

Effects of Quartz Powder as a Partial Replacement of Cement on Fresh and Hardened Properties of Normal and High Strength Concretes

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ABSTRACT

Concrete is the most extensively material used in civil engineering applications all over the world, and cement is the most essential constituent of concrete. The production of cement is responsible for about 8% of greenhouse gases emission into the air that assists the global warming. Consequently, in recent years, there has been an increased interest in the use of waste pozzolanic admixtures to supplement cement. Replacing cement with these admixtures has been known to reduce the cost of producing concrete, the air pollution resulting from cement production, as well as enhance certain concrete properties.

The relatively low cost, high availability, and high silica content in quartz powder has made it more popular compared to other waste natural pozzolans. As such, a significant amount of research is increasingly being directed towards evaluating the effects of quartz powder in cement.

When used to partially replace cement in concrete, quartz powder acts as filler for the spaces in the cement paste. Due to the 'very fine' nature of its particles (less than 1 μm in size), quartz powder increases the density and homogeneity of the cement paste, thereby enhancing the concrete's compressive strength and its overall quality in both its fresh and hardened states.

This study, evaluates the effects of five different percentages of quartz powders as a partial replacement of cement namely 0, 10, 20, 30 and 40% on the mechanical and physical properties of concrete of three classes of concrete namely C20/25, C35/45, and C50/60. For this aim, workability (assisted by slump test) test, compressive and

flexural strength tests, permeability by the rapid chloride test, water absorption capacity test, and heat resistance test were done. Finally, comparison is done between the results of control concrete and quartz powder test specimens. The test results shows that using 10% of quartz powder (QP) as a partial replacement of cement has a significant effect on the physical and mechanical properties of concrete such as a workability, compressive strength, flexural strength, resistance to chloride penetration and water absorption capacity for different classes of concretes (C20/25, C35/45 and C50/60).

Keywords: Compressive Strength, Flexural Strength, Heat Resistance, Rapid Chloride Permeability, Quartz Powder, Splitting Tensile Strength, Workability.

ÖZ

Beton dünyada inşaat mühendisliği uygulamalarında kullanılan en yaygın malzeme olmakla birlikte, çimento betonun en temel bileşenidir. Çimento üretimi, küresel ısınmaya sebep olan sera gazı emisyonunun yaklaşık 8%’inden sorumludur. Sonuç olarak, son yıllarda atık pozolonik katkılarının çimentonun içine takviye edilmesi konusunda artan bir ilgi vardır. Çimentoya bu katkı malzemelerinin katılması, beton üretim maliyetlerini düşürdüğü, çimento üretiminden kaynaklanan hava kirliliğinin yanı sıra belirli özelliklerini de arttırdığı bilinmektedir.

Nispeten düşük maliyetli yüksek erişilebilirlik ve kuvars tozundaki yüksek silika içeriği diğer atık doğal pozolanlara kıyasla bunu daha popüler hale getirdi. Bu nedenle, çimentoda kuvars tozunun etkilerini değerlendirmeye yönelik hızla önemli araştırmalara yönelenilmektedir.

Betonda çimentoyu kısmen değiştirirken kuvars tozu çimento macunundaki boşluklar için dolgu maddesi görevi görür. Parçacıkların “ çok ine” doğası nedeni ile (1µm’den küçük boyutta), kuvars tozu çimento macununun yoğunluğunu ve homojenliğini artırır. Böylece hem taze hem de sertleşmiş haldeki betonun basınç direncini ve genel kalitesini artırır.

Bu çalışma, beş farklı yüzdeler (0%, 10%, 20%, 30% ve 40%) ile kısmi kuvars tozunun değiştirilmesinin üç farklı sınıftaki betonun (C20/25, C35/45 ve C50/60) mekanik ve fiziksel özellikleri üzerindeki etkilerini göstermektedir. Bunun amacı, işlenebilirlik (çökme testine yardımcı olarak) testi, basınç ve eğilme testi, hızlı klorür ile geçirgenlik testi, su emme kapasite testi ve ısı direnci testlerinin yapılmış

olması. Sonuç olarak, beton kontrolünün sonuçları ve kuvars tozunun numuneleri arasındaki kıyaslama bitmiş bulunmaktadır. Test sonuçları gösteriyor ki; 10% kuvars tozu (QP) kullanılarak kısmi deęişiklik yapılmış çimento, betonun mekanik ve fiziksel özelliklerinde; işlenebilirlik, basınç direnci, bükülme direnci, klorür penetrasyonuna direnç ve su emilim kapasitesi üç farklı sınıf betona (C20/25, C35/45, C50/60) önemli etki yapmıştır .

Anahtar kelimeler: Basınç dayanımı, eğilme mukavemeleti, ısı direnci , kuvars tozu, ayrılma-çekme mukavemeti, işlenebilirlik.

DEDICATION

To all my valuable family

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TABLE OF CONTENTS

ABSTRACT	iii
ÖZ	v
DEDICATION	vii
ACKNOWLEDGMENT	viii
LIST OF TABLES	xiv
LIST OF FIGURES	xvi
LIST OF SYMBOLS AND ABBREVIATIONS	xix
1 INTRODUCTION.....	1
1.1 Background of the Study	1
1.2 The Aim of the Study	3
1.3 Objectives	4
1.4 Methodology.....	4
1.5 Thesis Outline.....	5
2 LITERATURE REVIEW	6
2.1 Introduction	6
2.2 Cement Replacement Materials.....	7
2.3 Replacement of Coarse Aggregate	9
2.4 Replacement of Fine Aggregate	10
2.5 Usage in the Reactive Powder Concrete (RPC)	10
2.6 Workability of Concretes.....	11
2.6.1 Description, Importance of Studing Workability of Concretes.....	11
2.6.2 Influence of Quartz Powder on Workability of Concretes.....	12
2.7 Compressive Strength of Concretes	14

2.7.1 Discription, and Importance of Studying Compressive Strength of Concrete.....	14
2.7.2 Influence of Quartz Powders on Compressive Strength of Concretes.....	15
2.7.3 Influence of Different Curing Temperatures and Pressure on Compressive Strength of Concretes	17
2.7.4 Influence of Different w/b Ratios on Compressive Strength of Concrete.....	20
2.8 Flexural Strength	22
2.8.1 Importance of Studying the Flexural Strength of Concrete	22
2.8.2 Influence of Quartz Powder on Flexural Strength of Concretes	22
2.9 Splitting Tensile Strength of Concrete	23
2.9.1 Importance of Studying the Tensile Strength of Concrete	23
2.9.2 Influence of Quartz Powders on Tensile Strength of Concretes.....	24
2.10 Permeability of Concrete	24
2.10.1 Description, and Importance of Studying Permeability of Concrete	25
2.10.2 Influence of Quartz Powders on Permeability of Concretes	25
2.10.3 Factors Influence Permeability of Concrete	26
2.11 Chloride Resistance of Concrete.....	26
2.11.1 Importance, and Evaluation of Chloride Resistance of Concretes	27
2.11.2 Influence of Quartz Powder on Chloride Resistance of Concretes	27

