Effects of Waste Marble and Glass Powders on Concrete Properties and Performance

Nour Eldeen M.A. Abo Nassar

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

Eastern Mediterranean University
January 2020
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Ali Hakan Ulusoy
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Prof. Dr. Umut Türker
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Assoc. Prof. Dr. Tülin Akçaoğlu
Supervisor

Examining Committee

1. Prof. Dr. Özgür Eren
2. Assoc. Prof. Dr. Tülin Akçaoğlu
3. Asst. Prof. Dr. Ayşe Pekrioğlu Balkıs

ABSTRACT

Concrete, consisting primarily of cement, water and aggregates, is the most used construction material all over the world and plays an important role in the growth of infrastructure and industrial sectors. Cement manufacturing industry is one of the carbon dioxide producing sources that is caused global warming. However, using the waste materials and by-products as cement replacement materials become an attractive alternative because it helps to reduce the cost of concrete and cement manufacturing, also has numerous indirect benefits such as saving energy, reducing landfill cost and protecting the environment from possible pollution effects.

Nowadays, marble dust and waste glass powders are two of the most polluting waste materials for the world environment. For this reason, in this thesis; the marble dust (MD) was examined as a partial cement replacement material with seven proportions as 0%, 10%, 20%, 30%, 40%, 50%, 60% and the glass powder (GP) was used as an additive material, 8% by cement weight, in a 0.55 water-binder ratio (w/b) concrete. Finally; experimental results indicated that MD can be used as a cement replacement material up to 10% replacement and with the use of GP both physical and mechanical properties of concrete can be improved.

Keywords: Concrete, Marble dust, Glass powder, Cement replacement materials, Mechanical properties, Workability, Durability, Compressive strength, Sulphate resistance.

ÖZ

Çimento, su ve agregalardan oluşan beton; tüm dünyada en çok kullanılan yapı malzemesi olmakla birlikte altyapı ve sanayi sektörlerinin büyümesinde de önemli rol oynamaktadır. Çimento üretimi endüstrisi, karbondioksit salınımına yol açtığından, küresel ısınmaya neden olan kaynaklardan birisi olarak kabul edilmektedir. Ancak, çimento yerine atık malzemeler ve yan ürünlerinin kullanılması; başta çimento üretim sırasında açığa çıkan karbondioksit gazı olmak üzere, üretim maliyetini de düşürecek ve de ayni zamanda çevre atık malzemelerden arınmış olacaktır. Bu yüzden, günümüzde çimento yerine atık malzemeler ve yan ürünlerini kullanmak cazip bir alternatif haline gelmiştir.

Günümüzde dünya için; atık mermer ve cam tozlarının, çevreyi en çok kirleten atık malzemelerden oldukları bilinmektedir. Bu nedenle, bu tezde; mermer tozu (MD); %0, %10, %20, %30, %40, %50, %60 yüzdelerinde çimento yerine, cam tozu ise (GP), çimento ağırıığının %8’i miktarında beton katkı malzemesi olarak kullanılmışlardır. Bunların etkileri; su/çimeto oranı 0.55 olan betonun bazı fiziksel ve mekanik özeliklerine olan etkileri araştırılmıştır. Sonuç olarak mermer tozunun cam tozu ile birlikte kullanılmasının dayanıma olan pozitif etkilerinin artan beton yaşı ile birlikte arttığı gözlemlenmiştir.

Anahtar Kelimeler: Mermer tozu, Cam tozu, Çimento yerdeğişimi, İşlenebilirlik, Dayanıklılık, Basınç dayanımı, Sülfat direnci.

DEDICATION

To My Family

ACKNOWLEDGMENT

I would like to express my sincere gratitude to those who helped me to fulfill this thesis successfully. First and foremost, my honest gratitude and deepest appreciation goes to my supervisor Assoc. Prof. Dr. Tülin Akçaoğlu for her inestimable supports, valuable comments and professional guidance. She did everything for me in order to manage this study step by step. She contributed many valuable instructions and suggestions on the structure and content of the study.

I would like to thank the laboratory staff especially Mr. Ogün Kılıç for his help during preparation of this thesis. I would like to extend my deepest gratitude to my dear friend Hussein Moussa, who did not hesitate to help me during the laboratory work and preparing the concrete specimens.

Special thanks goes to all Civil Engineering Department staff members for the suitable climate that they provided for us to accomplish our study.

Last but not least, I would like to express my sincere gratitude to my parents, my mother and my father, for giving me the opportunity to pursue education abroad and for their support and encouragement throughout my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

GP	Glass Powder
MD	Marble Dust
SCM	Supplementary Cementitious Material
W	Water
w/b	Water-Binder ratio
w/c	Water-Cement ratio
σ_c	Compressive Strength
σ_f	Flexural Strength
σ_s	Splitting Tensile Strength

Chapter 1

INTRODUCTION

1.1 General

The essence of new development is tightly connected to protecting natural resources through preventing environmental degeneration since building materials are mostly evaluated through their environmental properties. Concrete, which considered as the most used building material consisting primarily of cement, water and aggregates, plays an important part in the development of infrastructure and manufacturing sectors. It has been stated that concrete is not an environmentally friendly substance because of its devastating nature that consumes resources and its potentially severe environmental effect after its utilization. Even so, it will continue to be the main construction material being utilized worldwide (Karim et al, 2016).

Civil engineers are always searching about waste materials that can be used as a mixing ingredient in cements in order to reduce its cost and to improve its quality. There are several studies related with the utilization of waste materials in construction. Every year, a large amount of waste is produced and most of these waste is not recyclable. Moreover, recycling waste consumes energy and leads to pollution. Furthermore, suburban waste accumulation and waste elimination poses great risks to the environment (Sakalkale et al, 2014).

Throwing the wastes directly into the environment may lead to environmental issues. As a result, several countries are still dealing with the utilization of the waste material in order to minimize its risk to the environment. Strict environmental protection rules are used in the developed countries, whereas developing countries mostly do not have rules to save the environment from wastes. Wastes might be utilized to produce fresh products or can be utilized as additives and in this way natural environment are utilized more effectively and the environment can be saved from waste sediments (Karaşahin and Terzi, 2007).

Waste marble dust is considered as one of the most important materials that used to substitute the cement in concrete mixes. Marble, which is mainly used for decorative objectives, has been utilized in constructions since ancient times. In order to produce marble powder form, marble blocks are sawing and polishing in processing plants and approximately 25% of the processed marble becomes powder form. India being the largest exporter of marble, with millions of tons of marble waste processing plants being released each year (Sakalkale et al, 2014). The disposal of marble wastes from the soil reduces permeability and pollution of groundwater when deposited along the watershed area. Thus, the use of this marble waste in the construction industry itself would help protect the environment from marble dumps (Dachowski and Kostrzewa, 2016).

Due to the recent increased amount of wasted glass production, many researchers have begun to study the influence of glass utilized in concrete as aggregates replacement or cement replacement or as an additive to the concrete mix. As United Nations mentioned, about 7 per-cent of the yearly disposed solid waste materials are glass, which has an adverse impact on the environment. Therefore, its use in construction will help the environment for the removal of non-degradable waste (Topcu and Canbaz, 2004).

1.2 Significance of the Study

After the natural increase in population, the kind and amount of waste materials have raised accordingly. Many of the undissolved wastes will stay in the environment for several years (hundreds or probably thousands of years). The presence of non-decomposing waste materials will lead to a waste disposal crisis, which contributes to environmental problems (Batayneh, Marie and Asi, 2007). It is necessary to reuse and dispose these materials. Waste could be utilized in the construction manufacture in two ways: firstly, by reuse (reuse components), and secondly by recycling (waste curing to raw materials that can be utilized in the manufacturing of construction materials). Recycling waste as beneficial material is a substantial environmental management tool for obtaining sustainable development (Dachowski and Kostrzewa, 2016). Therefore, in this research, waste marble and glass powders will be used in the concrete production process.

1.3 Objectives of the Study

The present study evaluates the effects of using waste marble and glass powders on the concrete characteristics. MD will be used as a cement substitution material while glass powder will be used as an additive. For this purpose, seven various series of concrete mixes will be made by replacing the cement with MD at percentages of 0, 10, 20, 30, 40, 50 and 60% by cement weight, seven other mixes will also be prepared by replacing the cement with MD at percentages of 0, 10, 20, 30, 40, 50 and 60% by cement weight but with the addition of 8% (weight of cement) glass powder. The use of these powders will give some advantages to the environment such as minimizing waste disposal. Moreover, some concrete characteristics may be here are expected to be enhanced when these waste materials are utilized in the concrete production process.

In order to define the influence of the MD, incorporated with GP on concrete strengths and durability aspects, the following experiments will be done on prepared specimens:

- Concrete workability test.
- Compressive, flexural and split tensile strength.
- Concrete PH measurement.
- Sulphate resistance.
- Ultrasonic Pulse Velocity test.

The above experiments will be conducted by following professional standards, such as ASTM C496, ASTM C157 and ASTM C78.

1.4 Thesis Structure

This thesis is organized as; in chapter two literature review about properties and composition of MD and glass powders, and their properties exist. The experimental procedure and methods of the study will be explained in chapter three. In chapter four, results and discussions of the experiments are discussed. Finally, all critical conclusions are given in chapter five.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

During the last years, several achievements have been attained through concrete and cement technology. Important one of these successes is to utilize waste materials either as a filler or as an additive material in the manufacturing of cement and concrete with environmental and economic features. These waste materials have been found to have a reactive or filling effect in the production of concrete. Reactive materials which is called as pozzolanas have been widely utilized around the world when available. The inert fillers are also used worldwide (Onchiri et al, 2014).

Marble waste is considered as the main by-product in the building industry, that is produced in large quantities in various countries. The large marble blocks are cut to smaller blocks to make the required smooth shape. During the cutting and polishing of marble, approximately 30% of marble is converted into dust, mainly consisting of Al_2O_3, SiO_2, Fe_2O_3 and CaO, with some secondary components such as Mg, K, Mn and Ti oxides, which can cause dangerous damages to the environment, such as pollution of the soil and underground water, if not effectively treated before disposal (Dhanapandiana and Shanthib, 2009).

2.2 Cement Replacement Materials (CRM)

Many materials such as industrial wastes and natural materials could be utilized to replace the cement in any given mixture by percentage. These kinds of materials are named pozzolans, and they can improve durability of the cementitious mixtures and enhance its mechanical characteristics. Among all pozzolans, some of the most widely utilized CRM are briefly described below.

2.2.1 Fly Ash (FA)

Fly ash is the most common type of all SCM. Fly ash, also known as pulverized fuel ash (PFA), is a by- product from the burning of coal in power plants. FA is a pozzolanic material containing aluminous and siliceous materials which presents cement like properties when combined with water. Fly ash is made of fine and small particles, by this way, the density of the concrete mix is increased. Thus, permeability is minimized and chloride penetration is reduced (Xu and Shi, 2018). Moreover, the use of FA in the concrete mix leads to increase in strength and improve sulfate attack resistance.

2.2.2 Silica Fume (SF)

Silica fume which is also recognized as micro silica is a by-product from the production of silicon metal. The smoke which outcomes from the oven during the production of silicon operation is gathered and used as SF. Because of its very fineness and the high silica proportion, SF is an efficient pozzolanic material (King, D. 2012). It is mostly utilized in concrete as a mineral admixture to improve and enhance characteristics of concrete. Concrete which contains silica fume has rather high strength. Silica fume lowers the permeability of concrete due to its fineness as well as the positive effect from pozzolanic reaction, which produces denser and more homogeneous structures in the matrix, so water intrusion can be considerably minimized. Furthermore, it helps significantly in its superior resistance to corrosion from chemical attacks such as nitrates, acids, sulfates and chlorides.

2.2.3 Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag (GGBFS) is a by-product recovered from an industrial iron blast furnace during iron extraction from iron ore. The use of GGBFS goes back to 150 years in Europe where it was first used as a cement component in the production of bricks, since the late 1950's, the construction industry started to use GGBFS as a CRM where it is added in the mixer together with Portland cement to enhance a certain function. It is sometimes referred to as slag cement (Shumuye and Jun, 2018). Use of GGBFS increases the durability of concrete by having a high resistance to sulfate and by its reduced reaction of alkalis to aggregate. Moreover, the possibility of steel reinforcement corrosion can be reduced by decreasing the diffusion and penetration of chlorine.

2.2.4 Metakaolin

Metakaolin (MK) is a pozzolanic substance which is being used commonly in mortar and concrete. MK can be obtained by the calcification of kaolinitic clay at a temperature between 500 °C and 800 °C (Siddique and Klaus, 2009). MK is manly used in concrete for its pozzolanic and filling properties. MK is also well known for its significant effect in improving the mechanical and durability characteristics of mortar and concrete. Moreover, metakaolin increases the early age strength of concrete because of its aluminum content and fine particle size which accelerates the hydration reaction (Khamchin, Sri Ravindrarajah, and Sirivivatnanon, 2015). Additionally, MK is preferred when preparing acid resistance concrete. Previous studies showed that use of the MK gave good results for chloride permeability and sulphate resistance (Aiswarya, Prince and Dilip, 2013).

2.2.5 Rich Husk Ash (RHA)

RHA can be defined as a by-product of rice husk combustion. RHA consists mostly of amorphous form (85-90%) and has a very small porous structure which is suitable for changing cement with pozzolanic reaction. RHA amorphous silica can react with calcium hydroxide crystal formed during the hydration of concrete. RHA can increase the interlock between the concrete mixture and fill the gap between the cement particles. Thus, a density and strength can be produced higher (Cordeiro et al, 2009).

2.2.6 Glass Powder (GP)

Another source of CRM is GP, produced from waste glasses and called waste glass powder. Waste glass usually has the desired chemical composition to utilize as a CRM in concrete since GP has pozzolanic characteristics, and can enhance hydration process, mechanical and the durability properties of concrete. However, to obtain this properties of GP, the particles have to be graded to a small size in order to be able to react with cement particles and give better results (Aliabdo et al, 2016).

