Adaway & Wang, 2015, came to a similar conclusion that at 28 days the compressive strength values were higher than the seven days values.

At 56 and 90 days, it is observed that the compressive strength development reduced for Mix 2 and Mix 3, but it keeps increase for Mix 4. Further experiments are needed to determine the exact cause of the reduction in the compressive strength value for Mix 2 and Mix 3. However, the increasing of compressive strength development in Mix 4 is attributed to the small particles of glass powder that can react with $Ca(OH)_2$ formed by the hydration reaction of cement to form secondary C-S-H. The secondary C-S-H is a gel material filling the concrete voids due to the expansive nature of the C-S-H gel, and helps the compressive strength and the durability to increase. This process takes a long time, because it is known that glass powder reacts slowly. In summary, it can be said that the best compressive strength development yield is achieved through combination 30% glass powder and 5% sawdust. Figure 4.1 shows the compressive strength values for different concrete mixtures at different days of curing ages.

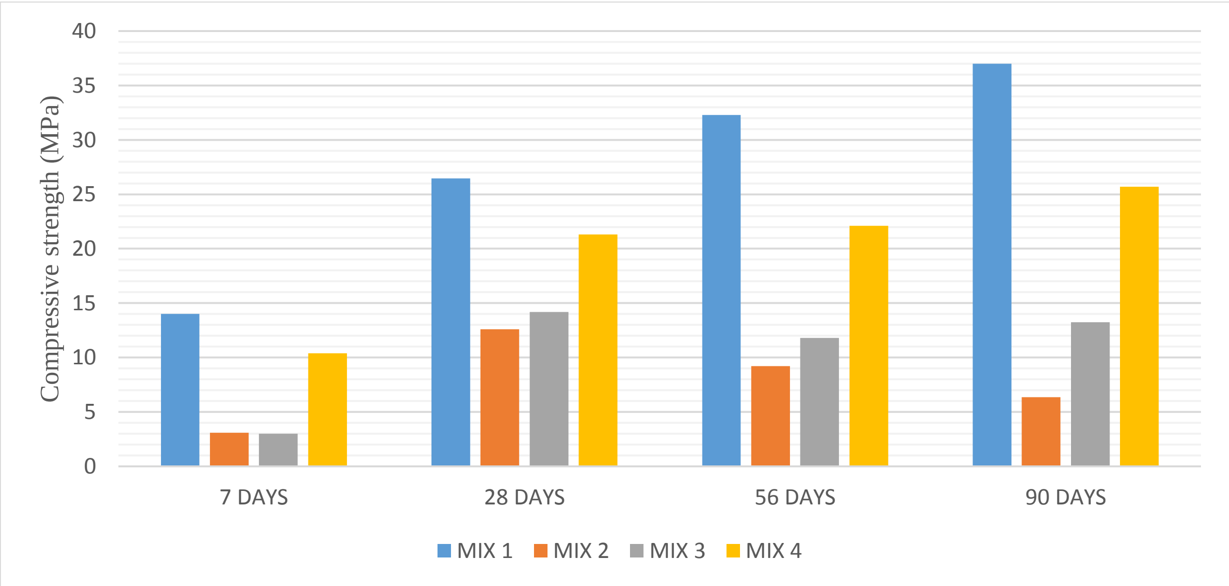

Figure 4.1: The compressive strength values for the studied mixes

4.4.2 Split tensile strength test

Table 4.7 shows the tensile strength values for the cylindrical samples for the four concrete mixtures for 56 days of curing ages.

Table 4.7: Tensile strength values for 56d

	Tensile Strength (MPa)
Mix 1	2
Mix 2	2.2
Mix 3	2
Mix 4	2

From Table 4.7, the splitting tensile strength for the control mix is 2 MPa, 2.2 MPa for Mix 2, 2 MPa for both Mix 3 and Mix 4. The results shown that glass powder and sawdust as a replacement of fine aggregates in concrete has no noticeable effect on the splitting tensile strength of concrete. This finding agrees with the result of (Meddah, 2019), where used the glass powder as a replacement of fine aggregates as 10%, 20%, and 30%. He found that the glass powder has no negative effect on the tensile strength of concrete. Unlike (Vimala, 2018) who used sawdust as a replacement of fine aggregates as 5%, 10%, 15%, and 20%. He found that using o sawdust has negative effect on the tensile splitting strength of concrete, and the tensile strength values decreased with increasing of replacement percentage. In this study, it is observed that the positive effects of glass powder on the splitting tensile strength get over the negative effects of sawdust on the tensile strength due to the high hardness of glass. Although it is possible to achieve positive effects through more grading adjustment and appropriate mixture ratios.

4.4.3 Permeability test

The permeability test of concrete was conducted by water penetration test under pressure. Table 4.8 illustrates the permeability values for the cubic samples for 28 days and 90 days of curing ages.