2.12	Water Absorption Capacity.....	28
2.12.1	Importance of Studying Water Absorption Capacity of Concrete.....	28
2.12.2	Influence of Quartz Powders on Water Absorption Capacity of Concretes	29
2.13	High Temperature Resistance Concrete.....	29
2.13.1	Importance of Studying the Concretes Subjected to High Temperature.....	29
2.13.2	Influence of Quartz Powders on High Resistance Concretes.....	31
3	EXPERIMENTAL WORK	36
3.1	Introduction	36
3.2	Materials Used.....	37
3.2.1	Cement	37
3.2.2	Mixing Water	38
3.2.3	Fine Aggregate	38
3.2.4	Coarse Aggregates.....	38
3.2.5	Quartz Powder.....	39
3.2.6	Superplasticizer	41
3.3	Mix Design	41
3.4	Experimental Method	43
3.4.1	Mixing, Casting, and Curing.....	43
3.5	Fresh Concrete Slump Test.....	45
3.6	Testing of Hardened Concrete	45
3.6.1	Compressive Strength	45

3.6.2 Flexural Strength	46
3.6.3 Splitting Tensile Strength.....	47
3.6.4 Rapid Chloride Penetration Test (RCPT).....	47
3.6.5 Water Absorption Capacity Test	48
3.6.6 Heat resistance.....	49
4 RESULTS AND DISCUSSION	51
4.1 Introduction	51
4.2 The Effects of Various QP Replacement Levels on Workability of Different Concrete Classes.....	51
4.3 The Influence of Various QP Replacement Levels on Compressive Strength of Different Concrete Classes	53
4.4 The Effects of Different QP Replacement Levels on Flexural Strength of Different Concrete Classes	56
4.5 The Influence of Various QP Replacment Levels on Splitting Tensile Strength of Different Concrete Classes.....	63
4.6 The Effects of Different QP Replacement Levels on Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration	69
4.7 The Effects of Various QP Replacement Levels with Different Concrete Strength on Water Absorption Capacity	71
4.8 The Effects of Various QP Replacement Levels on Heat Resistance of Different Concrete Classes at 600°C	79
4.9 Application and Cost of Quartz Powder (QP).....	82
4.9.1 Cost of Cement and Quartz Powder	83
5 CONCLUSION	85
5.1 Conclusions	85

5.2 Recommendations for Further Studies	88
REFERENCES.....	90
APPENDIX.....	102

LIST OF TABLES

Table 3.1: Chemical and Physical Analysis of Cement 32.5	37
Table 3.2: Chemical Analysis of Quartz Powder	40
Table 3.3: Percent Passing of Quartz Powder Particles in Hydrometer Analysis.....	41
Table 3.4: Proportions and Quantities of Mixing Materials for C20/25 Concrete Mixes.....	42
Table 3.5: Proportions and Quantities of Mixing Materials for C35/45 Concrete Mixes.....	43
Table 3.6: Proportions and Quantities of Mixing Materials for C50/60 Concrete Mixes.....	43
Table 4.1: Relationship Equations between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age..	59
Table 4.2: Relationship Equations between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age..	61
Table 4.3: Different Relationship Equations of Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP at 28 Days of Curing Age	66
Table 4.4: Relationship Equations between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age	67
Table 4.5: Chloride Ion Penetration Results of Cement Replacement Concretes with QP for Different Type of Strength at 56 Days	70

Table 4.6: Chloride Ion Penetrability Based on Charge Passed (ASTM C1202-08)..	70
Table 4.7: Relationship Equations between Water Absorption Capacity and Chloride Ion Penetration for Cement Replacement Concretes with QP for 56 Days of Curing Age	74
Table 4.8: Relationship Equations between and Water Absorption Capacity and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age	77
Table 4.9: Strength Loss of Concretes with Different Percentages of QP as a Partial Replacement of Cement Subjected to 600°C at 56 Days of Curing Age.....	80
Table 4.10 : Cost Analysis of QP and Blast Furnace Slag Cement	83

LIST OF FIGURES

Figure 3.1: Fine Aggregates Sieve Analysis	38
Figure 3.2: Coarse Aggregates Sieve Analysis	39
Figure 3.3: Quartz Powder	40
Figure 3.4: Particle Size Distribution of Quartz Powder	41
Figure 3.5: Different Types of Specimens in Curing Room Used in This Research..	44
Figure 3.6: Concrete Slump Test..	45
Figure 3.7 Flexural Strength Test.....	46
Figure 3.8: Splitting Tensile Strength Test	47
Figure 3.9: Rapid Chloride Penetration Test.....	48
Figure 3.10: Heating Samples to Test Heat Resistance Testing of Concrete with Different amount of QP.....	50
Figure 4.1: Effect of QP as Partial Replacement of Cement on Slump	53
Figure 4.2: Effect of QP on the 28 – Days Compressive Strength	54
Figure 4.3: Effect of QP on the 56 – Days Compressive Strength	55
Figure 4.4: Effect of QP on both 28 and 56 – Days Compressive Strength	55
Figure 4.5: Effect of QP on 28 – Days Flexural Strength.....	57
Figure 4.6: Effect of QP on 56 – Days Flexural Strength.....	57
Figure 4.7: Effect of QP on both 28 and 56 – Days Flexural Strength.....	58
Figure 4.8: Relationship between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age	60
Figure 4.9: Relation between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age	62

Figure 4.10: Linear Relation between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age.....	62
Figure 4.11: Effect of QP on 28 – Days Splitting Tensile Strength.....	64
Figure 4.12: Effect of QP on 56 – Days Splitting Tensile Strength.....	64
Figure 4.13: Effect of QP on both 28 and 56 – Days Splitting Tensile Strength.....	65
Figure 4.14: Relationship between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age ..	67
Figure 4.15: Relationship between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age ..	68
Figure 4.16: Linear Relationship between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age ..	68
Figure 4.17: Effect of QP on Water Absorption Capacity at 56 Days.....	72
Figure 4.18: Relationship between Water Absorption Capacity and Chloride Ion Penetration for Cement Replacement Concretes with QP for 56 Days of Curing Age ..	75
Figure 4.19: Linear Relationship between Water Absorption Capacity and Chloride Ion Penetration for Cement Replacement Concretes with QP for 56 Days of Curing Age ..	75
Figure 4.20: Relationship between Water Absorption Capacity and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age..	78
Figure 4.21: Linear Relationship between Water Absorption Capacity and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age ..	79

Figure 4.22: Effect of QP After Heat Resistance Up to 600°C on Residual
Compressive Strength at 56 Days 81

LIST OF SYMBOLS AND ABBREVIATIONS

MPa	Mega Pascal
QP	Quartz Powder
RPC	Reactive Powder Concrete
SF	Slica Fume

Chapter 1

INTRODUCTION

1.1 Background of the Study

One of the most commonly used materials in engineering construction the world over is concrete. There has been a recent rise in the use of natural waste materials as partial replacement cement or aggregates in the production of concrete. The use of waste materials provides some advantages for concrete in terms of both performance and microstructure. Furthermore, the use of waste materials in concrete production also reduces cost as less (factory-produced) cement is required. Waste materials are also more environmentally sensitive as they mitigate the emission of CO₂ into the atmosphere, a leading cause of global warming (Rashad, 2014; Rashad, 2013; Rashad& Zeedan, 2011; Rashad et al, 2012; Siddique, 2008).