2.3 Fillers in Concrete

Fillers are materials used in concrete to reduce the consumption of more expensive materials or to enhance some characteristics of the concrete mixes. Fillers have a considerable effect on concrete properties for fresh and hardened properties. These materials could be utilized to reduce the cement content by replacing it with the cement in mortar or concrete production. Large amount of fillers is available as by-products from various industries. The use of these fillers will help the environment to dispose of these materials and the utilization of by-products can decrease the use of cement which helps the environment in a positive way. There are many ways for fillers to interact with cement. They may be inert but can indirectly affect the chemical composition of the mortar and concrete in a positive way. The large surface area of the small particles may improve the density and homogeneity of the paste. Further, it will affect the concrete rheological properties, which will also affect the hardened concrete properties. The cross section of filler materials in concrete is shown in Figure 2.1

Addition of filler materials can influence the concrete in three ways:

1. Physical level: The filler materials will go through the voids between cement particles and fill it, thus improve the density of the concrete.
2. Surface chemical level: The filler materials will affect the hydration by acting as nucleation positions, they become an integral portion of cement paste.
3. Chemical level: The filler materials interact with a component of the cement, for instance with calcium hydroxide and hence form cement gel.

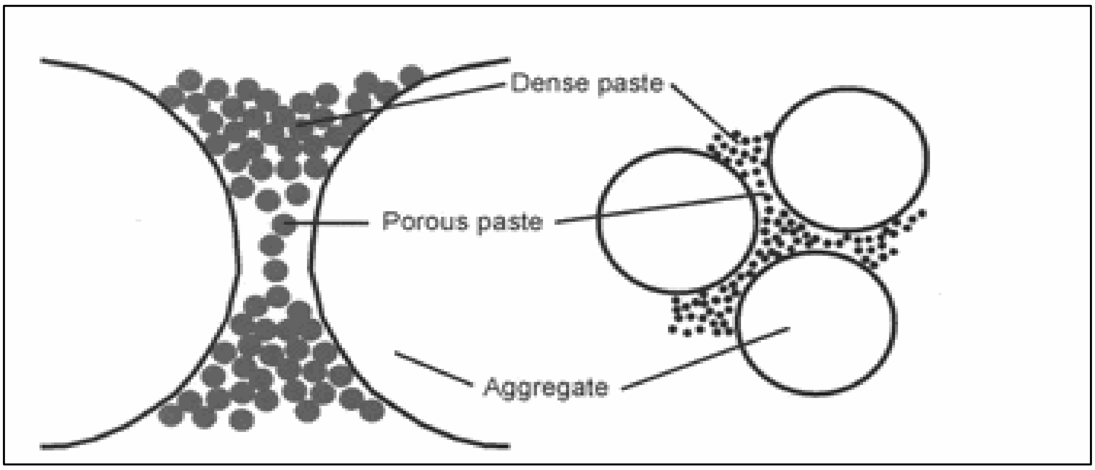

Figure 2.1: Cross Section of Filler in Concrete

2.4 Literature Studies on Marble Dust and Glass Powders Concrete

MD and GP can be utilized in concrete as a substitution for three materials (cement, fine aggregate and coarse aggregate) or as an additive. The utilization of MD in production of cement concrete as a substitute for cement or sand improves both physical and mechanical characteristics of concrete. Utilizing MD in concrete production, a denser structure can be obtained. Since marble dust is freely available (can be obtained from marble factories), so its use in concrete as a cement replacement will be more economical due to the high cost of cement. (Singh and Madan, 2017).

Marble is considered as one of the most substantial materials utilized in constructions, particularly for decorative objectives. However, its powder has negative influences on the environment, water, soil and cause health issues. MD is produced from treatment plants sawing and polishing of marble blocks and approximately 25% of treated marble is converted to powder or dust form. Disposal of the waste materials of the marble industry, consisting of very fine powders, is one of the environmental problems worldwide today (Alyamac and Ince, 2009).

Much work has been conducted on the partial replacement of cement by MD, replacement of fine aggregate by marble particles and replacement of coarse aggregate by marble aggregates. When Marble Dust has been used instead of Portland cement at various proportions, positive results were found such as improving some concrete properties and dispose these materials from the environment. (Aruntas et al, 2010).

Utilization of MD in concrete has not found enough attention. Characterization of MD utilized in concrete and mortar was extensively researched (Corinaldesi et al, 2010). The influence and usage of limestone as an additive material in concrete and cement has been studied by many researchers in the last years. A higher quantity of MD additive extends the setting times and reduces the strength of the samples for various treatment periods [Corinaldesi et al, (2010); Krstulovic et al, (1994)].

Binici et al, (2008) studied some of the properties of concrete mixes that contain MD and limestone. He concluded that as the proportion of MD in the mix increases, the compressive strength, sodium sulfate resistance, and abrasion resistance increase. Moreover, he studied the effects of utilization of granite and marble waste aggregates for concrete production and stated that they could be used to enhance the workability, mechanical characteristics and chemical impedance of normal concrete.

A study was conducted by Demirel, B. (2010), in his study, four different mixes of concrete studied by substitution fine aggregate (sand) with MD at various ratios of 0, 25, 50 and 100% by weight. He stated that, when the proportion of MD goes up in the mix, the compressive strength of the concrete may improve.

Habhoub et al, (2011) showed the potential of utilizing marble waste as a substitution to natural aggregates in concrete manufacture. Three series of concrete mixes have been studied, fine aggregate substitution, gravel substitution and a combination of each aggregate. The study outcomes showed that the mechanical characteristics of concrete samples were acceptable and the marble could be used in the concrete production process.

Shirule et al, (2012) studied the mechanical, chemical and physical characteristics of MD and stated that with the use of 10% of MD, the initial increase in concrete strength is high. Vardhan et al, (2015) investigated the potential of using MD as a CRM. The outcomes of the study showed that up to 10% of MD is the optimum percentage and can be used as an alternative to cement.

Elmoaty, (2013) investigated the utilization of granite dust in concrete production at proportions of 5, 7.5, 10 and 15%. After conducting the compressive strength test, the outcomes indicated an increase in the compressive strength of the concrete at the dust of 5% of granite as a replacement. The utilization of 5% granite dust raised the time of corrosion cracking.

Sounthararajan and Sivakumar, (2013) investigated the characteristics of hardened concrete by substitution the cement with MD up to 15%. The final outcome was evaluated for several ratios of MD replacement on compression, split tensile and flexural strength. A noticeable raise in the compressive strength was observed in seven days with 10% substitution of marble dust.

Sakalkale et al, (2014) mentioned in his study that the best proportion of MD as an alternative to sand in concrete production is 50%. Their study included four replacement ratios 0%, 25%, 50% and 100%. Rai B et al (2011) stated in their study that the substitution of cement and fine aggregate by changing the proportion of MD and marble granules will enhance the workability and the compressive strength of mortar and concrete.

A study was carried out by Binici et al, (2007) they found that the concrete made by MD contain better compressive strength than the concrete made by limestone dust with the same w/b ratio and equal mixing ratios. The outcomes indicated that MD concrete is likely to have less water permeability than limestone concrete. When MP is utilized in concrete, the quantity of water needed to produce a given slump will increase, this attributed to the high surface area of MD compared to cement or sand. The total workability value of MD concrete is lower than that of normal concrete. It was also stated that by the utilization of MD, a dense concrete can be obtained in concrete by decreasing the void content (Chandra and Choudhary, 2012).

Shelke et al, (2012) studied the impact of utilizing MD as a fractional substitution of cement and compare it with ordinary M30 concrete. They also tried to determine the optimum ratio of MD and silica fume substituted in concrete that gives the maximum concrete strength. In this research, a group of compressive tests were carried out on cubic samples of 150 mm, and 150 mm x 300 mm cylindrical samples utilizing an adjusted test method that gave the complete compressive strength, 8% of silica fume was used as constant with and without MD of ratios of 0%, 8%, 12% and 16%.

A study was carried out by Shirule et al, (2012) described the probability of utilizing MD in concrete production as a fractional substitute for cement. 3 cubes and 3 cylinders were poured for 7 and 28 days. Final strength of the cubes and cylinders was checked after 7 days and 28 days of treatment. They performed the tests utilizing compression testing instrument to test the compressive strength of the cubes and split tensile strength of the cylinders. MD was gathered in a wet form (slurry), it was then dried by sun exposure and then sieved by using 90 µm sieve before being mixed in concrete. They concluded that the best proportion for substitution of MD with Portland cement is about 10% of cement for both cubes and cylinders. Thus, this is a simple step to reduce construction costs with free or cheaply available marble powder.

Chikhalikar and Tande, (2012) conducted a study on concrete by replacing the cement with glass powder up to 40%. He stated that, as the amount of glass powder goes up in the mix, the workability of concrete tends to increase.

Patil and Sangle, (2013) stated in their study that replacing 10% of cement with GP gives the optimum compressive strength of concrete. He utilized GP with a maximum diameter of 90 µm. Subramani and Ram, (2015) perfprmed a study to determine the strength parameters of concrete by replacing the cement with GP. they stated that 10% substitution of cement by GP is the best proportion and it gives the best splitting tensile and flexural strength.

2.5 Components of Concrete

Concrete is a material which is made up of air, water, cement, fine and coarse aggregate. In general, it is recognized that the essential requirement for producing concrete structures is the production of concrete with best properties (strength, no cracks, little porosity, the expected rate of carbonation is very low). These properties can be obtained by carefully mixing for the concrete components and using admixtures as needed.

Air is the major portion of the cement paste matrix. Air is the isolated portion trapped in cement paste during concrete mixing process (Mindess, Young, and Darwin, 2003). However, trapped air can minimize the strength of concrete. Therefore, careful preparation and sufficient compaction for the specimens are important in order to remove air voids as much as possible (Du and Folliard, 2005).

Cements are compounds that contain calcium silicate, calcium aluminofarrite and calcium aluminates. The most important things for any cement that should be considered: (1) strength progress with age, (2) facilitating suitable rheological properties when fresh. The hydration process of cement particles, aggregates and water will lead to form the concrete.

Water is a substantial component of concrete where it shares in interactive way in chemical reactions with cement. Cement concrete strength is mostly obtained from the binding work of the cement gel. Water requirements for the chemical reaction of non-hydrated cement should be reduced because the excess water will end up forming unwanted voids only in the hardened cement paste in the concrete (Choudhary, Bajaj, and Sharma, 2014).

It was found that the utilization of various materials such as industrial waste in the production of concrete plays an essential role in obtaining the required properties of concrete.

2.6 Workability of Concrete

Workability is defined as flowability of mortar or concrete in its fresh state. Slump test is the most common and oldest test for measuring concrete workability. If the workability is lower than required, it may need more labor and time for compaction, which raise the final cost of ready concrete job. On the other hand, if the workability obtained higher than the normal, level of segregation might happen and the strength of concrete expected to reduce, (Segregation of concrete is the separation of cement paste and aggregates of concrete from each other during handling and placement. Segregation also occurs due to over-vibration or compaction of concrete, in which cement paste comes to the top and aggregates settles at the bottom).

Many factors can affect the concrete workability, but the most important one is the water content in concrete. When the amount of water in the mixture increases, it may increase the workability, but it may also reduce the concrete strength. This is because of the high number of initial micro-cracks caused by excess water evaporation. So, by using the workability test, an optimum can be obtained between the required workability and the strength of the concrete (Anderson and Dewar, 2003).

2.6.1 Effect of MD on Workability of Concrete

Kumar, R., and Kumar, S., (2015) studied MD that passed through 90 µm sieve. The influence of various proportions of MD on the concrete properties have been investigated. In their experimental study, five mixes of concrete having 0, 5, 10, 15 and 20% of MD as cement replacement by weight has been made. W/C ratio was 0.43

and it was constant for all mixes. They concluded that, as the ratio of MD increases from 0% to 20% in the mix, the slump tends to decrease due to the fineness of MD (high surface area). Low slump value may have significant effect on the concrete workability.

Sharma and Kumar, (2015) investigated the use of MD in concrete production without mentioned the particle size of the MD utilized. Various concrete mixes were produced by utilizing different proportions of MD (0%, 10% and 20%) as a partial replacement of cement and fine aggregate. The results indicated that as the amount of MD in the mixture increased, the workability of concrete tended to decrease.

2.6.2 Effect of GP on Workability of Concrete

Raju and Kumar, (2014) studied the concrete that contain GP as a replacement of cement in concrete. The replacement level was from 5% up to 40% with an increment of 5%. The study results for workability test showed that when the glass amount increases in the mix, the concrete workability decreases. They attributed this to the reduction in fineness modulus of cementitious material.

Chikhalikar and Tande, (2012) studied the concrete behavior that contain GP that passed 600-micron sieve. They mentioned that the concrete workability tends to increase with increase cement replacement up to 20% and after this percentage of replacement the workability starts to decrease. Saribiyik, Piskin and Saribiyik, (2013) stated in their study that the workability of concrete that contain glass powder tends to increase as a result of increased glass powder percentage up to 40%.

2.7 Compressive Strength of Concrete

The concrete compressive strength is usually recognizing as the most substantial feature of concrete among other properties since it determines the quality of concrete. In some cases, properties, such as durability and permeability of concrete are considered as important features, but compressive strength is the major description of the quality of concrete (Neville, 1995). Compressive strength indicates the influences of the constituent concrete material, and can easily show the effect of materials used in order to improve the characteristics of concrete.

Many researchers reported that there are some factors that may affect the compressive strength of concrete which include the raw material, the percentage of raw material used, aggregate sizes and shapes, w/b ratio, curing temperature, concrete age, and other things, which can affect concrete strength (Ansari Ismail, 2015).

2.7.1 Effect of MD on Compressive Strength of Concrete

Many works have been done to study the benefits of using MD in making and improving the concrete properties. The study of (Malay, Kumar and Kujur) investigated the use of MD as a replacement for cement in concrete production. In their study they used a 0.5 w/c ratio and cement replacement levels (0, 5, 10, 15 and 20%) by MD. The compressive strength results showed that the utilization of 5% and 10% MD as cement replacement improves slightly the concrete compressive strength when compared with control mix. The use of MD of amount more than 10% cement substitution has a bad effect on concrete compressive strength. The increase in concrete compressive strength at 10% MD as cement replacement may be due to MD acts as a filler.

A study was conducted by Shirule, Rahman and Gupta, (2012) to investigate the use of MD in concrete production. MD was utilized as a CRM with proportions of 0, 5, 10, 15 and 20%. They stated that the concrete compressive strength increases with the use of MD up to 10% substitution by cement weight and any increase in the addition of MD decreases the concrete compressive strength.