Table 4.8: Concrete permeability for the four concrete mixtures

	Water Penetration Depth(mm)	
	Day28	**Day90**
Mix 1	42	30
Mix 2	83	77
Mix 3	79	71
Mix 4	64	54

From Table 4.8, at 28 days water penetration for the control mix is 42 mm, while for Mix 2 and Mix 3 water penetration is two times the water penetration of the control mix to record 83 mm and 79 mm respectively. These high values could be due to the high w/c ratio that will leave voids after the hydration process takes its place, and also for the high water absorption of the sawdust in concrete mixture. Water penetration for Mix 4 is 1.5 time the water penetration of the control mix to reach 6.4. The difference of the water penetration values in the last three mixtures could be to the increasing of glass powder content on the fine aggregate account, where glass powder has less ability to absorb water. In addition, the small size of glass powder particles can react with the portlandite that produced from the hydration process of cement to form the secondary C-S-H gel. This gel can fill the concrete voids and thus reduce the porosity of the concrete. At 90 days, the water penetration values for the concrete samples for the last three mixtures decrease and it take almost the same way in the 28 days samples as compared to the control mix.

In summary, it can be said that the increasing of glass powder content, the increasing of concrete resistance for water penetration. Figure 4.2 shows the permeability values of the concrete samples for 28 and 90 days as a chart.

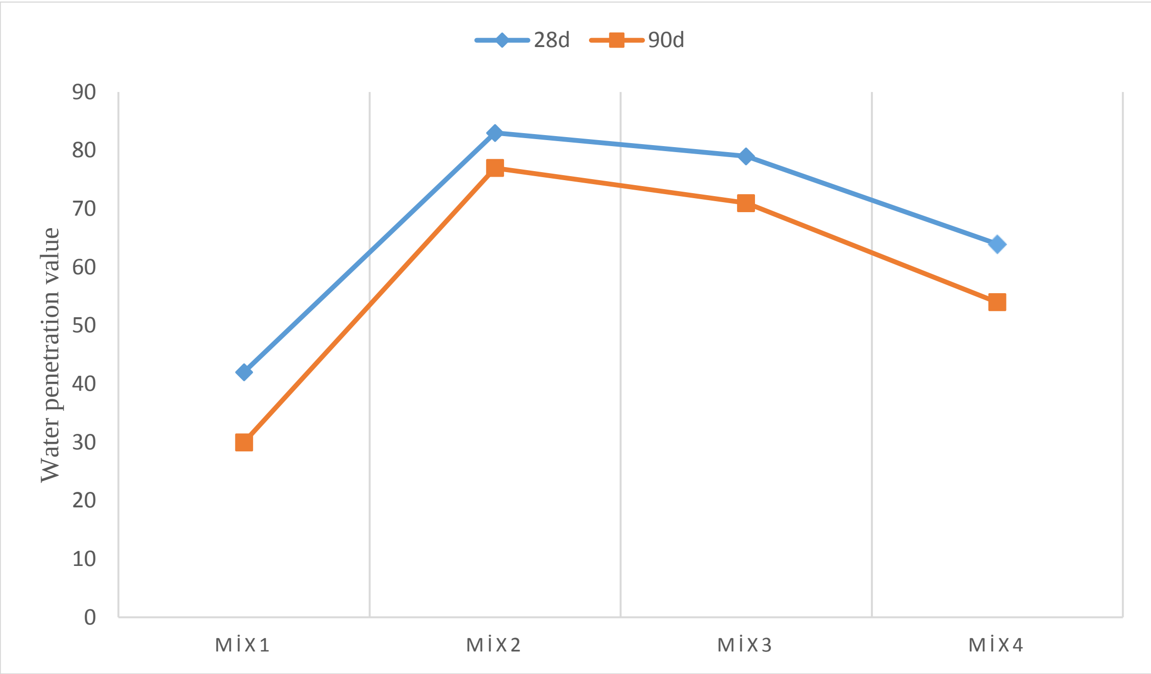

Figure 4.2: Water penetration of the concrete samples (mm)

4.5 The Relation between the Replacement Percentage and the Weight of Concrete

The weight of concrete considered an important factor for designing buildings. It has an important role to determine the base shear force that used to design the buildings to resist the earthquakes. It is also important for multi-storey building due to the decreasing of the dead load of structure. The decreasing of the weight of the concrete yields to decrease the building weight which reduce the reinforcement needed and that reduce the cost of the building. Figure 4.3 shows the change in the weight of concrete with the increasing in the replacement percentage.