According to the International Energy Agency (IEA), cement is responsible for between 7% and 8% of CO₂ released into the atmosphere. Relative to other greenhouse gases, CO₂ is responsible for nearly 65% of global warming. It is estimated that the average global temperature will rise somewhere between 1.4 and 5.8°C in the next century (Rehan & Nehdi , 2005).

Contemporary research is concerned with finding materials with, amongst others, high durability levels, fire resistance, and high mechanical properties. In line with this, one available option for the improvement of slag cement is the replacement of

certain cement properties with other materials, such as quartz powder (QP), metakaolin (MK), silica fume (SF), and fly ash (FA) (Rashad, 2014).

The mineral quartz is found in sandstones and is extremely resistant to both physical and chemical weathering. As such, it can be used to partially replace aggregate in cement concrete without significantly reducing the strength of the concrete. The generation of sandstone waste is particularly high in countries like India, where Rajasthan alone is estimated to produce 900 million tons of sandstone waste, thus resulting in the mass dumping of these materials without putting them to use (Rashad, 2014).

Quartz powder is a type of mineral powder (MP). Mineral powders are understood to be fine powders (like quartz and limestone powder) with ultra-fine particles relatively close to or even finer than cement particles.

Mineral powder concrete, in addition to decreasing the total cost of cement and concrete production, also improves energy conservation, decreases air pollution, and decreases the use of cement (Tikkanen et al, 2014).

The use of fine powders affects the properties of concrete. These effects can be placed in three categories:

1. Chemical effects like pozzolanic or hydraulic effects (Tikkanen et al, 2014).
2. Physical effects: fine powders can be used as a filler to fill the voids between the cement paste and coarser aggregates, thus resulting in a denser binder matrix, as in the case of self-compacting concrete (Larbi, 1993).

3. Improvement of the hydration: when fine powders are added as part of the cement paste, the result is a stronger binder matrix (Gutteridge & Dalziel, 1990; Lawrence et al, 2003).

1.2 The Aim of the Study

A number of recent studies have been concerned with investigating pozzolanic admixtures obtained from waste materials. One of such waste materials is quartz powder, which has garnered considerable attention due to its high silica content and availability. This study aims to cover the effects on the physical and mechanical properties of concrete caused by the use of different percentages of quartz powder in its production. As such, the motivating factors for this study can be summarized as follows:

1. Despite being the most expensive material used in the production of concrete, cement is still requires in large quantities during the process. Consequently, it is necessary to explore how the use of cement can be minimized through its partial replacement with quartz powder, thus reducing the overall cost of concrete.
2. The effects of quartz powder as a partial cement replacement in in five different percentages (0, 10, 20, 30 and 40%) for three classes of concretes (C20/25, C35/45 and C50/60) have not been given sufficient attention. This study aims to fill this gap by exploring this line of research.
3. Lastly, there is an apparent need for further research into the effects of five different percentages of quartz powder on different properties of concrete, including chloride resistance, compressive strength, flexural strength, and heat resistance.

1.3 Objectives

The objectives of this study include:

1. Exploring how five different percentages of quartz powder as a partial replacement of cement affect the workability and mechanical properties of concrete produced for three distinct classes of concrete.
2. Discovering the optimal amount of quartz powder needed for the most cost-effective concrete mix.
3. Determining how different w/c ratios affect the performance of concrete with different proportions of quartz powder.
4. Comparing the performance of concrete with different percentages of quartz powder as a cement replacement, using concrete without quartz powder as a control.

1.4 Methodology

ASTM tests are used in this study to investigate how different percentages of quartz powder as a cement replacement (0, 10, 20, 30 and 40%) affect the physical and mechanical properties of concrete. The experiments performed are listed as follows:

1. Workability test (by means of slump test)
2. Compressive strength test
3. Flexural strength test
4. Splitting tensile strength test
5. Rapid chloride test
6. Water absorption capacity test
7. Heating resistance test

The results of each test are compared, both to each other, and to the control test results. The reason for this is to offer an evaluation of how the properties of concrete are affected by the partial replacement of cement with quartz powder. This evaluation is also useful in that it aids efforts towards mitigating the environmental impact of concrete production.

1.5 Thesis Outline

The first chapter provides an introduction of the study; the second chapter includes a literature review of previous experimental works on the effects of quartz powder on the properties of concrete; the third chapter outlines the materials and experimental works used in this study; the fourth chapter contains an outline and discussion of the results of the study; and the fifth chapter outlines the conclusions derived from the study.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The most common construction materials in the world are concrete and mortar. In 2016, around 4.2 billion metric tons of cement was produced all over the world (US Geological Survey, 2016). By considering a typical concrete mixture proportions for normal concrete (cement of 300 kg/m³), hence this amount of cement is incorporated into about 34 billion metric tons of concrete. The total emissions from the cement industry contribute as much as 5-7% of the global CO₂ emissions, which makes about 0.9 ton of CO₂ is emitted into the atmosphere for the production of one ton of cement (Benhelal et al, 2013). On the other hand, cement production causes air pollution, moreover, needs too high energy for heating and grinding the cement (Pade & Guimaraes, 2007).

A significant number of researchers have increasingly begun to investigate ways through which the amount of cement contained in concrete can be reduced without adversely affecting the quality of the concrete. One possible way to do this is through the partial replacement of cement with waste materials, which both enhances the concrete and simultaneously minimizes the cost of production, energy consumption, and environmental contamination.

2.2 Cement Replacement Materials

Many researches have been carried out on materials as cement replacement materials in mortar or concrete such as industrial, natural and waste materials in different percentages. These materials are known as pozzolans or supplementary cementitious materials, and they improve the durability of the concrete mixtures and modify the mechanical properties concrete. These pozzolans are described below:

Fly Ash: It is a fine powder made by burning pulverized coal in thermal power-generating plants and is the most common kind of supplementary cementitious material (SCM). Fly ash is most significantly advantageous in that it promotes an increase in the hydration rate, enhances the strength of the cementitious mixture, and is resistant to sulfate attacks.

Ground Granulated Blast Furnace Slag (GGBS): This kind of pozzolanic material is made by quickly cooling a molten blast furnace slag in water and is comprised of aluminosilicate and silicate. Due to its relatively lower levels of crystal formation, GGBS is particularly cementitious and has a hydration similar to portland cement (PC) when its particles have fineness similar to cement particles (Dali & Tande, 2012). An improved resistance to chemical attacks, reduced permeability, increased compressive strength, and good workability are only some of the advantages in concrete properties that result from using slag as a partial replacement for PC.

Silica fume (SF): This consists of extremely fine silicon dioxide particles that are produced when an electric arc furnace is used to melt either metallic silicon or ferrosilicon in the alloy industry. The rate of amorphous silica in the SF lies

somewhere between 85-99% and is accompanied by significant amounts of SiO₂ (Dali & Tande, 2012). The size of the particles usually ranges from 10 to 500 nm.

The cement paste is affected by the SF in either of two ways: physical and chemical. In terms of the physical effects, the ultra-fine particles have a filler effect on increase the density of the cement paste, thereby reducing the porosity and permeability of the paste by filling the holes. The durability of the paste may also be enhanced as a result. Chemically, the use of SF enhances the compressive strength and other hardened properties of the cement paste, such as tensile strength (splitting tensile and flexural strength), by creating siliceous hydrates through the addition of lime (Rashad & Zeedan, 2011; Johari et al, 2011).