Anwar et al, (2014) performed a study to investigate the compressive strength of concrete that contain MD as a partial replacement of cement. The replacement levels were 0, 5,10, 15, 20, and 25% by cement weight. The study was performed to find a solution to the issue of elimination of MD by utilizing it in concrete production to develop sustainable construction. The compressive strength results indicated that the best ratio for replacing the cement with MD is approximately 10%.

2.7.2 Effect of GP on Compressive Strength of Concrete

Many works have been done to investigate the benefits of utilizing GP in making and improving the concrete properties. Anwar (2016) conducted a research study, where the cement has been partially replaced by GP in the ratios of 0, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50% by cement weight. The compressive strength test results indicated a raise in strength when the amount of GP increase in the mix up to 15%. The researcher estimated that the increase in strength occurred after 28 days due to the effect the pozzolanic action of the GP; however, there was no explanation for the significant reduction in strength from the rate of 20% to 50%.

2.7.3 Effect of MD and GP on Compressive Strength of Concrete

Arunkumar, Karpagaraj and Nandhini, (2017) conducted a study using both MD and GP in the same mix in order to produce a high performance concrete. GP replaced the cement with proportions of 10, 20, 30, 40 and 50% and MD replaced the fine aggregate with proportions of 10, 20, 30, 40 and 50%. For the compressive strength, in all the 26 different mixes, two mixes M8 (20% GP and 30% MD) and M10 (20% GP and 50% MD) are selected as optimum. When comparing M8 and M10 with the control mix, the compressive strength of M8 and M10 mixtures increased by 8.7% and 8.3% respectively at 28 days.

2.8 Flexural Strength of Concrete

2.8.1 Effect of MD on Flexural Strength of Concrete

P.N, Raghunath et al, (2018) carried out a work to study the properties of high-strength concrete by using MD. The cement was replaced by waste MD at proportions of 0, 5, 10, 15, and 20%. w/b ratio was 0.36 for all mixes. The flexural strength test results showed that replacement the cement with MD from 5% up to 15% improved the flexural strength of the concrete. After 15% of substitution, a slightly decrease in flexural strength was obtained. This may be due to a decrease in the amount of available cementing materials.

A study was carried out by Arun and Ankush, (2018) in order to investigate the influence of MD on the characteristics of concrete. In their study, they used 0%, 7.5%, 15%, 22.5%, 30% of MD as a cement substitution material. w/b ratio was constant (0.4) for all mixes. The flexural strength of all samples that contain MD is higher than the control mix. The specimen containing 7.5%, 15%, 22.5%, and 30% of MD for 28 days presents a raise of 6.6%, 26.6%, 13.3% and 3.3% in flexural strength, respectively.

2.8.2 Effect of GP on Flexural Strength of Concrete

A study was done by Raju and Kumar, (2014) to investigate the concrete properties that contain GP as a cement substitution in concrete. The substitution levels were 5, 10, 15, 20, 25, 30, 35 and 40% by cement weight. For the flexural strength results after 28 days. The optimum flexural strength was for the mix that contain 20% cement replacement by GP compared to the control mix.

Chikhalikar and Tande, (2012) studied the σ_f in their study and concluded that 20% of GP is the best percentage for cement substitution. BhatVeena and Rao, (2016) concluded in their study that flexural strength at the age of 7 days and 28 days is highest when 20% of GP replacing the cement. Vijayakumar, Vishaliny and Govindarajulu, (2013) mentioned in their study that flexural strength is improved when cement is replaced by 40% of GP.

2.8.3 Effect of MD and GP on Flexural Strength of Concrete

Arunkumar, Karpagaraj and Nandhini, (2017) conducted a study using both MD and GP in the same mix in order to produce a high performance concrete. GP replaced the cement with proportions of 10, 20, 30, 40 and 50% and MD replaced fine aggregate with proportions of 10, 20, 30, 40 and 50%. In all the 26 different mixes, two mixes M8 (20% GP and 30% MD) and M10 (20% GP and 50% MD) are selected as optimum, so the flexural strength test was performed just on these two mixes. When comparing M8 and M10 with the control mix, the flexural strength of M8 and M10 mixture increased by 12.6% and 30% respectively at 28 days.

2.9 Splitting Tensile Strength of Concrete

Tensile strength is one of the main and fundamental mechanical features of concrete. It is the ultimate pressure that it can be applied to concrete before fracture. Concrete is very weak in tension when compared to compression, because of its fragile nature. When the concrete is exposed to tensile strength, cracks will improve. Therefore, it is essential to define the pressure that the concrete elements may crack.

2.9.1 Effect of MD on Splitting Tensile Strength of Concrete

Shirule, Rahman and Gupta, (2012) inestigated the properties of concrete that contain MD as a CRM. The cement was substituted by MD at proportions of 0%, 5%, 10%, 15% and 20% by weight. The concrete splitting tensile strength on cylinders was measured at various proportions of MD. They concluded that by 10% replacement, there was 11.4% raise in the initial split tensile strength after 28 days.

A study was carried out by Khaliq et al, (2016) to investigate the characteristics of concrete containing MD as a cement replacement with proportions of 5, 10, 15, 20, 25 and 30% by cement weight. From the results, the optimum tensile strength was found at 10% replacement.

2.9.2 Effect of GP on Splitting Tensile Strength of Concrete

The study of Mageswari and Vidivelli, (2010) indicated a raise in the tensile strength of concrete that contain GP of approximately 20%. The work of Vijayakumar, Vishaliny and Govindarajulu, (2013) stated that the GP in concrete lead to increase the tensile strength effectively compared with control concrete.

2.9.3 Effect of MD and GP on Splitting Tensile Strength of Concrete

Arunkumar, Karpagaraj, and Nandhini, (2017). conducted a study using both MD and GP in the same mix in order to produce a high performance concrete. GP replaced the cement with proportions of 10, 20, 30, 40 and 50% and MD replaced fine aggregate with proportions of 10, 20, 30, 40 and 50%. In all the 26 different mixes, two mixes M8 (20% GP and 30% MD) and M10 (20% GP and 50% MD) are selected as optimum, so the tensile strength test was performed just on these two mixes. When comparing M8 and M10 with the control mix, the tensile strength of M8 and M10 mixture increased by 15.5% and 23.5% respectively at 28 days.

2.10 Alkalinity of Concrete (PH)

In chemistry, the PH value gives an indication if the substance is alkali or acid. The pH in the alkali ranges between 14 and 7. The PH of the acid is less than 7. In fresh concrete the PH value is about 12.5, thus the concrete is considered very alkaline.

2.10.1 Effect of MD on Concrete PH

Malay, Kumar and Kujur, carried out a study to investigate the impact of replacement of cement with MD on the properties of concrete. Concrete specimens were prepared with 0.5 w/c ratio and partial substitution of cement (0%, 5%, 10% 15% and 20%) by MD. PH test results showed that the PH values is usually between 7.8 and 8.4. Although there is no pattern, it can be concluded that the using MD in concrete as a partial substitute to cement does not make it acidic. Therefore, it should not have negative effects on rebar.

2.10.2 Effect of GP on Concrete PH

A study was done by Raju and Kumar, (2014) to investigate the concrete properties that contain GP as a cement replacement in concrete. The replacement levels were 5, 10, 15, 20, 25, 30, 35 and 40% by cement weight. To conduct PH test on the specimens, concrete specimens were break in order to get mortar samples. Then the mortar is converted into powder form and sieved through 150μm sieve. Then the powder mixed with distilled water. Then immerse the pH meter into the solution and pH value of the solution is noted. The test results indicated that the PH values in the range of 12.4 and 13. It also indicated that the tested samples were found to be more alkaline and therefore more resistant to corrosion.

2.11 Sulphate Resistance of Concrete

Sulphate attack on concrete is considered as a major durability problem. Sulphate attack can cause expansion, cracking, spalling, and lead to reduce the strength (Chabrelie, 2010). In general, sulphate attack classified as internal or external taking into account the source of sulphate. Internal attack indicates where the components required for expansion and cracking, like those resulting from sulphate -rich aggregates or excess gypsum content, are incorporated into concrete during the time of mixing. External sulphate attack may occur due to some species that come from an external source and penetrate into concrete such as natural water or soil (Brown and Hooton, 200; Ramezanianpour, 2012). One of the most popular ways utilized to enhance the concrete's resistance to external sulphate attack is to reduce concrete permeability. The permeability of concrete can be minimized by using SCM as well as waste materials (Amar et al, 2018).

2.11.1 Effect of MD on Sulphate Resistance of Concrete

A study was conducted by Binici, Kaplan and Yilmaz, (2007) to investigate the properties of concrete that contain MD and Limestone. They prepared seven different concrete mixes in three series with control mix. The cement amount was 400 kg. The control mix was adjusted to 5, 10 and 15 % MD and limestone instead of the fine aggregate. The sodium sulphate resistance were measured for 12 months. The results of the sulphate resistance test showed is a clear raise in the resistance of sodium sulphate to concrete when the amount of dusts increase in the mix. The results also included the minimizing of the relative compressive strength (the ratio of the compressive strength in sulphate solution to the compressive strength in normal water) and at the end of the 12-month period, concrete samples exhibited no resistance to the effect of sodium sulphate since the reduction in compressive strength was too much.

Singh and Madan, investigated the influence of using MD as a partial replacement of cement by 5%, 10%, 15% and 20% by weight on the properties of concrete. Cubes that have 150mm in dimensions were used. After 28 days of curing, the samples were put for both water curing and subjected to sulphate solution for other 28, 90, 180 and 365 days. 5% Na_2SO_4 solution was utilized as a sulphate solution (Each liter of solution contains 50.0 g of Na_2SO_4 in water). Concrete samples were removed from sulphate solution after 28 days, 90 days, 180 days and 365 days and the compressive strength were measured. They concluded that sulphate attack could give a gradual loss of both strength and mass because of the deterioration in the cohesion of cement hydration products.

2.11.2 Effect of GP on Sulphate Resistance of Concrete

Tayeh et al, (2019) carried out a study to investigate the influence of GP on the mortar properties. In their study, two series of mortar were prepared. Series one with GP that passed through sieve 200µm, and series two utilized GP that passed through sieve 400µm. The replacement levels were 10, 20 and 30% by cement weight. w/c was constant for all mixes (0.4). For the sulphate resistance test, at 28 days of curing, the samples were immerged in 5, 10 and 20% $MgSO_4$ solution for 10 ,30 and 60 days. They mentioned that the compressive strength of series one was significantly greater than that of series two. Thus, the influence of $MgSO_4$ solution on compressive strength was performed only on series one. The concentration of $MgSO_4$ and immersion period had a considerable impact on the mortar compressive strength. The compressive strength decreased for different proportions of $MgSO_4$ solutions and changed considerably when 20% concentration was used for 60 days of external exposure. The minimum compressive strength was for the mix that contain 30% GP as a replacement for cement. They attributed this to the porosity of the cement mortar. A considerable decrease in unit weight occurred because the raise in the GP replacement caused an increase in porosity; therefore, compressive strength is expected to decrease (Al Saffar, 2017; Santhanam, Cohen, and Olek, 2002).

2.12 Ultrasonic Testing of Concrete

Ultrasonic Pulse Velocity (UPV) is a test which does not destruct the concrete samples, used for quality control of concrete members as well as showing the damages in building components. UPV methods are utilized to control the quality of materials, especially metals, welded joints and concrete members. According to the recent advancement in transducer technology, the test has been widely utilized in testing concrete members. Ultrasonic concrete testing is an efficient method to assess quality and to estimate crack depth in concrete.

The Pulse Velocity Method

The idea behind this test is to measure the travel time of waves in a medium, and to link them to the elastic characteristics and density of the material, as shown in Figure 2.2. The transmitting transducer of the device sends a wave to the concrete and the receiving transducer, at an L distance, receives the pulse through the concrete at a different point. Thus, the transit time takes for the wave to go through the concrete is display on the device screen. The wave pulse velocity V, is $V = \frac{L}{T}$

where:

V = velocity, km/s,

L = concrete specimen length, and

T = transit time.

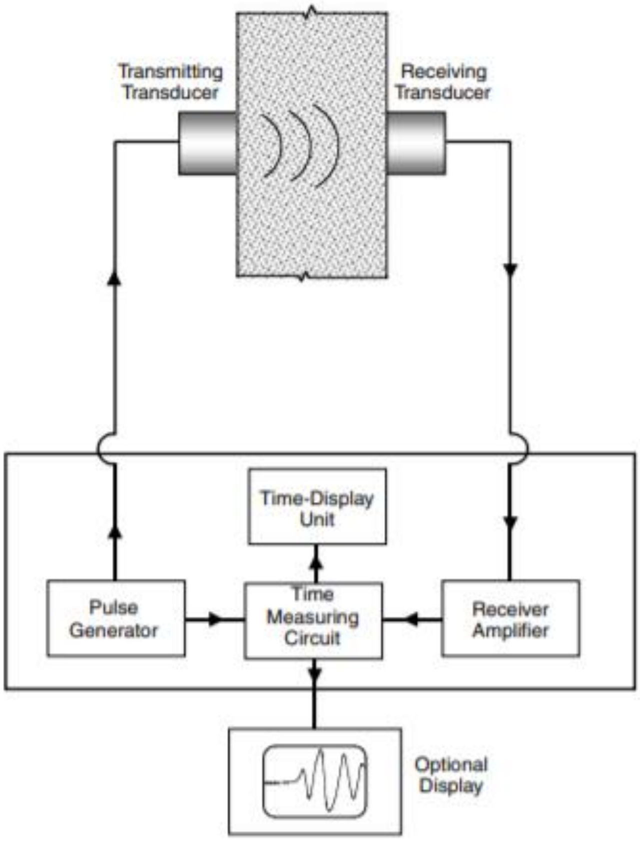

Figure 2.2: Ultrasonic Test (ASTM C597)

To send or receive the wave, the transducers should be in full contact with the concrete surface; otherwise an air enter between the concrete and transducer and this may cause an error in the travel time. Generally, for a specific track, longer transit time is associated with low quality concrete with more deficiencies, while lower transit time is associated with better quality concrete.

Various arrangements of transducers can be utilized to conduct the UPV test including direct transmission, semi-direct transmission, and indirect (surface) transmission. Figure 2.3 illustrates the various arrangements of transducer according to the reaching the surface of concrete. Figure 2.4 shows of the influence of concrete deficiencies on the wave transit time and the identical velocity during a given path.