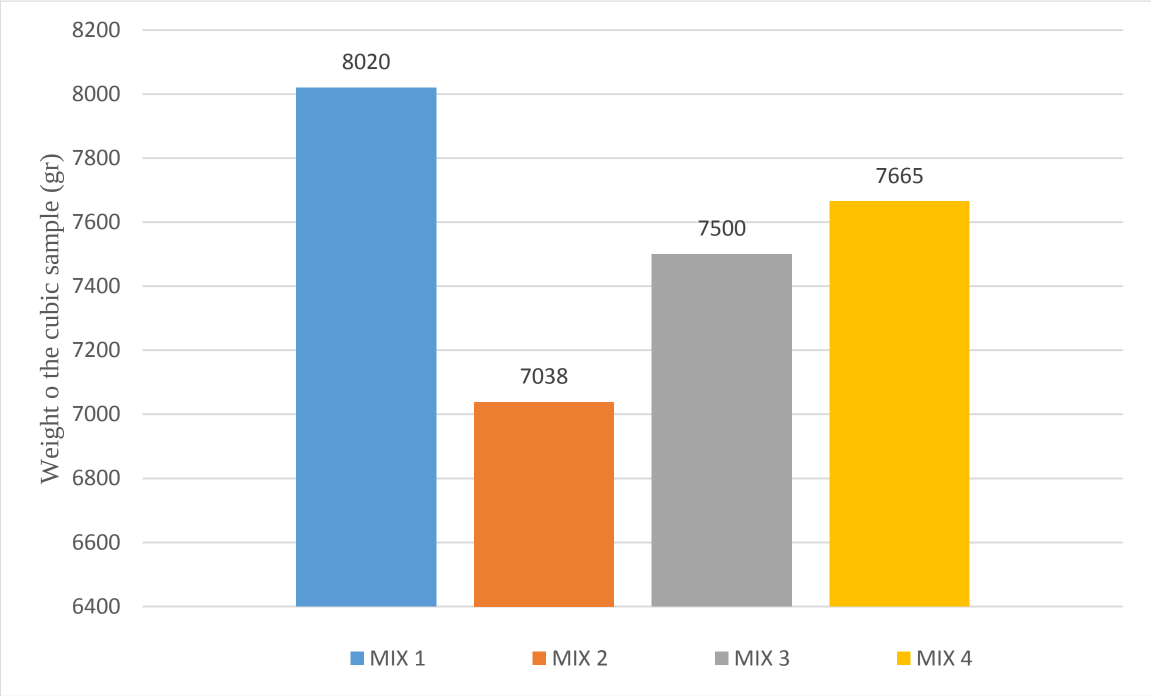

Figure 4.3: Concrete weight values by changing replacement percentage

The Figure shows a reduction in the weight of Mix 2 cubic sample with around 1000gr as compared with the control mix. This reduction due to the presence of the sawdust in the mixture on the fine aggregates account which has a specific gravity less than the specific gravity of fine aggregates. With the increase of the replacement percentage, the weight of the cubic sample increases due to the increase of the glass powder content with maintaining the sawdust content. This increasing because of the glass powder that has specific gravity higher than the fine aggregates.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research includes experimental and theoretical investigations, aiming to study the effects of using glass powder and sawdust as fine aggregates in concrete production. Four concrete mixtures were prepared with glass powder content varying in between 0 and 30% replacement combined with constant sawdust content of 5%. 12 cubes and 1 cylinder were produced for each concrete mixture. Samples were tested for compressive strength, split tensile strength, and permeability test.

Through experiments and calculations, the following conclusion are drawn:

- Glass powder and sawdust could be used together as a replacement of fine aggregate.
- Using glass powder and sawdust as fine aggregates can reduce the specific gravity of concrete, thus the weight of concrete.
- Glass powder and sawdust have no negative effect on the split tensile strength of concrete as compared to the control mix.
- Using waste materials, such as glass powder and sawdust as a substitute of fine aggregates can reduce the cost of concrete materials.
- The mix that has 10% glass powder and 5% sawdust showed low workability as compared to the control mix. However, with the increasing of glass powder content, the workability increased to be close to the control mix. As a conclusion, the sawdust water absorbent nature could be modified by increasing the glass powder amount.
- Among the glass powder ratios (10%, 20%, and 30%) and sawdust content of 5%, the best compressive strength development was observed with the combination of the 30% glass powder and 5% sawdust. The weakest compressive strength development was achieved with the combination of the 10% glass powder and 5% sawdust. As a general conclusion, the higher glass powder content, the higher compressive strength, the lower glass powder content, the lower compressive strength.

- Mix that has 30% glass powder and 5% sawdust showed the lowest water penetration value comparing by the other replacement percentage but it still higher than the control mix.
- For structural elements such as beams, columns, and slabs, it is not recommended to use glass powder and sawdust as a substitute of fine aggregates, because of the low compressive strength values.
- As a final conclusion, the optimum replacement percentage of fine aggregates by glass powder and sawdust were determined to be 30% and 5% respectively, which gives the best mechanical properties as compared to the other replacement percentage.

5.2 Recommendations

- The results and observations of this study should be repeated to confirm the results.
- Further experiments could be conducted by using different amounts of glass powder more than 30% with different amounts of sawdust more than 5%.
- More tests on concrete could be performed such as fire resistance test.
- The effects of glass powder and sawdust could be tested using different types of curing and at higher curing temperature.

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