At early ages, the micro-filler ability and positive impact on the hydration rate of SF enhances the overall strength of the concrete (Johari et al, 2011). Concrete made using SF is particularly useful for places requiring low permeability and high abrasion resistance, or where there is an important need to prevent bleeding and segregation using highly cohesive mixes (Roy& Sil, 2012).

Quartz powder (QP): This is an ultrafine material, the particles of which range between 0.125 µm and 300 µm in size, and contains a high level of SiO₂ (over 99.2%). The extremely fine particles in QP mean that it has a particularly large specific surface area, which acts as filler in the concrete, increase the density of the particles and the cement paste in general, and also homogenize the cement paste, thus enhancing the mechanical properties of the concrete. Furthermore, these particles react with calcium hydroxide when added to the cement paste, resulting in the production of calcium silicate hydrates. Because surface area is the most important

attribute of the particles in QP, they must be finer than 5 microns in order to serve as a pozzolan in concrete. The quartz powder also requires an autoclave cure of over 85°C in order to react as a pozzolan (Courtial et al, 2013). The use of quartz sandstone as a replacement for coarse aggregate and fine powders (quartz sand) as a replacement for fine aggregate has increased in recent years. These replacements have served to produce ultra-high performance concrete, especially reactive powder concrete, and high-strength concrete.

2.3 Replacement of Coarse Aggregate

Despite being highly resistant to chemical and physical weathering, Quartz is practically of no use. Found in sandstones, it can be used to partially replace aggregate in cement concrete while avoiding any adverse effects on the strength of the concrete. The generation of sandstone waste is particularly high in countries such as India, where Rajasthan is singularly responsible for about 900 million tons of sandstone waste. This waste is subsequently dumped without being used. In response to this, a study Courtial et al (2013) investigated ways through which these sandstone wastes could be used in concrete production so as to mitigate massive dumping, and also reduce the use of natural aggregates.

Courtial et al (2013) investigated how the use of superplasticizer, silica fume, and crushed quartz in different percentages affected the properties of ultra-high-performance concrete (UHPC). He found that the use of 25% crushed quartz to replace coarse aggregate enhanced practically all the properties of UHPC, including flexural and compressive strength, but more than 25% quartz that doesn't have an efficient effect. This is attributed to the effect concerns the dispersion of quartz. Quartz is well dispersed in the ITZ sand grains in UHPC samples.

Using quartz sandstone as a coarse aggregate replacement in percentages ranging from 0 to 100% and water cement ratios of 0.35, 0.4, and 0.45, Kumar et al (2016) investigated how the use of quartz sandstone affected the permeability, abrasion resistance, flexural strength, and compressive strength of the concrete samples. He found that while the compressive strength of the concrete trended upwards until 55:45 (20mm:10mm) in the case of natural aggregates, the upward trend in the case of quartz sandstone persisted until 60:40 (25mm:10mm). The subsequent reduction in compressive strength after a particular gradation is attributed to a larger amount of void spaces and segregation resulting from the use of bigger aggregates.

Fine powders, such as crushed quartz (the particles of which range between 100 and 600 μm), can be used as a substitute for coarse aggregate in Reactive Powder Concrete (RPC), thereby increasing the homogeneity of the RPC (Ipek et al, 2011).

2.4 Replacement of Fine Aggregate

Arulkumaran et al (2016) investigated the effects of 0, 25, 50 and 100% quartz sand (QS) as a fine aggregate replacement and 1% superplasticizer on the flexural and compressive strength of the concrete in his mix design. He found that 50% QS increased flexural and compressive strength by 13.53% and 9.53% respectively, relative to conventional concrete mixes. Additionally, there was also a corresponding 0.31% decrease in water absorption relative to conventional mixes.

2.5 Usage in the Reactive Powder Concrete (RPC)

The components of RPC include a superplasticizer, optional steel fibers, and very fine powders (such as silica fume, quartz powder, sand, and cement). The optimal quantity of superplasticizer in the concrete mix has the effect of enhancing the workability of the concrete while simultaneously decreasing the water to cement

(w/c) ratio. It is possible to achieve a particularly dense matrix by ensuring that the granular packing of the dry fine powders is optimized.

It has been found that it is possible to enhance the compactness and homogeneity of particle sizes that increases microstructure density by incorporating quartz powder in RPC. This is so because the use of quartz powder allows for the replacement of coarse aggregates with ultra-fine powders, e.g. crushed quartz (100–600 μm) (Mostofinejad et al., 2016).

2.6 Workability of Concretes

This section explores the crucial factors affecting the workability of fresh concrete. In particular, the workability of a control sample of fresh concrete is tested relative to the concrete modified with quartz powder.

2.6.1 Description, Importance of Studying Workability of Concretes

The first definition of (concrete and mortar) workability was provided by Glanville (1947) who defined it as referring to the degree of inner work necessary to make mortars and concrete fully compact. Similarly, ASTM C125-93 defines workability as a characteristic of fresh mortars and concrete which determines the level of effort needed to handle them without any significant loss of homogeneity.

Workability is generally understood to refer to the flowability of fresh concrete and mortar. A less than optimal workability means that more time and labor is required for compaction, thus increasing the cost of the job. Conversely, a higher than normal flowability can result in level segregation, thus decreasing the overall strength of the concrete (Neville, 1995).

An important contributor to the degree of workability is the amount of water contained in the concrete mix. While increasing the amount of water enhances workability, it adversely affects the strength of the hardened concrete due to the micro cracks that result when surplus water evaporates. Consequently, the optimal workability test is one that provides an adequate balance between workability and strength. To this end, it is possible to dominate the internal abrasion between the individual particles in the concrete (Neville, 1995).

2.6.2 Influence of Quartz Powder on Workability of Concretes

In investigating how different percentages of quartz powder (10, 20 and 30%) and particles of different sizes (from 10 μm to 120 μm) affect alkali activated slag cement (AASC), Yuan et al (2013) found that the increased use of quartz powder as a replacement for slag powder consistently decreased the amount of water required of the AASC. Furthermore, the water requirement decreases the finer the quartz powder. The reason for the reduction in the amount of water required in this replacement is that quartz powder does not consume water for reaction when mixed as in the case of slag powder because the former is inactive in an alkali solution.

Collins & Sanjayan (1999) investigated the impact of ultra-fine materials on concrete workability when alkali-activated slag (AAS) is used as the binder for the concrete. He found that using 10% ultra-fine fly ash in partially replacing the slag noticeably enhances the workability of the concrete.

According to Rashad (2014), the appropriate ratio of slag to QP significantly improves workability even in the absence of an admixture in AAS mixtures. Furthermore, he also found that the combination of blended slag with high levels of

QP (up to 30%) also has an approximately 3.5 times higher workability relative to mixtures without QP.

Rashad & Ouda (2016) also investigated the modification of alkali activated fly ash (AAFA) through the addition of QP. He found that workability could be enhanced by increasing the percentage of quarts from 5% to 30%, as opposed to fly ash. The workability of mixtures containing the highest possible percentage of QP (30%) was found to be nearly twice that of mixtures with zero QP. The enhancement of workability is attributed to the ability of the QP to fill the spaces between the grains of fly ash (FA), known as particle packing. This also reduces the amount of water required for mixing but because the level of mixing water is fixed, there is a corresponding increase in workability.