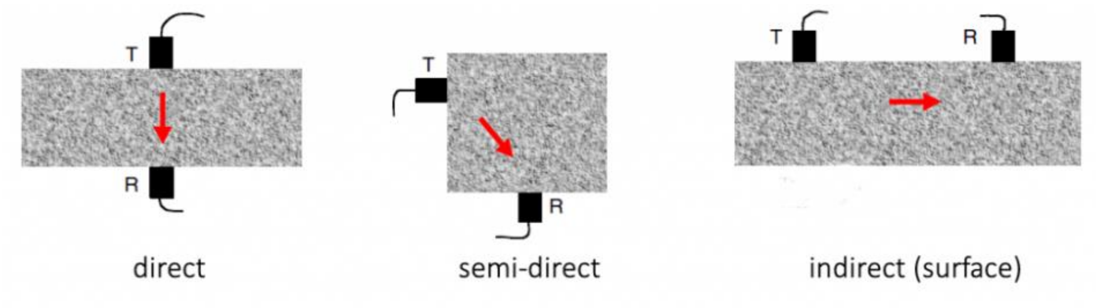

Figure 2.3: Pulse Velocity Measurement Arrangements. (Direct, Semi-direct and Indirect surface method).

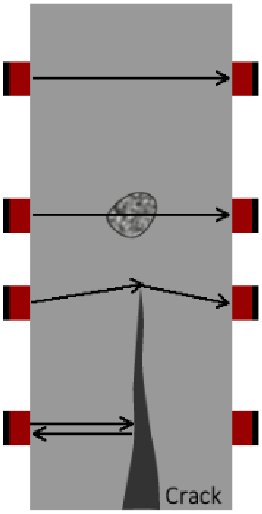

Figure 2.4: Influence of Concrete Deficiencies on The Wave Transit Time

Chapter 3

MATERIALS AND EXPERIAMENTAL PROCEDURES

3.1 Introduction

This chapter shows the materials that utilized through the study and explains the experimental procedures. Furthermore, it contains explanation about preparation, curing and testing methods. This chapter also explains the utilized ASTM standards and any other methods that used for conducting the experiments, and describes how to use and deal with relevant machines and apparatuses.

3.2 Materials Used

The materials that were utilized for this study are listed and described as follows;

Cement: CEM II Portland sulfate resistance slag cement of 42.5N was used for this thesis. Utilizing this type of cement gives highly resistance to harmful chemical reactions like sulfate resistance which will be investigated in this study. The chemical composition of cement powder is illustrated in Table 3.1.

Marble Dust (MD): Marble waste powder was collected from the industry area in Famagusta (Maraş), was utilized in this study as a CRM in concrete production. The particle size of the MD utilized in this thesis was less than 75 µm. The chemical composition of MD is shown is Table 3.1. MD is shown in Figure 3.3.

Glass Powder (GP): GP was prepared by crushing the glass bottles and make them powders, GP was used as an additive. The particle size of the GP was less than 90 µm in diameter. The chemical composition of GP is shown is Table 3.1. GP is shown in Figure 3.3.

Table 3.1: Chemical Composition of Cement, Marble Dust and Glass Powder

Oxide Compounds	Cement (%)	Marble Dust (%)	Glass Powder (%)
SO_3	2.55	0.0213	-
SiO_2	19.00	0.194	69.42
CaO	60.88	56.1	8.27
CaO free	1.00	-	-
Na_2O	-	-	12.31
MgO	2.27	0.926	4.25
Al_2O_3	2.19	0.123	1.09
Fe_2O_3	2.89	0.0550	0.48
Cl	0.000	-	-
L.O.I	-	-	16.18

Mixing Water: Normal water which is supplied for drinking and clear of harmful substances like acids, oils, alkalis and organic materials was utilized for concrete mixing and curing.

Fine Aggregate (FA): Fine aggregates utilized in this research was crushed limestone with a maximum diameter of 5 mm. Sieve analysis was carried out for FA according to ASTM standard C136M-14 and was controlled by ASTM standard C33M-16. Sieve Analysis of FA is presented in Figure 3.1.

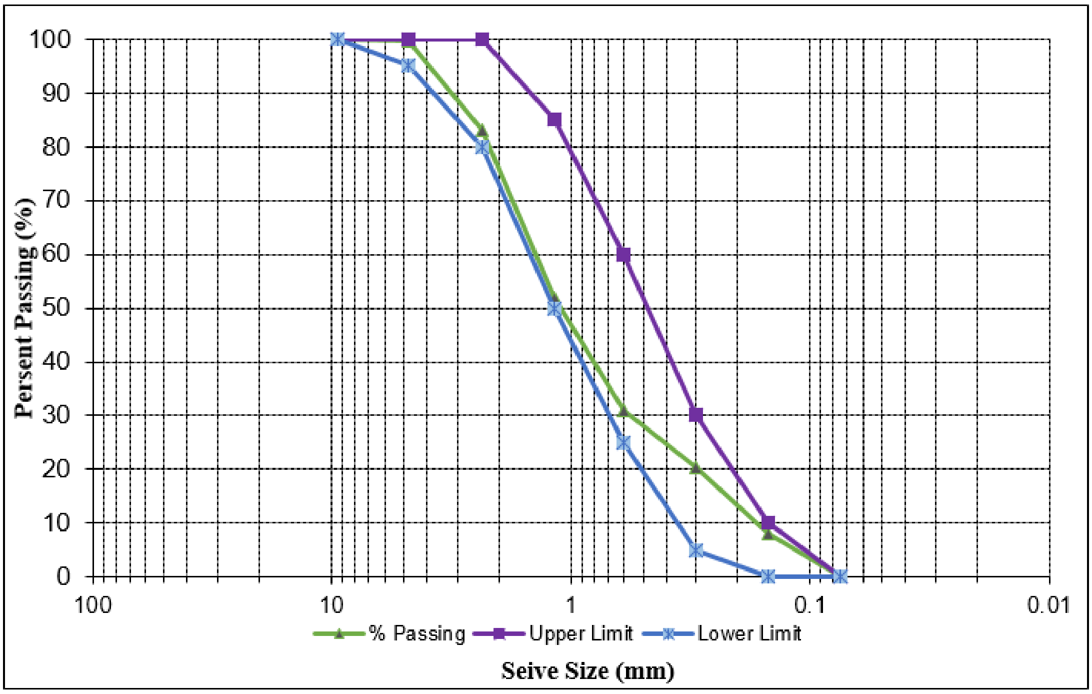

Figure 3.1: Sieve Analysis of Fine Aggregate

Coarse Aggregate (CA): The CA that utilized in this study crushed limestone with different diameters: 10mm, 14mm, and 20 mm. Sieve analysis was performed according to ASTM C136M-14 standard, and controlled by ASTM C33M-16. Sieve Analysis of Coarse Aggregate is illustrated in Figure 3.2.

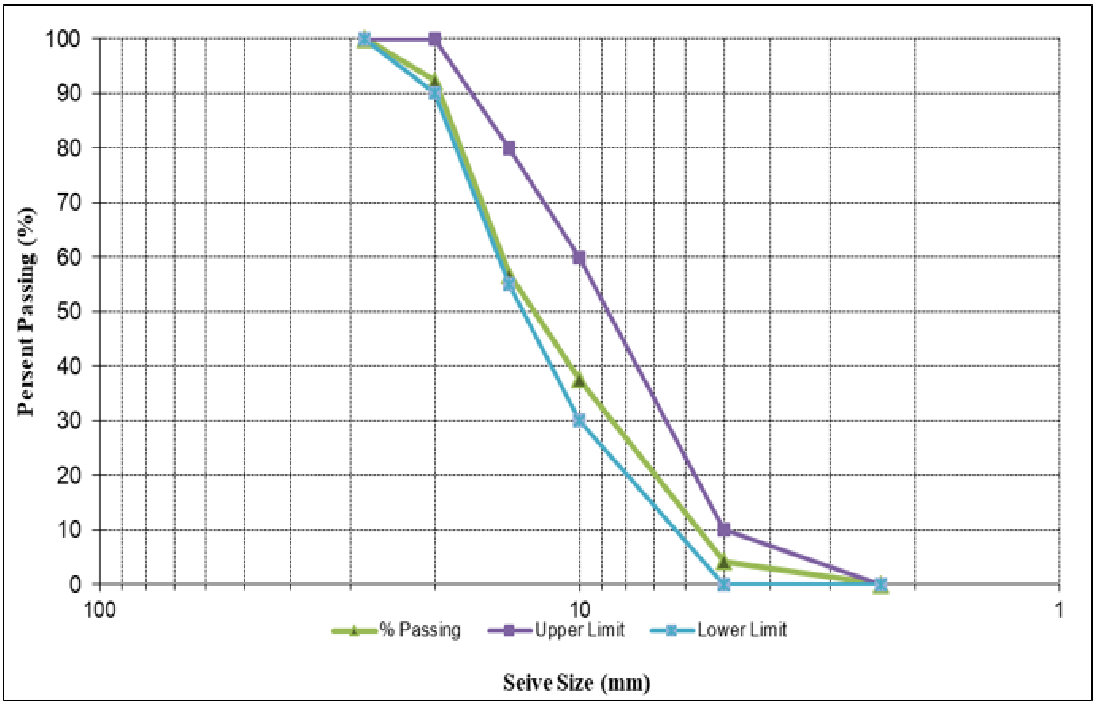

Figure 3.2: Sieve Analysis of Coarse Aggregate

Figure 3.3: Marble Dust and Glass Powder

3.3 Mix Proportions

In accordance with the *(BRE 331, 1988) standard*, Design Mix for Concrete was prepared by utilizing Marble dust instead of cement (CRM) and by using GP as an additive in concrete production. Table 3.2 outlines the mix proportions.

Table 3.2: Concrete Mix Proportions (w/b = 0.55)

Concrete Type	C (kg/m^3)	MD (kg/m^3)	W (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	GP (kg/m^3)
Control 1	409	0	225	821	925	0
Control 2	409	0	225	821	925	32.72
MD10	368.1	40.9	225	821	925	0
MD20	327.2	81.8	225	821	925	0
MD30	286.3	122.7	225	821	925	0
MD40	245.4	163.6	225	821	925	0
MD50	204.5	204.5	225	821	925	0
MD60	163.6	245.4	225	821	925	0
MD10GP8	368.1	40.9	225	821	925	32.72
MD20GP8	327.2	81.8	225	821	925	32.72
MD30GP8	286.3	122.7	225	821	925	32.72
MD40GP8	245.4	163.6	225	821	925	32.72
MD50GP8	204.5	204.5	225	821	925	32.72
MD60GP8	163.6	245.4	225	821	925	32.72

C: Cement MD: Marble Dust W: Water FA: Fine Aggregate
CA: Coarse Aggregate GP: Glass Powder

It should be mentioned here that the normal percentage of additive is approximately 2% but since its effect is limited and known, we preferred to jump up to 8% of GP as an additive in order to investigate the effect of that proportion on concrete properties.

3.4 Experimental Procedures

To examine the effects of MD and GP on the performance and characteristics of concrete, seven various series of concrete mixes were produced by substitute the cement with MD at percentages of 0, 10, 20, 30, 40, 50 and 60% by cement weight with 0.55 w/b ratio, seven other mixes also were produced by replacing the cement with marble powder at percentages of 0, 10, 20, 30, 40, 50 and 60% by cement weight but with the addition of 8% (weight of cement) glass powder.

3.4.1 Concrete Mixing Procedures

Mixing was performed utilizing a laboratory mixer with 0.25 m^3 capacity. Coarse and fine aggregates were first mixed inside the mixer followed by cement then MD and GP, then dry mixing was done for approximately a minute. Water then was added and the mix continued until achieving a homogeneous mixture. The Concrete Mixer is illustrated in Figure 3.4.

Figure 3.4: Concrete Mixer (0.25) m^3 Capacity

3.4.2 Specimens Preparation and Curing

Three various types of specimens were casted for each mixture: three cubes (150 mm), three beams (100×100×500 mm) and three cylinders (100×200 mm). The molds were firstly cleaned and oiled in order to ease demolding samples. After casting, specimens were put on a vibration machine in order to perform the compaction for the specimens as illustrated in Figure 3.5. After that, the molds were kept in a curing room for 24 hours at 99% relative humidity. Then, the samples were transferred into water curing tank with a normal temperature of about 25°C for 28 days before performing the experiments as presented in Figure 3.6.

Figure 3.5: Concrete Specimens Compaction

Figure 3.6: Curing Tank

3.5 Workability of Concrete

Immediately after the mixing of concrete was finished, a sample of fresh concrete was collected to perform the slump test for investigating the workability of fresh concrete for each batch. The slump test carried out in accordance with the ASTM C143/C143M 15a standard. The slump test is shown in Figure 3.7.

Figure 3.7: Slump Test for Workability

3.6 Compressive Strength of Concrete

To perform the compressive strength (σ_c) of concrete specimens to determine the influence of MD and GP on σ_c results, 3 cubic specimens with 150x150x150 mm dimensions for each concrete mix were casted and cured for 28 days and subjected to σ_c test, according to BS EN 12390-3:2009 standard as can be seen in Figure 3.8. The average of the 3 values was calculated and considered. The maximum capacity of the compression testing machine, is 3000 KN.

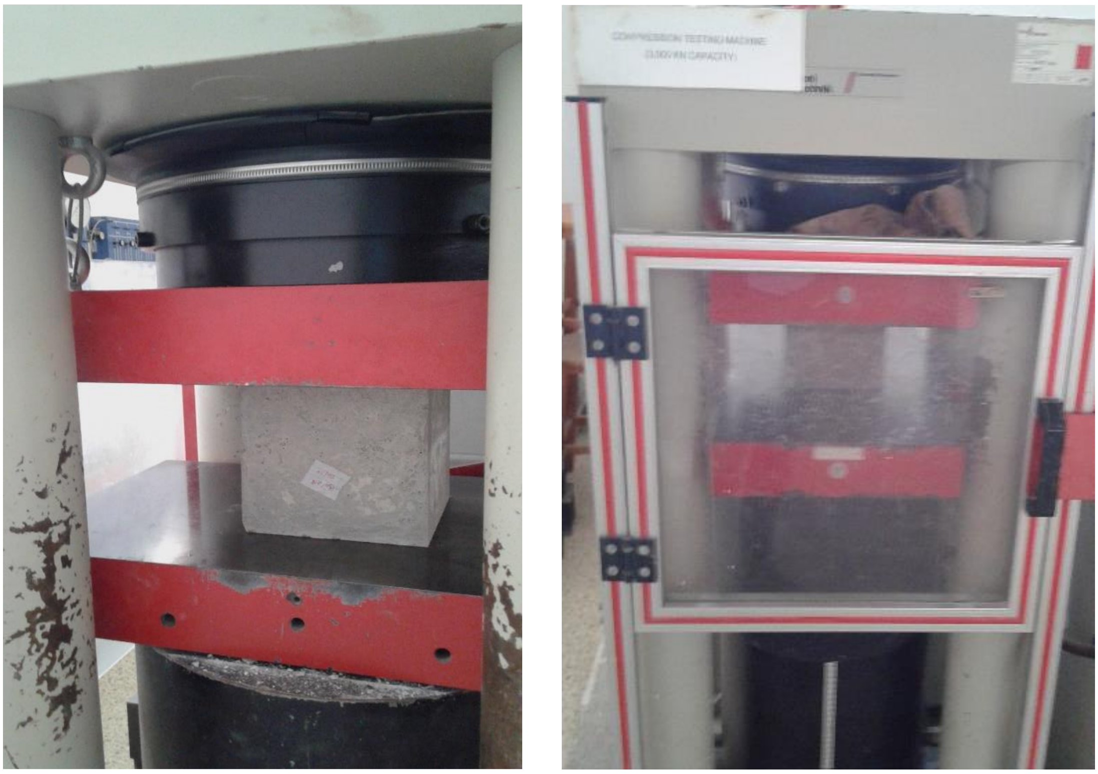

Figure 3.8: Compression Testing Machine

3.7 Splitting Tensile Strength

Cylindrical specimens with dimensions of (100x200) mm, were examined for 28 curing ages to see the effect of MD and GP on splitting tensile strength. The experiment process was carried out in accordance with ASTM C496/C496M – 17. 3 cylindrical samples were examined for each mix and the average was taken.

3.8 Flexural Strength

In order to conduct the flexural strength on the prepared samples, beams (100x100x500 mm) were used. The prepared beams specimens were examined at 28 days' age as illustrated in Figure 3.9. Experimental procedures were performed based on ASTM C78/C78M–16. Three samples were examined for flexural strength for each mix and the average was considered. The ultimate capacity of the flexural testing machine is 200 KN.

Figure 3.9: Flexural Strength Testing

3.9 Concrete PH

In order to perform this test, the specimens were crushed by using a crushing press, then the samples utilized for PH test were powdered by a grinding machine. Approximately 30 g of the concrete was powdered. Therefore, 15 g of concrete powder was dissolved in 15 g of distilled water (1:1 proportion by mass) then it was mixed for approximately 5 minutes. After mixing about 10 g of the suspension was taken out and put in a test tube and its PH measured. This test was carried out by using PH meter as illustrated in Figure 3.10.

Figure 3.10: PH Meter

3.10 Sulphate Resistance

Samples that have 100×100×100 mm in dimensions were selected to perform this test. The samples were cured in 99% humidity at approximately 25 °C in the laboratory conditions for 24 hrs., and thereafter put into the water tank for standard curing. After the samples have reached 28 days of curing, they were removed from the water tank and placed into sulphate solution (5% Na_2SO_4) for another 28 days to see the influence of the solution on the compressive strength. Samples that cured in sulphate solution is presented in Figure 3.11.

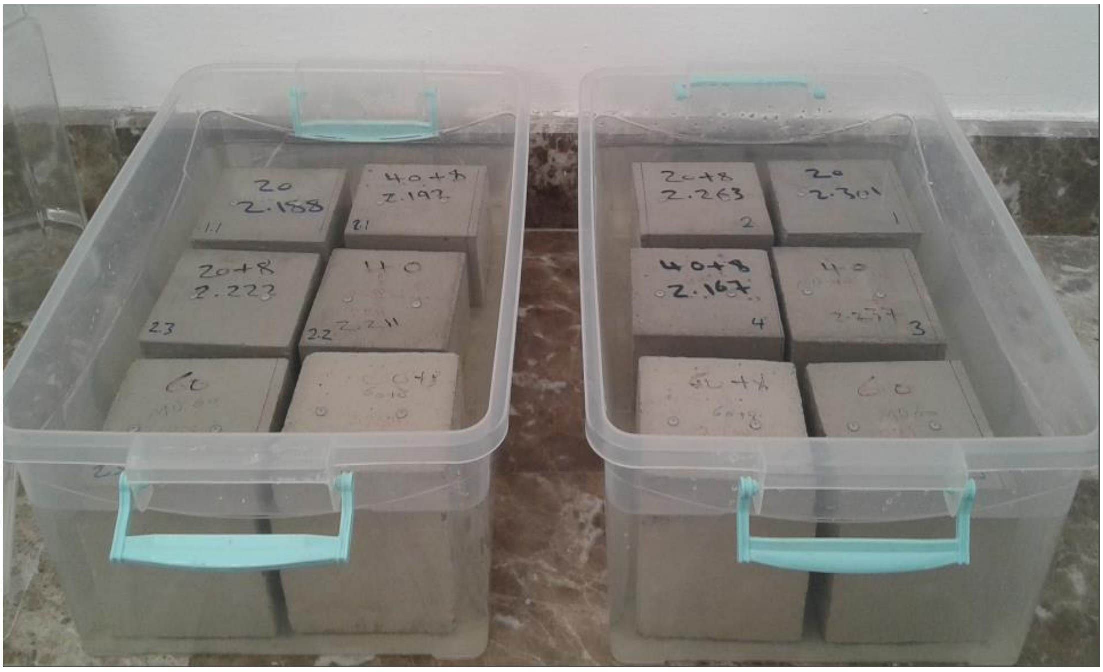

Figure 3.11: Samples in Sulphate Solution

3.11 Ultrasonic Testing of Concrete

This experiment was done in line with ASTM C597. Cubes with dimensions of 100 mm were used for this experiment. Firstly, the device was calibrated at zero time. Then the transducers were located directly opposite each other in the center of each face of the concrete samples in order to give best results. After that, the transit time was measured and recorded. The pulse velocity can then be calculated by dividing the sample length (100 mm) by the pulse transit time. The device is shown in Figure 3.12.

Figure 3.12: Ultrasonic Testing

In order to classify the quality of concrete, Table 3.3 should be followed;

Table 3.3: Concrete Quality Grading for Ultrasonic test

Pulse Velocity (km/s)	Concrete Quality Grading
> 4.5	Excellent
3.5 - 4.5	Good
3 - 3.5	Fair
2 - 3	Poor
< 2	Very Poor

Chapter 4

RESULTS AND DISCUSSIONS

4.1 General

This chapter illustrate the experimental results for fourteen various concrete mixes to see the effects of MD and GP, on the performance and properties of concrete. The following tests; workability test, compressive, flexural and splitt tensile strengths, PH value, sulphate resistance and ultrasonic test will be examined in this chapter. For analyzing experimental results, outcomes are plotted in tables and drawn in diagrams for better understanding.

4.2 Effect of MD and GP on Workability of Concrete

The workability of the concrete mixtures, was performed utilizing slump test, which was tested for different mixes with different proportions of MD (0, 10, 20, 30, 40, 50 and 60%) as an alternative to cement and 8% of GP as an additive with a fix 0,55 w/c ratio. Workability (slump) results of concrete are illustrated in Table 4.1 and Figure 4.1.

It is noticeable from Figure 4.1 that as the use of MD in concrete mixes increases from 0% to 60%, the mix becomes stiffer, and the workability of concrete mixes were found to decrease when compared with control. This can be attributed to that, the cement paste amount has decreased as some part of it was replaced by the MD and as the particle size of the MD utilized was finer than the cement, so the fineness in the mix will increase (specific surface area) and the demand for water will tend to increase.

In the case of mixes that contain GP, the workability results were observed to be less comparing with the mixes that do not contain GP, this can be attributed to the fact that the GP was used as an additive, so higher amount of water is required since the total fineness in the mix has increased as there is and it is clear in this case that the slump values have direct relation with the particles size.

Table 4.1: Effect of MD and GP on Workability

Specimen Type	Slump without GP (mm)	Slump with 8% GP (mm)
Control	150	145
MD10	140	137
MD20	135	130
MD30	127	125
MD40	120	115
MD50	108	105
MD 60	100	97

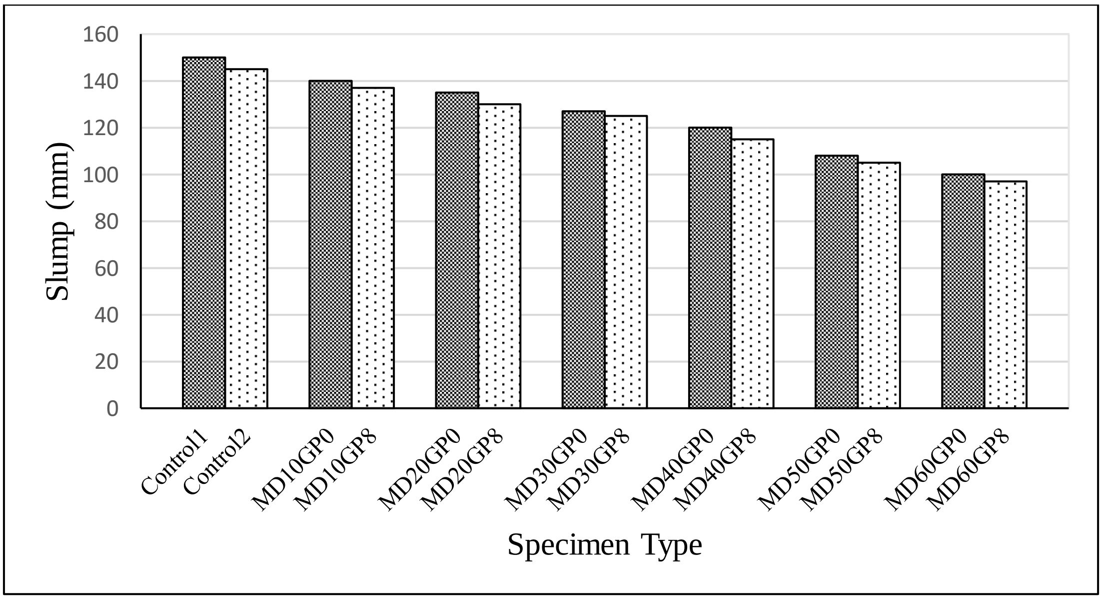

Figure 4.1: Influence of MD and GP on Workability

4.3 Effect of MD and GP on Compressive Strength of Concrete (σ_c)

The effects of MD as CRM and GP as an additive on concrete compressive strength after 28 days are illustrated in Table 4.2 and Figure 4.2.

Table 4.2: Effect of MD and GP on Compressive Strength of Concrete

Specimen Type	Compressive Strength without GP (MPa)	Compressive with 8% GP (MPa)
Control	43.9	45.2
MD10	48.6	49.8
MD20	35.9	38.1
MD30	26.8	28.2
MD40	21.13	22.85
MD50	15.17	13.33
MD 60	11.24	10.52

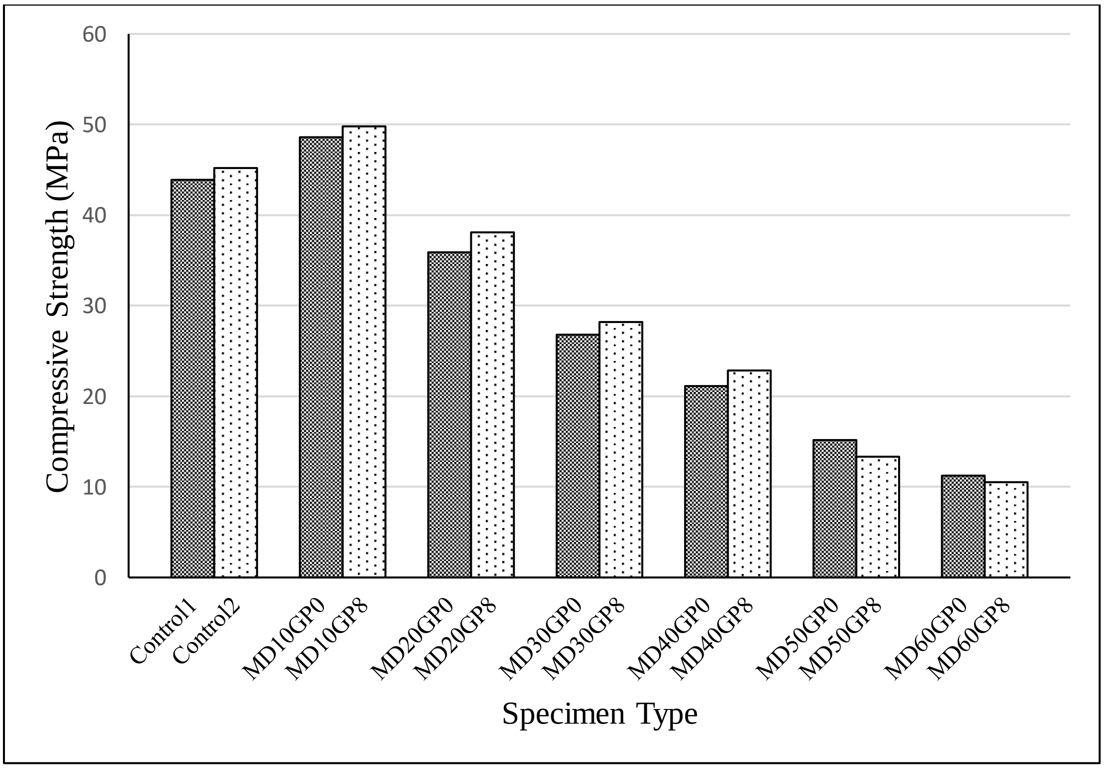

Figure 4.2: Effect of MD and GP on Compressive Strength of Concrete

From Figure 4.2, it is obvious that the use of 10% MD as a CRM improves the concrete compressive strength when compared with control mix. This enhancement is 9.7% at 28 days of moist curing. The utilization of MD of proportion higher than 10% as a CRM has a negative effect on concrete compressive strength. The enhancement on concrete compressive strength at 10% MD as cement replacement may be because of marble dust acts as a filler.