In addition to improving the slump of concrete by as much as 160mm, mineral powders (MP) also enhance compressive strength and hydration. This results from the improved particle packing, which can be described as the filling the voids between the cement grains (Kjellsen & Lagerblad, 1995; Kronlöf, 1994), (Gallias et al, 2000). Consequently, it is possible to decrease the level of water required for mixing concretes using MP while maintaining a workability consistent with that of the reference mix and simultaneously enhancing compressive strength (Tikkanen et al, 2014).

While investigating the mechanical properties of concrete in which QP was used to partially replace silica fume, Nikdel (2014) found that there was a reduction in the slump (from 140 mm to 110 mm) corresponding to an increase in the QP by up to

20%. The reason for this is that the particles of the QP are relatively more water absorbent than cement particles.

2.7 Compressive Strength of Concretes

This section provides an outline of the compressive strength test of concrete in which cement has been partially replaced by different percentages of QP, water/binder ratios (w/b), and the effects of curing on concrete properties, as gathered from the extant literature.

2.7.1 Discription, and Importance of Studying Compressive Strength of Concrete

Of all the properties of concrete, compressive strength is arguably the most important as it determines the quality of the concrete (Neville, 1995). While other properties, such as permeability and durability, are similarly important, compressive strength is paramount because of its direct relation to the internal structures of both wet and dry cement paste, and its deterministic role for the overall quality of the concrete (Neville, 1987).

A number of studies have been dedicated towards investigating the compressive strength of concrete; in particular, the primary concern has been uncovering all of the factors relevant for the strength of the concrete. It has been discovered that compressive strength is affected by the age of the concrete, the curing temperature, the w/b ratio, the sizes and shapes of the aggregates, the raw materials used, the proportions of raw materials, amongst others (Ansari & Sahare, 2015).

(Kmalı & Ghahremaninezhad, 2016; Ansari & Sahare, 2015) both studied the compressive strengths of concretes integrated with varying percentages of pozzolanic

admixtures as a cement replacement. They both found that the use of these admixtures positively affected the compressive strength of the cement. Additionally, a new strand of research dedicated to reducing the cost of concrete and enhancing its practical use has also recently emerged. This strand of research explores the properties of common waste materials with a view to how these can be used to enhance the properties of concrete.

2.7.2 Influence of Quartz Powders on Compressive Strength of Concretes

A study by Yuan et al (2013) investigated the replacement of cement in alkali activated slag cement mixtures with slag powders having different percentages (10, 20, and 30%) and sizes (120, 74, 37 and 15 μm) of quartz powder. They found that higher percentages of QP corresponded to increases in the compressive strength of the mixture. The highest level of compressive strength was found to occur at a 30% QP replacement and a particle size of 74 μm particle.

Chen et al (2017) similarly studied the mechanical properties of cement pastes where cement had been replaced by varying percentages of modified quartz tailing (MQT). Quartz tailing was combined with 50% carbide slag (CS) for twenty-four hours in a concrete mixer to produce a better-distributed powder. The resulting mixture was calcined in a furnace at a temperature of 1050°C for two hours and subsequently air-cooled to room temperature to obtain MQT.

He found that the addition of MQT to a cement paste enhances its compressive strength relative to blended cement pastes with unmodified QT. This occurs due to the hydration of the β -C₂S layer formed within the particles of the MQT. The C-S-H gels produced by the hydration occupy the space between the cement matrix and the

QT particles, thus decreasing the total porosity of the cement paste and increasing its compressive strength.

Using various percentages of QP (0, 5, 10, 15, 20, 25 and 30%) in alkali activated slag (AAS) as a replacement for granulated blast furnace slag, Rashad & Zeedan (2012) found that the use of QP significantly affected both early and lateral age strength. The filler effect of the fine QP particles enhances the compressive strength of the hardened alkali-activated pastes and the QP also increases the density of the paste's structure by filling the interstitial space within the skeleton of the microstructure of the hardened pastes.

Isu et al (1995) explored the mechanical properties of autoclaved aerated concrete (AAC) with various sizes of quartz particles. It was discovered that compressive strength was improved during the autoclaving process due to tobermorite formation in samples with larger quartz particles. These coarser particles improved the compressive strength even more than fine quartz due to larger crystallite sizes and larger quantities of tobermite formed. Compressive strength was also found to be higher in samples with large residual quartz particles.

Tikkanen et al (2014) similarly found that the use of mineral powders (limestone and quartz powders) as a substitute for cement both increases slump test concrete with a constant w/c and improves compressive strength. The use of mineral powder also minimizes the quantity of cement needed for the concrete and affects the hydration of the concrete and the heat evolution in both the concrete and cement paste. The degrees of hydration in concrete where mineral powders were added was found to be higher than in the reference sample produced with just portland composite cement.

The hydration process was also accelerated following the addition of mineral powders as a result of the extra surface provided for nucleation and hydration product growth. He found that, at 28 days, the mineral powder concretes had a compressive strength 4.1 MPa higher than normal concrete.

2.7.3 Influence of Different Curing Temperatures and Pressure on Compressive Strength of Concretes

Temperature is an essential factor in cementitious material hydration. Weather changes, curing, and the heat of hydration can alter the temperature of concrete. Higher temperatures accelerate pozzolanic activity and increase the hydration rate, as well as alter the density and form of hydration products (Elkhadiri et al, 2009). In some cases, however, it can adversely affect the overall strength of the concrete and even make it more permeable, due to the fact that higher temperatures lead to higher levels of drying shrinkage and internal cracks (Chini et al, 2003).

Concrete curing is defined as the process of promoting cement hydration through the provision of the adequate temperature and moisture for the concrete over a satisfactory period of time. Proper concrete curing is integral to obtaining design strength and the maximum possible durability, particularly in the case of concrete subject to intense environmental conditions at an early age (Cable et al, 2003). When done properly, curing provides a moist, warm environment conducive to the development of hydration products, thus improving microstructure density while simultaneously reducing the porosity of the hydrated cement paste (Safiuddin et al, 2007). According to Zain et al (2000), when done at an appropriate temperature and moisture level, proper curing simultaneously enhances cement paste hydration and decreases the number of pores.

Isu et al (1995) studied the mechanical properties of autoclaved aerated concrete (AAC) with various sizes of quartz particles (fine and coarse). The samples were prepared using saturated steam pressure at a temperature of 180°C for different times ranging between 5 and 64 hours. He found that coarser quartz samples improved compressive strength, the formation of tuberosity, and fracture energy relative to finer quartz.

The microstructure of the hardened concrete is improved by different curing conditions, such as autoclave, steam, heat, and standard water curing, as they create more hydration product (C-S-H layers), thus promoting hydration and pozzolanic reaction (Mostofinejad et al, 2016). Helmi et al (2016) investigated how the properties of reactive powder concrete (RPC) were affected by pressure/heating. He found that both pozzolanic and hydration reactions were accelerated by the pressure caused by the heat curing treatment (heat curing at 240°C for 48 hours and a static pressure of 8 MP). Furthermore, compressive strength was also improved due to the decreased porosity and increased skeletal density.