The latter age strength of concrete samples at 28 days for 10% replacement are higher than that of the control specimens. This can be attributed to the filler effect of certain very fine particle of the marble dust in the mix which improves the particle packing of the cement that the strength reduction expected due to cement reduction is balanced by the enhancement of particle packing of the cement. But beyond 10% replacement range (from 10% up to 60%), the 28 days' strengths decrease with the addition of MD than the corresponding control specimens with reduction increment with the increment of percentage of MD; this attributes to the replacement of cement by the powder which causes dilution of C_3S & C_2S which is responsible for strength development.

In the case of using GP as an additive material, the same trend was obtained. The optimum compressive strength was found for the mix that contain 10% MD as replacement to cement with 8% GP. As a result of chemical reactions of cement particles, some amount of heat was produced, which could increase the chemical reaction activities (pozzolanity) of GP particles. It can be also observed from Figure 4.2 that the addition of 8% GP enhanced the compressive strength for the mixes up to 40% and beyond this percent a decrease in compressive strength was observed, this can be attributed to the increase in total micro fines in the mix that have higher surface area which results in higher water demand which leads to lower strength.

It can be stated that the optimum value of compressive strength is obtained at 10% replacement of cement with MD with 8% of glass powder as an additive. If the cement was replaced with MD with a proportion more than 10%, it is observed that the compressive strength starts to decrease.

4.3.1 Effect of MD and GP on Compressive Strength at 56 days

In this test 6 mixes were selected in order to do a comparison between the mixes that contain GP and the mixes which do not contain to see the effect on the strength development after 56 and 90 days.

Table 4.3: Comparison between Compressive Strength after 28, 56 and 90 days

Specimen Type	Compressive Strength at 28 days (MPa)	Compressive Strength at 56 days (MPa)	Compressive Strength at 90 days (MPa)	Increasing in Compressive strength (%) 56 days	Increasing in Compressive strength (%) 90 days
MD20	35.9	37.3	37.8	3.9	5.3
MD40	21.13	23.24	23.4	9.9	10.7
MD60	11.24	12.15	12.3	8.1	9.4
MD20GP8	38.1	41.8	42.4	9.7	11.3
MD40GP8	22.85	25.23	25.7	10.4	12.5
MD60GP8	10.52	12.38	12.7	17.7	20.7

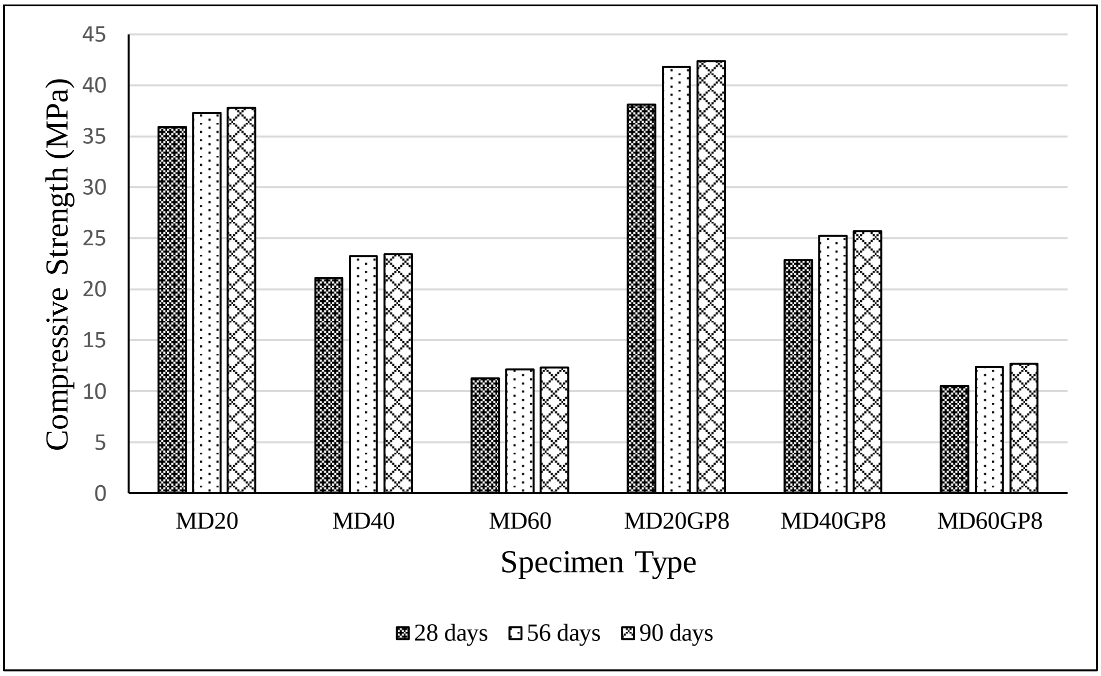

Figure 4.3: Comparison between Compressive Strength after 28, 56 and 90 days

As it can be seen from Table 4.3 and Figure 4.3, the mixes that contain GP have higher strength than that without GP for all ages (28, 56 and 90 days). It can be observed also that when time passes, the increasing percent in compressive strength for the mixes that contain glass powder is higher than those with no GP. As a result of chemical reactions of cement particles, some amount of heat was produced, which could increase the chemical reaction activities (pozzolanity) of GP particles, hence an increase in compressive strength is expected.

4.4 Effect of MD and GP on Flexural Strength of Concrete (σ_f)

To investigate the influence of MD and GP on flexural strength, the average flexural strength test of 3 beams with dimensions of (100 mm× 100 mm × 500 mm), for 28 days were measured for fourteen various concrete mixes. The results of concrete flexural strength are illustrated in Table 4.4 and Figure 4.4.

The test results of flexural strength of concrete with cement substitution by MD and GP as additive at 28 days are illustrated (Table 4.4, Figure 4.4). It is observed that; the flexural strength of concrete with 10% cement replacement by MD showed flexural strength with 4.62MPa and when compared to control1 concrete an increase up to 6.2% at 28 days testing was observed. It is also noted that the flexural strength of concrete with 10% cement replacement by MD and 8% GP showed the optimum flexural strength among all mixes with 4.68 MPa and when compared to control2 concrete an increase up to 5.6% at 28 days testing was observed. The enhancement in the results was because of better strength and low porosity of both the interfacial transition zone (ITZ) and cement paste matrix. Further increases in the proportion of MD leads to reduction in flexural strength.

Table 4.4: Effect of MD and GP on Flexural Strength of Concrete

Specimen Type	Flexural Strength without GP (MPa)	Flexural with 8% GP (MPa)
Control	4.35	4.43
MD10	4.62	4.68
MD20	4.02	4.58
MD30	3.98	4.25
MD40	3.37	3.64
MD50	2.66	2.35
MD 60	1.86	1.76

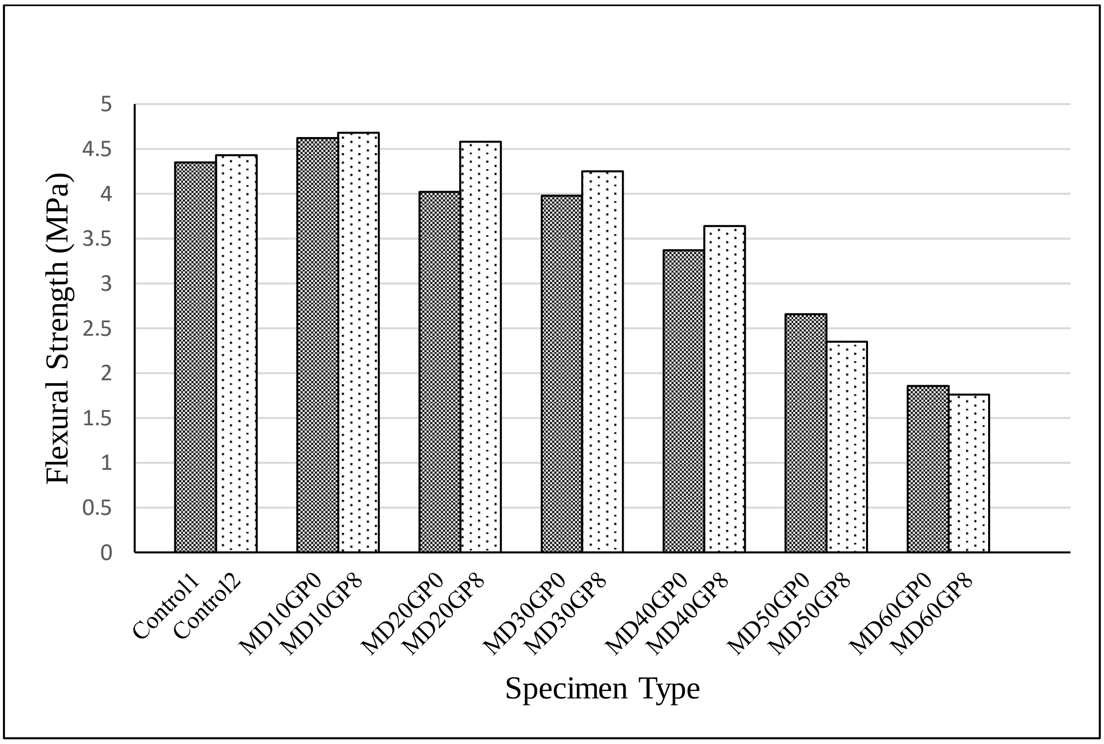

Figure 4.4: Effect of MD and GP on Flexural Strength of Concrete

4.4.1 Relationship between Flexural and Compressive Strengths

In order to determine the correlation between the flexural and compressive strengths (28-days) of concrete, regression model was used utilizing linear relation factor. Figure 4.4 illustrates the relation between flexural and compressive strengths for all mixes. Analyses showed that, when the compressive strength increases, flexural strength tends to increase also.

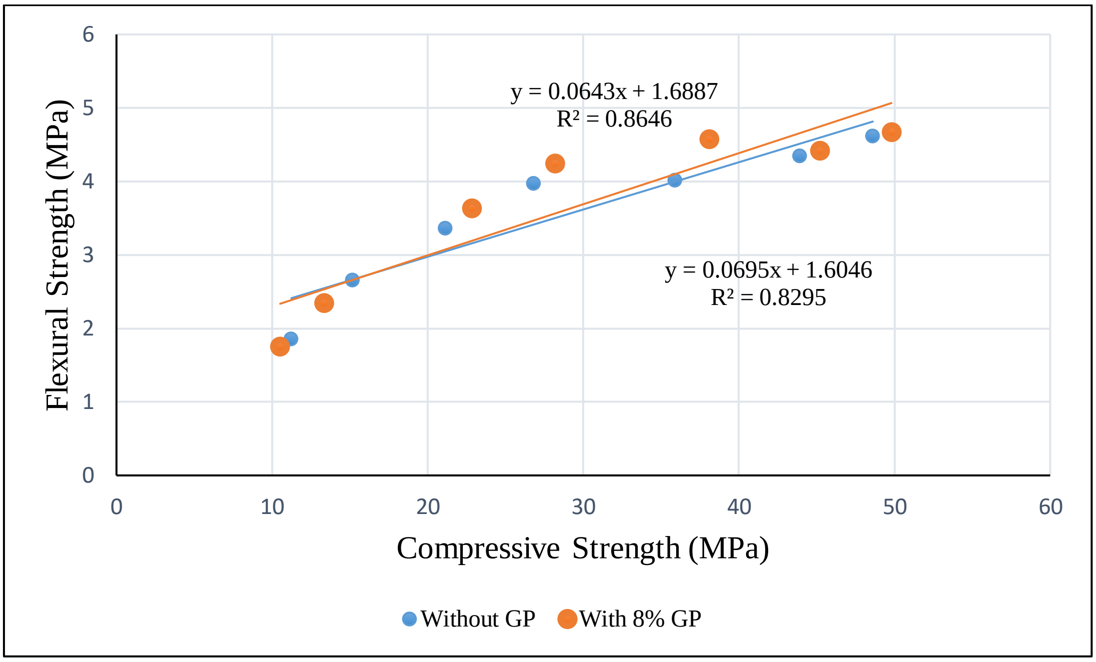

Figure 4.5: Relation between Flexural Strength and Compressive Strength for Concrete with and without GP

4.5 Effect of MD and GP on Tensile Strength of Concrete (σ_s)

The average of 3 cylindrical specimens (100 mm × 200 mm) for tensile strength test results of fourteen various concrete mixes at 28 days are presented in Table 4.6 and Figure 4.6.

A similar trend as that in compressive strength was observed for tensile strength and the values are presented in Table 4.5 and Figure 4.6. The tensile strength of cylinders is increased when MD was used in the mix up to 10% replace by weight of cement and further any addition of MD the split tensile strength tends to decrease. Similarly, in the case of using GP, the optimum split tensile was observed for the mix that contain 10% MD with 8% GP. The increase tensile strength was noticed due to low porosity for blended cement concrete incorporating marble dust as a micro fine filler product.

Table 4.5: Effect of MD and GP on Splitting Tensile Strength of Concrete

Specimen Type	Splitting Tensile Strength without GP (MPa)	Splitting Tensile Strength with 8% GP (MPa)
Control	3.59	3.67
MD10	3.78	3.85
MD20	3.22	3.32
MD30	2.84	2.95
MD40	2.28	2.55
MD50	1.73	1.66
MD 60	1.38	1.18

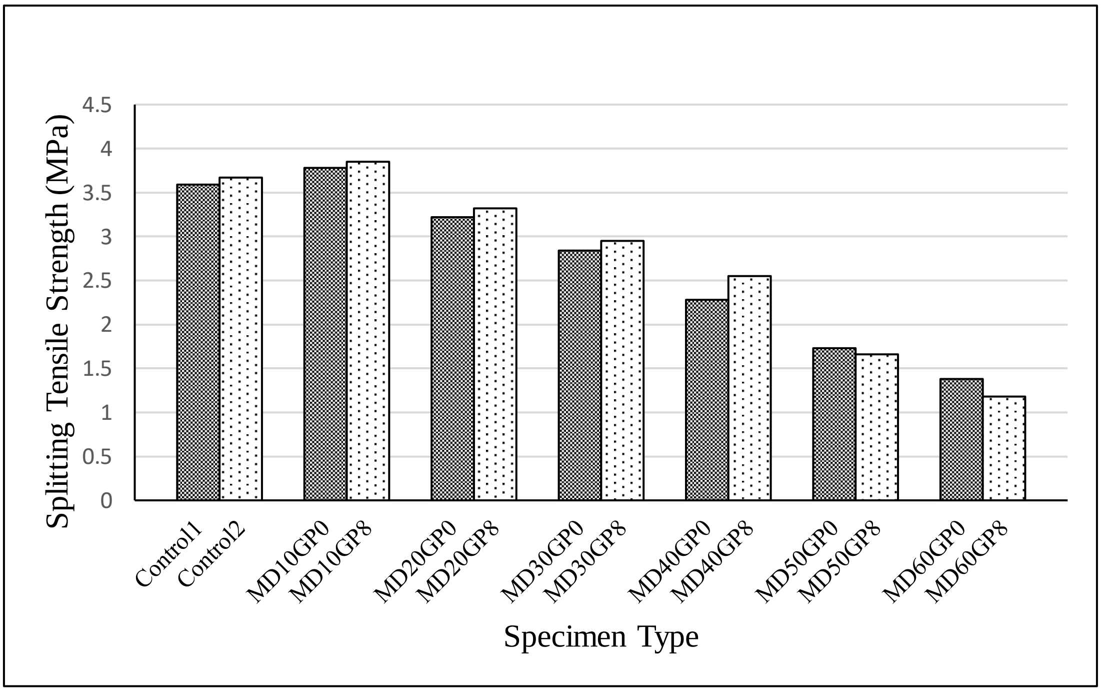

Figure 4.6: Effect of MD and GP on Splitting Tensile Strength of Concrete

4.5.1 Relationship between Splitting Tensile Strength and Compressive Strength

In order to obtain the correlation between the tensile and compressive strengths, the regression coefficient R^2 was considered as a linear regression type. The much close the value of R^2 to 1, the less is the dispersion. Figure 4.7 displays the linear correlation between tensile strength and compressive strength for concrete incorporated with MD and with or without GP at 28 days.

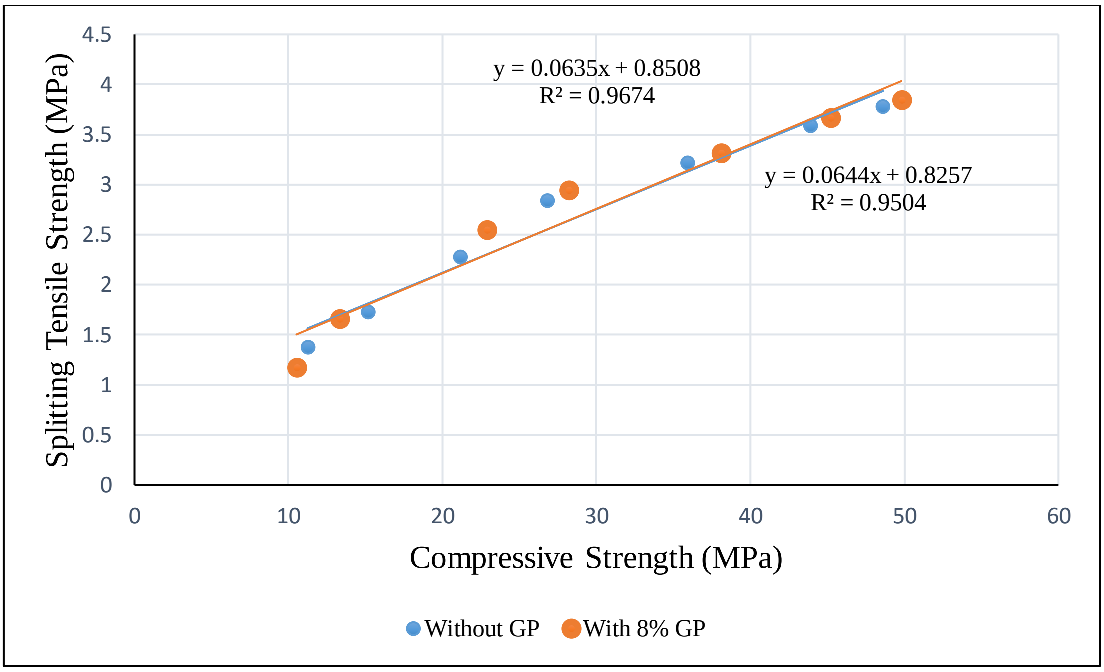

Figure 4.7: Relation between Splitting Tensile Strength and Compressive Strength for Concrete with and without GP

4.6 Effect of MD and GP on Alkalinity of Concrete (PH)

The pH values obtained from the alkalinity test on various specimens are illustrated in Table 4.6 as well as Figure 4.8. As it can be seen from Figure 4.8 the PH values are usually in the range of 11.65 and 12. The mixes that contain MD as cement replacement have higher PH values when compared to control. For the mixes that contain GP, the PH values were always higher than that mixes with no GP with same percentage of MD. In general, although there is no specific pattern, it can be concluded that the introduction of MD in concrete by partially replacing cement and GP as an additive does not make the concrete acidic. Therefore, it should not have negative effects on steel reinforcement and will be more resistant towards corrosion.

Table 4.6: Effect of MD and GP on Concrete Alkalinity

Specimen Type	PH Value without GP (MPa)	PH Value with 8% GP (MPa)
Control	11.65	11.69
MD10	11.71	11.77
MD20	11.8	11.85
MD30	11.77	11.87
MD40	11.9	12
MD50	11.88	11.94
MD 60	11.93	12

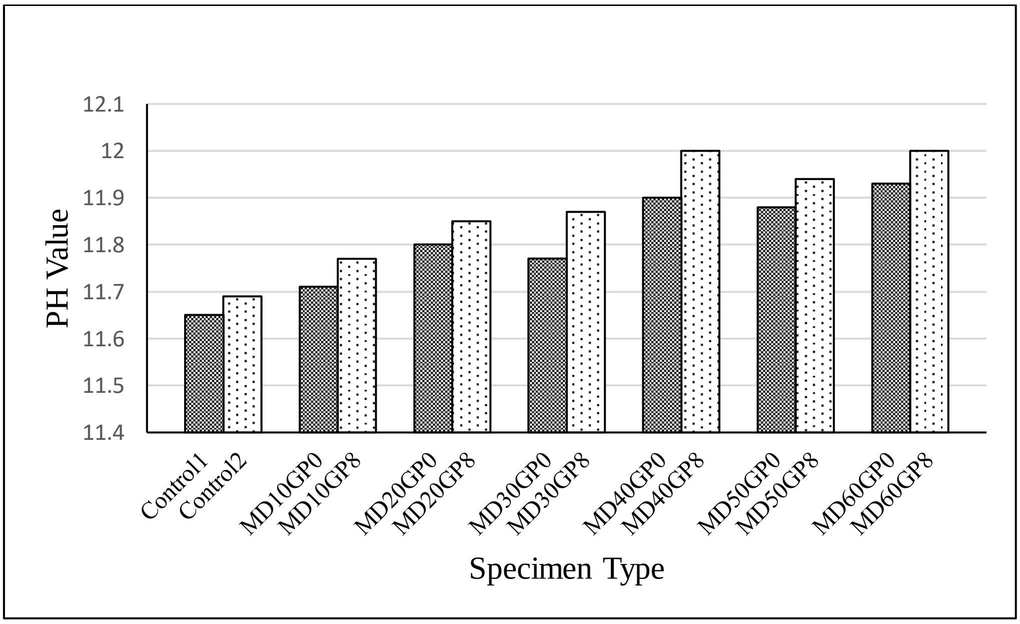

Figure 4.8: Effect of MD and GP on Concrete Alkalinity

4.7 Effect of MD and GP on Sulphate Resistance of Concrete

Sulphate attack can be clear in the form of concrete expansion. When cracks occure in concrete, the permeability will increase and aggressive water will infiltrate more easily inside the concrete, which speeds up the degradation process. Sulphate attack can also take the form of gradual loss of both strength mass because of the deterioration in the cohesion of cement hydration products. In this study, Sulphate resistance of concrete cube samples was investigated in terms of strength loss when immersed in 5% Na_2SO_4 solution. Compressive strength of concrete cube specimens with different percentages of MD as a CRM and GP as an additive material at the age of 56 days are displayed in Table 4.7 and Figure 4.9.

As it can be observed from Figure 4.9 that the compressive strength for cubes immersed in water always higher than compressive strength for cubes that immersed in 5% Na_2SO_4, also the mixes that contain GP gave higher resistance to sulphat attack than the mixes that do not contain GP. Increases in the additive content leads to increase in sulphate resistance of concrete. These results showed that as the dust content in concretes increased, the resistance of the concretes against sulphate attack increased. For instance, the MD60GP8 specimen had the highest sulphate resistance among all the samples. This result also indicated the feature of utilizing GP to resist Na_2SO_4 attack.

The reduction in compressive strength for cubes that immersed in sulphate solution can be attributed to sulphate attacks occurred in by the reaction of sulphates with hydrated compounds in the hardened cement paste (calcium hydroxide, and calcium aluminate hydrate). The products of the reactions (gypsum and calcium sulphoaluminate) have considerably greater volume than the compounds that they replace, so the reactions lead to expansion and disruption of the concrete. These reactions can induce sufficient pressure to disrupt the cement paste, resulting in disintegration of the concrete (loss of paste cohesion and strength).

It has long been recognised that sulphate attack usually results in the formation of expansive products, such as ettringite, gypsum and thaumasite, which are produced by sulphate ions reacting with hydration products in cement, resulting in expansion, cracking, spalling, and concrete strength loss (Baghabra Al-Amoudi, 2002).

Table 4.7: Compressive Strengths of Concretes Immersed in Sulphate Solution

Specimens	Compressive strength after 28 days	Compressive strength after 56 days		
		Normal water	5% Na_2SO_4	Compressive strength reduction (%)
MD20	35.9	37.3	35.5	5
MD40	21.13	23.24	22.38	3.8
MD60	11.24	12.15	11.76	3.3
MD20GP8	38.1	41.8	40.5	3.2
MD40GP8	22.85	25.23	24.57	2.7
MD60GP8	10.52	12.38	12.1	2.3

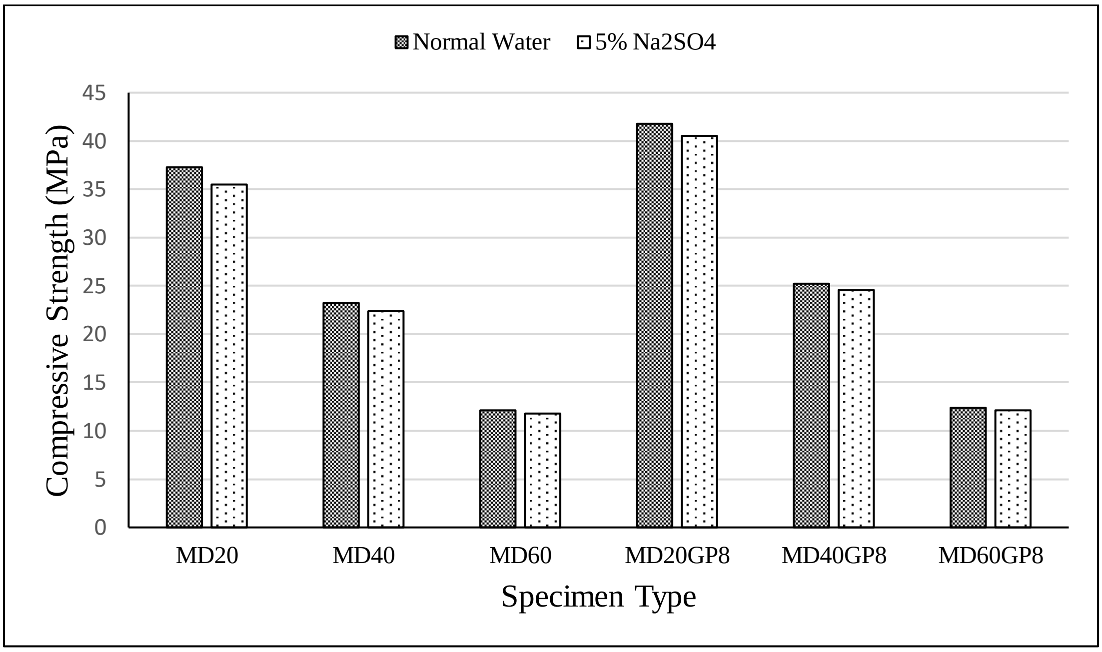

Figure 4.9: Compressive Strengths of Concretes Immersed in Sulphate Solution

4.8 Ultrasonic Test Results

The results of ultrasonic test are illustrated in Table 4.8;

Table 4.8: Ultrasonic Test Results

Specimen Type	Pulse Velocity without GP (km/s)	Pulse Velocity with 8% GP (km/s)	Quality
Control	4.65	4.67	Excellent
MD10	4.73	4.74	Excellent
MD20	4.6	4.62	Excellent
MD30	4.44	4.48	Good
MD40	4.3	4.32	Good
MD50	4.31	4.17	Good
MD 60	4.24	3.95	Good

As it can be seen from Table 4.9, the higher the velocity will have better elastic properties, better density and less voids and cracks in concrete specimen. Therefore, it is clear that MD10 and MD10+GP8 have the best quality among all mixes followed by control 2 and control 1 then MD20 and MD20+GP8 (all these 6 mixes listed as excellent quality since its pulse velocity is higher than 4.5km/s). The quality for the other mixes is defined as good quality since its pulse velocity is between 3.5 km/s and 4 km/s.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, fourteen various mixes were produced by substituting the cement with marble dust with 0%, 10%, 20%, 30%, 40%, 50% and 60% proportions and also with and without 8% of GP. The aim was to determine the influences of MD incorporated with GP as an additive on the mechanical and durability properties of concrete. The mixes that contain 0% marble dust replacement with either 0% GP or 8% GP were utilized as a control. The results of the testing for fresh and hardened concretes led to draw the following conclusions and some suggestions for other researches, which are presented below:

1. The replacement of cement with MD influences the properties of plastic concrete. The slump test indicated that the workability tends to decrease as the MD content increase in the mix. But the flow ability (slump) value was lower for mixtures containing GP as an additive since the total surface areas has increased, as well as flowability has a direct relation with the particle sizes, in which finer particles will increase viscosity.

2. It was found that the utilization of 10% MD as cement replacement improved the concrete compressive strength compared with control mix and more than 10% cement substitution has an adverse effect on concrete compressive strength. The reason for this improvement on concrete compressive strength at

10% marble dust as cement replacement was attributed to marble dust acts as a filler.

3. The optimum compressive strength was found for the mix that contain 10% MD as replacement to cement with 8% GP. This is due to the chemical reactions of cement particles, some amount of heat was produced, which could increase the chemical reaction activities of GP particles.