Cwirzen (2007) investigated how the properties of reactive powder concrete were affected by a heat-treatment regime. He found that an increase in the heating time corresponded to an increase in the degree of hydration, as well as a refinement of the microstructure and an ultimately higher compressive strength. Applying the heat treatment either too early or too late, however, reduced both the degree of hydration and the amount by which compressive strength was improved.

It has been suggested by the likes of Richard & Cheyrezy (1995) and Sadrekarimi (2004) that combining heat and pressure curing can altogether improve the strength

of the concrete relative to just heat treatment. This is so because when added, pressure treatment decreases the porosity and increases the density of fresh concrete.

When combining heat and pressure curing, compressive strength can be improved even further through the application of heat treatment by static pressing. The increased strength is due to the formation of xonotlite/tobermorite due to the pozzolanic reaction, which is responsible for pore-filling and the enhancement of the paste-aggregate bonding mechanism (Helmi et al, 2016).

Ipek et al (2011) used crushed quartz (100–600 μm) rather than coarse aggregate in investigating how the mechanical behavior of reactive powder concrete (RPC) is affected by the application of pre-setting pressure. He found that the compressive strength of the concrete doubled when the curing heat is increased from 25 to 90 °C and the pre-setting pressure is increased from 25 to 100 MPa. Two factors are responsible for this increase: first, the heat cure process of RPC continued for a prolonged period of time, thus increasing the pozzolanic activates and the compressive strength as a result; second, a 25 MPa pre-setting pressure was sufficient enough to allow the passage of free water and large air spaces in samples. The increment of particular gravity values allows for a reduction in the permeability of pre-setting pressurized samples. This also makes the samples more durable, which is of particular importance for elements continuously exposed to outside factors. While the maximum compressive strength of 475 MPa occurred at a pre-setting pressure of 100 MPa, 25 MPa remained more appropriate in terms of applicability.

2.7.4 Influence of Different w/b Ratios on Compressive Strength of Concrete

The water/binder or water/cement ratio is an extremely important aspect of concrete as it is highly influential for the compressive strength of the mixture, as well as its workability. Consequently, particular attention must be paid to the amount of water contained in a cement-based mixture. In terms of hydration, w/c ratios below 24% decrease compressive strength and do not contain a sufficient amount of water to complete hydration. This is based on stoichiometric calculations, which demonstrate that 0.24 g of water is needed to completely hydrate 1 gram of cement (Larrard, 1999).

Lower w/c ratios in concrete or mortar also cause autogenous shrinkage, which leads to loading-independent cracks within the first few days of casting, thus decreasing compressive strength. Similarly, higher than normal w/b ratios can result in segregation when the concrete is being put in place, and also decrease the strength of the concrete as aggregates settle in the base (Paillère et al, 1989).

Because water requirement is particularly important in the case of fine minerals, a good strategy is to incorporate admixture in the concrete. As a result, the primary parameter used in measuring the amount of water required is the specific surface area of the admixture. The structure and shapes of the particles are similarly important for the water requirement. Irregularly-shaped particles, for example, require twice as a much water as regular particles due to their lessened structural density. Irregularly-shaped particles also require more water than rounded and angular quartz particles due to the latter's rougher surfaces, which decreases friction. The use of such rounded and angular particles in a cement paste improves the compressive strength of the hardened concrete and also increases its density (Gallias, 2000) Mineral

powder also affects the concrete hydration process. Previous studies by (Guang et al, 2007) and (Péra et al, 1999) found that the hydration process was accelerated by the addition of these minerals due to their surfaces acting as a nucleation site and an increase in hydration products.

Using different percentages 10, 20, 30 and 40% of mineral powders (quartz powder and limestone) as a cement replacement with w/c ratios ranging from 0.33 - 0.69, Tikkanen et al (2011) found that the addition of mineral powder corresponded to an increase in the level of hydration relative to the reference concrete, which was without any mineral additives. The compressive strength of the cement paste with 10 or 20% mineral powder replacement has become almost identical to that of the reference cement paste within 28 days. Furthermore, even with the reduction in the amount of portland cement contained in the cement paste, the 10 and 20% mineral powder replacement pastes still had strength values and hydrates almost identical to the reference paste. This is due, in part, to the additional space for the creation of hydration products generated by the increased w/c ratio that results when mineral powder is used to replace cement. It also appears that limestone is partially incorporated into the C-S-H and aluminate phases when hydration occurs at a higher w/c ration as evidenced by the reduced CaCO_3 level.

An additive or filler is a material with fineness similar to portland cement. Its unique physical properties allow to positively affecting concrete in terms of the tendency for cracks, capillary bleeding, permeability, density, and workability. Evidence of these effects has been found in the case of concrete containing mineral powders, titanium dioxide, and fly ash particles less than 1 μm in size. The structure of the hydrated cement paste is also enhanced by the incorporation of CaCO_3 into the C-S-H phase

(Neville 1987). Additionally, lower w/c ratios have been known to have higher amounts of mineral powder and a greater degree of heat resulting from hydration as a result.

2.8 Flexural Strength

This section explores the significance of concrete tensile strength and how different quantities of quartz powder have been known to affect the flexural strength of concrete.

2.8.1 Importance of Studying the Flexural Strength of Concrete

The goal of using concrete in a structure is to increase its compressive stress endurance and tension resistance. The tensile strength of a concrete structure can be modified using steel bars. To prevent dams, runways, or pavements made of concrete from cracking due to shear forces, it is imperative that the concrete is adequately resistant to tension stresses. As such, engineers should remain particularly concerned with investigating how concrete tensile strength is affected by a variety of conditions and parameters (Neville, 1995). A number of standard tests, direct and indirect, can be conducted for the purpose of measuring the tensile strength of cementitious mixtures. Because there is typically some difficulty and a high degree of complexity in deriving direct measurements of the tensile strength of either mortar or concrete, researchers usually resort to splitting, bending, and other indirect tests. One such indirect test is the three-point bending test through which it is possible to measure and investigate the factors affect tensile strength (Neville, 1987).

2.8.2 Influence of Quartz Powder on Flexural Strength of Concretes

Yuan et al (2013) investigated how alkali activated slag cement (AASC) was affected by the replacement of slag powder with different percentages of QP (10, 20, and 30%). He concluded that the control AASC sample had a relatively smooth

fracture section with small particles. Relative to the control sample, the AASC samples incorporated with QP tend to be less smooth and have larger particles – larger quartz particle sizes result in rougher sections. A rough fracture section results in a much more complex crack path when subject to flexural load, which absorbs the extra energy and increases the toughness and flexural strength of the concrete. Overall, therefore, it can be concluded that the toughness of AASC is positively increased through the replacement of slag powder with a suitable quantity and fineness of quartz powder.

Results obtained by Isu (1995) show that the replacement of a coarse aggregate with varying sizes of quartz sand (4.3 μm , 7.5 μm , 12.4 μm and 32.3 μm) in autoclaved aerated concrete (AAC) enhanced both its fracture energy and its resistance to crack growth. This is due to the fact that the use of coarse quartz as a starting material results in the formation of more tobermorite and larger crystallite sizes. The fracture toughness and compressive strength of samples with larger residual quartz particles was also found to be higher than those without.