4. The flexural strength of concrete with 10% MD as a CRM and 8% GP exhibited the optimum flexural strength among all mixes with 4.68 MPa. This improvement was attributed to good strength and low porosity of both (ITZ) and cement paste matrix. Further increases in the proportion of MD leads to decrease in flexural strength.

5. A similar trend as that in compressive strength was found for split tensile strength. The split tensile strength of cylinders are increased with addition of MP up to 10% replace by weight of cement and further any addition of MD the split tensile strength tends to decrease. Similarly, in the case of using GP, the optimum split tensile was observed for the mix that contain 10% MD with 8% GP. The increase in split tensile strength was noticed due to low porosity for blended cement concrete incorporating MD as a micro fine filler product.

6. The PH values were usually in the range of 11.65 and 12. The mixes that contain MD as cement replacement have higher PH values when compared to control. For the mixes that contain GP, the PH values were always higher than

that mixes without GP with same percentage of MD. Therefore, the use of MD and GP in concrete mixes do not have negative effects on steel reinforcement and will give more resistant towards corrosion.

7. The compressive strength for samples immersed in water were always higher than compressive strength for samples that immersed in 5% Na_2SO_4. The mixes that contain GP gave higher resistance to sulphat attack than the mixes that do not contain GP. Increases in the additive content caused increases in sulphate resistance of concrete. These results indicated that as the amount of dust in concretes increased, the resistance of the concretes against sulphate attack increased.

8. For the quality of the specimens, MD10 and MD10+GP8 had the best quality among all mixes followed by control 2 and control 1 then MD20 and MD20+GP8. The quality for the other mixes is defined as good quality since its pulse velocity is between 3.5 km/s and 4 km/s.

5.2 Recommendations for Future Studies

For future studies, it is recommended that researchers focus on:

1. Study the effect of marble dust and glass powder on the long term compressive strength.

2. Study effect of sulphate solution on the specimens under freezing and thawing condition by measuring the mass loss of the specimens.

3. Investigate the durability properties of MD incorporated with GP concrete, such as porosity, water permeability, chloride permeability, creep and shrinkage.

4. Increase the pozzolanic activity of glass powder and/or marble dust by using activators such as NaOH to give higher strength.

REFERENCES

Aiswarya, S., Prince Arulraj, G., & Dilip, C. (2013). A review on use of metakaolin in concrete. IRACST–*Engineering Science and Technology*: An International Journal (ESTIJ), 3(3), 592-597.

Aliabdo, A. A., Elmoaty, A. E. M. A., & Aboshama, A. Y. (2016). Utilization of waste glass powder in the production of cement and concrete. *Construction and Building Materials*, 124, 866-877.

Alyamaç, K. E., & Ince, R. (2009). A preliminary concrete mix design for SCC with marble powders. *Construction and Building Materials*, *23*(3), 1201-1210.

Al Saffar, D. M. A. R. (2017). Experimental investigation of using ultra-fine glass powder in concrete. Int J Eng Res Appl, 7(9), 33-39.

Amar, M., Benzerzour, M., Safhi, A. E. M., & Abriak, N. E. (2018). Durability of a cementitious matrix based on treated sediments. Case studies in construction materials, 8, 258-276.

Anderson, R., & Dewar, J. D. (2003). *Manual of ready-mixed concrete*. CRC Press.

Ansari Ismail, S. S. (2015). utilization of glass powder as a partial replacement of cement and its effect on concrete strength. *IRF InternationalConference*, 1-5.

Anwar, A. (2016). The influence of wast glass powder as pozzolanic material in concrete. *International Journal of Civil Engineering and Technology (IJCIET)*, 7, 131-148.

Anwar, A., Ahmad, J., Khan, M. A., Ahmad, S., & Ahmad, S. A. (2014). Study of compressive strength of concrete by partial replacement of cement with marble dust powder. *International Journal on Mechanical Engineering and Robotics (IJMER)* ISSN (Print), 2321-5747.

Arunkumar, K., Karpagaraj, J., & Nandhini, U. (2017). Experimental Studies on High Performance Concrete by Waste Glass and Marble Powder, (March), 76–82.

Aruntaş, H. Y., Gürü, M., Dayı, M., & Tekin, I. (2010). Utilization of waste marble dust as an additive in cement production. *Materials & Design*, *31*(8), 4039-4042.

Arun Kumar and Ankush Thakur, Strength Behaviour of Concrete Produced with Marble Dust Powder, *International Journal of Civil Engineering and Technology*, *9*(7), 2018, pp. 1058-1065.

ASTM, C597 - Standard Test Method for Pulse Velocity Through Concrete (2010).

Baghabra Al-Amoudi, O.S., 2002. Attack on plain and blended cements exposed to aggressive sulfate environments. *Cement and Concrete Composites*, 24(3-4):305-316.

Batayneh, M., Marie, I., & Asi, I. (2007). Use of selected waste materials in concrete mixes. *Waste management*, *27*(12), 1870-1876.

BhatVeena V, Rao N. Bhavanishankar "Influence of Glass Powder On The Properties Of Concrete" *International Journal of Engineering Trends andTechnology (IJETT)*, ISSN: 2319 –8753, Volume16, Number-5, October 2016

Binici, H., Kaplan, H., & Yilmaz, S. (2007). Influence of marble and limestone dusts as additives on some mechanical properties of concrete. *Scientific Research and Essays*, *2*(9), 372-379.

Binici, H., Shah, T., Aksogan, O., & Kaplan, H. (2008). Durability of concrete made with granite and marble as recycle aggregates. *Journal of materials processing technology*, *208*(1-3), 299-308.

Brown, P., & Hooton, R. D. (2002). Ettringite and thaumasite formation in laboratory concretes prepared using sulfate-resisting cements. *Cement and Concrete Composites*, *24*(3-4), 361-370.

Chabrelie, A. (2010). Mechanisms of degradation of concrete by external sulfate ions under laboratory and field conditions (No. THESIS). EPFL.

Chandra, S., & Choudhary, R. (2012). Performance characteristics of bituminous concrete with industrial wastes as filler. *Journal of materials in civil engineering*, *25*(11), 1666-1673.

Chikhalikar, S. M., & Tande, S. N. (2012, August). An experimental investigation on characteristics properties of fibre reinforced concrete containing waste glass powder as pozzolona. *In 37th Conference on Our World in Concrete and Structures*, Singapore.

Choudhary, S., Bajaj, R., & Sharma, R. K. (2014). Study of high performance concrete. Civil Engineering and Environmental Technology, 1(5), 109-113.

Cordeiro, G. C., Toledo Filho, R. D., & Fairbairn, E. D. M. R. (2009). Use of ultrafine rice husk ash with high-carbon content as pozzolan in high performance concrete. *Materials and structures*, *42*(7), 983-992.

Corinaldesi, V., Moriconi, G., & Naik, T. R. (2010). Characterization of marble powder for its use in mortar and concrete. *Construction and building materials*, *24*(1), 113-117.

Dachowski, R., & Kostrzewa, P. (2016). The use of waste materials in the construction industry. *Procedia engineering*, *161*, 754-758.

Demirel, B. (2010). The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete. *International journal of physical sciences*, *5*(9), 1372-1380.

Dhanapandiana, S., & Shanthib, M. (2009). Utilization of marble and granite wastes in brick products. *Journal of Industrial Pollution Control*, *25*(2), 145-150.

Du, L., & Folliard, K. J. (2005). Mechanisms of air entrainment in concrete. *Cement and concrete research*, *35*(8), 1463-1471.

Elmoaty, A. E. M. A. (2013). Mechanical properties and corrosion resistance of concrete modified with granite dust. *Construction and Building Materials*, 47, 743-752.

Hebhoub, H., Aoun, H., Belachia, M., Houari, H., & Ghorbel, E. (2011). Use of waste marble aggregates in concrete. *Construction and Building Materials*, *25*(3), 1167-1171.

Karaşahin, M., & Terzi, S. (2007). Evaluation of marble waste dust in the mixture of asphaltic concrete. *Construction and Building Materials*, *21*(3), 616-620.

Karim, Y., Khan, Z., Alsoufi, M. S., & Yunus, M. (2016). A review on recycled aggregates for the construction industry. *American Journal of Civil Engineering and Architecture*, *4*(1), 32-38.

Khaliq, S. U., Khan, S., Alam, B., Bilal, F., Zeb, M., & Akbar, F. (2016). Marble powder's effect on permeability and mechanical properties of concrete. *International Journal of Civil and Environmental Engineering*, *10*(4).

Khamchin Moghaddam, F., Sri Ravindrarajah, R., & Sirivivatnanon, V. (2015, September). Properties of Metakaolin Concrete–A Review. *In International Conference on Sustainable Structural Concrete*.

King, D. (2012, August). The effect of silica fume on the properties of concrete as defined in concrete society report 74, cementitious materials. *In 37th Conference on our world in concrete and structures*, Singapore (pp. 29-31).

Krstulovic, P., Kamenic, N., & Popovic, K. (1994). A new approach in evaluation of filler effect in cement I. Effect on strength and workability of mortar and concrete. *Cement and Concrete Research*, *24*(4), 721-727.

Kumar, R., & Kumar, S. K. (2015). Partial replacement of cement with marble dust powder. *International Journal of Engineering Research and Applications, 5*(8), 106-114.

Mageswari, M., & Vidivelli, B. (2010). The use of sheet glass powder as fine aggregate replacement in concrete. *Open Civil Engineering Journal*, 4, 65-71.

Malay, N., Kumar, M., & Kujur, J. (2015). Effect of partial replacement of cement by marble dust on compressive strength and carbonation of PPC concrete. *International UKIERI Concrete Congress* (PP. 633-643). NIT Jalandhar, Punjab, India.

Mindess, S., Young, J. F., & Darwin, D. (2003). *Concrete*, 2003. Prentice Hall, Upper Saddle River, NJ.

Neville, A. M. (1995). *Properties of concrete* (Vol. 4). London: Longman.

Onchiri, R., James, K., Sabuni, B., & Busieney, C. (2014). Use of sugarcane bagasse ash as a partial replacement for cement in stabilization of self-interlocking earth blocks. *International Journal of Civil Engineering and Technology*, *5*(10), 124-130.

Patil, D. M., & Sangle, K. K. (2013). Experimental investigation of waste glass powder as partial replacement of cement in concrete. *Int. J. Adv. Technol. Civ. Eng*, *2*(1), 112-7.

P.N, Raghunath, Suguna K, Karthick J, and SarathKumar B. 2018. "Mechanical and Durability Characteristics of Marble Powder Based High Strength Concrete." Scientia Iranica.

Rai, B., Naushad, K. H., Abhishek, K., Rushad, T. S., & Duggal, S. K. (2011). Influence of Marble powder/granules in Concrete mix. *International journal of civil and structural engineering*, *1*(4), 827.

Raju, S., & Kumar, P. R. (2014). Effect of using glass powder in concrete. *International journal of innovative research in science, engineering and technology*, 31, 21-427.

Ramezanianpour, A. M. (2012). Sulfate Resistance and Properties of Portland-Limestone Cements (Doctoral dissertation).

Sakalkale, A. D., Dhawale, G. D., & Kedar, R. S. (2014). Experimental study on use of waste marble dust in concrete. *Int. J. Eng. Res. Appl.*, *4*(10), 44-50.

Santhanam, M., Cohen, M. D., & Olek, J. (2002). Mechanism of sulfate attack: A fresh look: Part 1: Summary of experimental results. *Cement and concrete research*, 32(6), 915-921.

Saribiyik, M., Piskin, A., & Saribiyik, A. (2013). The effects of waste glass powder usage on polymer concrete properties. *Construction and building materials*, 47, 840-844.

Sharma, N., & Kumar, R. (2015). Use of waste marble powder as partial replacement in cement sand mix. *Int J Eng Res Appl*, 4(5), 501-504.

Shelke, V. M., Pawde, P., & Shrivastava, R. (2012). Effect of marble powder with and without silica fume on mechanical properties of concrete. *IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) ISSN*, 2278-1684.

Shirule, P. A., Rahman, A., & Gupta, R. D. (2012). Partial replacement of cement with marble dust powder. *International Journal of Advanced Engineering Research and Studies*, *1*(3), 2249.

Shumuye, E. D., & Jun, Z. (2018). A Review on Ground Granulated Blast Slag (GGBS) in Concrete. *In Proc. of the Eighth International Conference on Advances in Civil and Structural Engineering*. CSE.

Siddique, R., & Klaus, J. (2009). Influence of metakaolin on the properties of mortar and concrete: A review. *Applied Clay Science*, 43(3-4), 392-400.

Singh, G., & Madan, S. K. Durability of Concrete made with Marble Dust as partial replacement of Cement subjected to Sulphate attack.

Singh, G., & Madan, S. K. (2017). Review on the feasibility of Marble Dust as Replacement of Cement in Concrete. *International Journal of Current Engineering and Technology*, 7(6), 2119-2123.

Sounthararajan, V. M., & Sivakumar, A. (2013). Effect of the lime content in marble powder for producing high strength concrete. *ARPN Journal of Engineering and Applied Sciences*, 8(4), 260-264.

Subramani, T., & Ram, S. S. (2015). Experimental Study on Concrete Using Cement With Glass Powder. Department of Civil Engineering, VMKV Engg. College, Vinayaka Missions University, Salem, India, 5(V3), 43-53.

Tayeh, B. A., Al Saffar, D. M., Aadi, A. S., & Almeshal, I. (2019). Sulphate resistance of cement mortar contains glass powder. *Journal of King Saud University-* Engineering Sciences.

Topcu, I. B., & Canbaz, M. (2004). Properties of concrete containing waste glass. *Cement and concrete research, 34*(2), 267-274.

Vardhan, K., Goyal, S., Siddique, R., & Singh, M. (2015). Mechanical properties and microstructural analysis of cement mortar incorporating marble powder as partial replacement of cement. *Construction and Building Materials*, 96, 615-621.

Vijayakumar, G., Vishaliny, H., & Govindarajulu, D. (2013). Studies on glass powder as partial replacement of cement in concrete production. *International Journal of Emerging Technology and Advanced Engineering*, 3(2), 153-157.

Xu G, Shi X. Characteristics and applications of fly ash as a sustainable construction material: *A state-of-the-art review.* Resour Conserv Recycl. 2018;136(August 2017):95–109.