2.9 Splitting Tensile Strength of Concrete

This section provides an outline of concrete tensile strength and how it is affected by the addition of QP in different percentages.

2.9.1 Importance of Studying the Tensile Strength of Concrete

The tensile strength of concrete refers to the most tensile stress (load) the concrete can handle before it fails and is one of the most important basic mechanical properties. The brittle nature of concrete is generally understood to make it weaker in tension relative to compression. Thus, cracks tend to develop when the concrete is exposed to tensile forces and so determining the threshold after which cracks start to

develop in the concrete is particularly important. One method used in making this determination is the splitting tensile strength test, an indirect tensile strength test that usually produces better results than direct tensile strength tests.

The ASTM standard C496/C496M – 17 suggests that the splitting tensile strength test be conducted by “applying a diametral compressive force along the length of a cylindrical concrete specimen at a rate that is within a prescribed range until failure occurs”. Tensile stresses are exerted on the plain containing the applied load through this loading, while relatively high compressive stresses are exerted on the immediate surrounding area.

2.9.2 Influence of Quartz Powders on Tensile Strength of Concretes

Nikdel (2014) investigated how the properties of concrete are affected by the partial replacement of cement with silica fume (SF) and quartz powder by fixed w/c ratio. The silica fume was found to have a highest tensile strength value of 20%, which is 23% higher than that of the control sample. The increased tensile strength following the addition of SF is caused by the pozzolanic action and filling effect on the pores between cement and SF particles. Conversely, increasing the percentage of quartz powder (by 10 and 15%) was found to cause a reduction in the tensile strength (5.6 and 4% respectively), making it lower than even that of the control sample. 20% more quartz powder, however, caused a minor increase (1.3%) in the tensile strength as a result of the binding of quartz and aggregate particles.

2.10 Permeability of Concrete

The permeability of concrete made using normal aggregate is determined by how porous the cement paste is. This relationship is not direct, however, as the distribution of the pore sizes is also an important factor (Neville, 1995).

2.10.1 Description, and Importance of Studying Permeability of Concrete

Permeability is generally understood to be a function of capillary porosity, which itself is determined by the w/c ratio and the level of hydration. Furthermore, cement permeability also depends on these factors. In terms of hydration, the permeability of cement pastes with lower w/c ratios is typically lower, especially when the w/c ratio falls below 0.6 as the capillaries become discontinuous or segmented (Neville, 1987)

Porosity refers to the proportion of the concrete which is covered with pores and is usually written as a percentage (Neville, 1995). A concrete sample with a high porosity and interconnected pores would similarly have a high permeability as it facilitates fluid transport. Permeability, however, is not determined solely by porosity but is also dependent on the continuity, shape, distribution, and size of the pores.

2.10.2 Influence of Quartz Powders on Permeability of Concretes

Tam et al (2012) carried out a study on reactive powder concrete (RPC) in which fine powders like crushed quartz and quartz sand, with particle sizes ranging from 45 – 600 μm , were used to replace coarse aggregates. Results indicated that the permeability of the concrete was adversely affected by the use of quartz particles due to the increased homogeneity and density of the concrete due to the quartz's filler effect, which had the effect of making its pores discontinuous and reducing its porosity overall.

Nikdel (2014) similarly found that the permeability of cement is decreased though the incremental replacement of cement with quartz powder as the spaces between these ultra-fine particles and cement particles become filled, thus decreasing water penetration and increasing the homogeneity of the cement paste even under pressure.

2.10.3 Factors Influence Permeability of Concrete

2.10.3.1 Improvement of Hydration

Cement paste permeability differs depending on the level of hydration (Neville, 1995). The further along the cement paste is in the hydration process, the more rapidly the permeability decreases. This is because the aggregate gel volume (including pores) is twice the volume of unhydrated cement, causing the gel to slowly fill up some of the spaces originally filled by water. The permeability of a mature past is determined by whether or not the capillaries are discontinuous, as well as the cement properties, w/c ratio, shape, size and concentration of gel particles (Powers et al, 1959)

2.10.3.2 Water/Cement Ratio (w/c)

Lower w/c ratios in concrete or cement pastes lead to lowered permeability. For example, lowering the w/c ratio of a cement paste to 0.3 from 0.7 would cause a corresponding decrease in its permeability coefficient by 3 orders of magnitude (Powers et al, 1954). Whiting (1988) similarly found that lowering the w/c ratio to 0.26 from 0.75 will result in a corresponding four-fold decrease in permeability.

2.10.3.3 Properties of Cement

Cement properties also exert an effect on the permeability of concrete. Keeping the w/c ratios constant, finer cement has been found to produce a softer and less porous cement paste relative to coarse cement (Tam et al, 2012)

2.11 Chloride Resistance of Concrete

This section outlines the definitions and importance of cementitious material chloride resistance and the rapid chloride permeability test. It also presents the effects of varying percentages of quartz powder as discovered by past studies.

2.11.1 Importance, and Evaluation of Chloride Resistance of Concretes

The ASTM C 1202–08 test serves as the basis for the rapid chloride resistance test, which is used to determine the level of electric charge that passes through cylindrical specimen with a diameter of 100 mm over a period of 6 hours. The amount of electric charge determines the resistance of the concretes to chloride ion penetration.

A number of researchers have investigated the relationship between this phenomenon and other parameters, including curing conditions, concrete microstructure, and raw materials. It has been found that chloride resistance is affected by a number of factors, including the kind of admixture, w/c ratio, air content, aggregate type, and cement type.

Used primarily as accelerators, most admixtures contain ionic salts, such as Calcium Chloride, Calcium Nitrite, Sodium Thiocyanate, and Calcium Nitrate, which with the help of ionic salts, allow a higher percentage of charge to pass even when permeability is kept constant (Ansari & Sahare, 2015; Lothenbach et al, 2007; Aydın & Baradan, 2007; Grace, 2006).

While this test is generally used to measure the resistance of concrete or mortar to ion penetration as opposed to permeability, it has been discovered that there is some degree of overlap between ion resistance and permeability in concrete (Grace, 2006).

2.11.2 Influence of Quartz Powder on Chloride Resistance of Concretes

A study conducted by Mohseni et al (2017) investigated the properties of concrete in which cement and sand (fine aggregate) had partially been replaced by zeolite (from Iran's volcanic northern region) and tuff respectively. He made concrete using different percentages of zeolite (10 and 15%), as well as different percentages of tuff

(5, 10 and 15%). Results indicated that the use of zeolite and tuff significantly increased the resistance of the specimen to chloride. In terms of chloride diffusion, the optimal distribution was found to be a 10% replacement of cement with zeolite and a 15% replacement of sand with tuff.

It is noteworthy that the pozzolanic activity in zeolite is attributed to the high levels of SiO_2 and Al_2O_3 it contains and its crystalline structures.

Najmi et al (2008) investigated the durability of concrete in the presence of natural pozzolans and found that while the improvement of chloride ion permeability was only minimal, there were significant improvements in alkali reactivity, expansion caused by alkali-silica reaction, and water penetration depth.

2.12 Water Absorption Capacity

In this section, researches on the water absorption capacity of concrete with different percentages of quartz powders are explained.

2.12.1 Importance of Studying Water Absorption Capacity of Concrete

An ASTM C642–13 test revealed that the absorption of water by oven-dried concrete specimens was increased following their immersion in water for a predetermined period of time. Water absorption is an important characteristic of quality concrete as it is useful in predicting other properties, such as compressive strength, permeability, and sulfate attack resistance as a test of durability.

The ability of concrete to absorb water is also affected by a number of factors, including environmental condition, mix proportions, the volume of admixtures and aggregate, relative humidity, w/c ratio, and the component materials in general (Castro et al, 2011).

2.12.2 Influence of Quartz Powders on Water Absorption Capacity of Concretes

Zhang & Zong (2014) illustrated that surface water absorption of concrete is significantly affected by the curing condition as different curing conditions result in different microstructures. Consequently, internal water absorption was lower than surface water absorption for all the specimens due to the quick water loss the concrete sustained during curing.

Also, Zhang & Zong (2014) found that there was no obvious correlation between internal and surface water absorption on the one hand, and compressive strength on the other, thus indicating that water absorption is not a sufficient measure of strength. Permeability is primarily dependent on and correlates strongly with the surface water absorption of concrete. In contrast, there was virtually no correlation between permeability and internal water absorption. The higher the level of water absorption, the less resistant the concrete is to sulfate attack; a linear relationship exists between sulfate attack resistance and surface water absorption.

2.13 High Temperature Resistance Concrete

This section provides an overview of the extant literature on the residual compressive strength of concrete with different proportions of quartz powder and exposed to high temperatures.

2.13.1 Importance of Studying the Concretes Subjected to High Temperature

The occurrence of building, drilling platform structure, and tunnel fires has been the primary reason for the increased interest in how concrete behaves when it is exposed to high temperatures. Temperatures in building fires can reach highs of 1100°C or

even 1350°C in tunnels, resulting in irreparable damage to the concrete structure (Neville, 1995).

Contemporary developments in the technology behind pre-stressed and reinforced concrete structures have been instrumental in enhancing the strength and durability of concrete. Regardless, numerous concrete structures become defunct after they have been exposed to a fire (Cioni et al, 2001). It is known that fires cause such high temperatures that they adversely affect the durability and strength of concrete structures. The resistance of concrete to a fire is determined by its moisture content, the size of its member structures, the kinds of cement and aggregate used, and the duration and temperature of the fire (Phan et al, 2001; Diederchs & Schneider, 1981; Noumowe et al, 1994). Although aggregates typically have a high fire resistance, uneven high temperatures and cooling the aggregate by spraying water can cause the internal pressure to build up and eventually cause the aggregate to spall. The expansion of cement is partly responsible for some concrete deformation. There is a significant amount of calcium hydroxide in portland cement that, following water loss at temperatures around 400-450°C, decomposes into calcium oxide. While wetting this calcium oxide transforms it back to calcium hydroxide, the change in volume can cause the concrete to crumble (Malhotra, 1956; Akoz et al, 1995).

Concrete is known to be particularly resistant to fires and high temperatures in general due to its similarly high specific heat and low thermal conductivity (Arioz, 2007). Regardless, it is still affected by high temperatures, which have the capacity to alter its appearance, density, elasticity, compressive strength, and color (Morsy et al, 2009). It is for this reason that a number of researchers remain concerned with enhance the resistance of concrete to fire. This line of research has already identified

some ways through which the fire resistance of concrete can be improved, such as adding polypropylene fibers to the concrete mix (Xiao & Falkner, 2006), the use of admixtures and the replacement of cement with pozzolanic materials (Demirboga et al, 2007). Overall, the main contributors to thermal resistance are aggregates (Shetty, 2005). Even as it is known that the resistance of concrete to fire and high temperatures depends, to a large extent, on its constituent materials (especially pozzolans), the effects of QP on concrete fire resistance remain under researched.

2.13.2 Influence of Quartz Powders on High Resistance Concretes

According to Neville (1987), temperatures of up to 250°C decrease the strength of hydrated hardened concrete and generally affect the properties of concrete negatively (Ca(OH)_2). Temperatures of around 400°C lead to water loss and cause Ca(OH)_2 to decompose into CaO. The introduction of wet air to the calcium oxide both expands its volume and rehydrates it to Ca(OH)_2 , causing the concrete to decompose.

Moersy et al (2010) investigated the effects of replacing cement with different percentages (0, 10, 15 and 20%) of silica flour and at different temperatures (100, 200, 400, 600 and 800°C) on the mechanical properties of concrete. Results indicated that adding 20% silica flour significantly improved the performance of the blended concrete when subject to temperatures as high as 400°C. The compressive strength of the concrete was also increased between 100 and 400°C relative to the control concrete, primarily as a result of the hydrothermal interaction of the silica flour particles due to the higher temperatures and the free lime liberated over the course of the hydration reaction. Additionally, the pozzolonic reaction also contributed to this increase as it increased the volume of hydration products. As such, the decreased compressive strength of the blended concrete with 5, 10, 15 and 20% silica flour at

temperatures in excess of 400°C is attributed to the thermal stress created around the cracks, which in turn lead to microcracks.

Hossain et al (2006) investigated how resistant cement mortar with different percentages of fly ash (30, 40, 50, 60 and 70%) is to fire. The samples were exposed to heat at different temperatures (25, 50, 100, 200, 400 and 600°C) for one hour, after which they were cooled at room temperature for another 24 hours. Results indicated that the compressive strength of the cement with 50% fly ash initially experienced an incremental increase up until 200°C, after which it began to decline as the temperature increased.

Terro (2006) investigated the effects of exposure to high temperatures on the properties of concrete made using recycled crushed glass as a replacement for fine and coarse aggregate. Results indicated that higher temperatures corresponded to a reduction in the concrete's compressive strength. The compressive strength of the control mix, however, was consistently lower than that of the 10% coarse waste glass (CWG), fine waste glass (FWG), and fine and coarse waste glass (FCWG) at temperatures up to 700°C.

Furthermore, the replacement of aggregates at high percentages of FCWG had a negative effect on the compressive strength of the concrete at high temperatures. This is due to the lower initial strength of the FCWG concrete, which is caused by a lack of cohesion between the cement matrix and the coarse and fine aggregates.

The compressive strength of the control concrete, however, was slightly higher than that of the concretes with glass aggregates at ambient temperatures. This is due to

dissipation of the water retained in the mix at high temperatures, which occurs more readily in glass mixes as a result of the non-water-absorbent nature of glass. As a result, concrete mixes made with waste glass become more compact once his water evaporates at about 150°C.

Sudarshan & Vyas (2017) investigated the mechanical properties of concrete containing marble waste as a replacement for coarse aggregate at various temperatures (200, 400, 600 and 800°C). The marble waste was initially crushed to the gradation of a coarse aggregate and subsequently combined (75%) with either quartzite or conventional aggregate (25%). By increasing the temperature, he found that there was a reduction in compressive strength due to the break up of siliceous aggregates at a temperature of approximately 350°C. A further increase in temperature between 460°C and 540°C causes the portlandite to decompose and leads to the formation of CaO as evidenced by the whitish patches that begin to appear. The aggregates begin to display some physical changes at 573°C and a further reduction in compressive strength occurs due to the second phase in the decomposition of C-S-H. Overall, however, the compressive strength of the marble waste concrete remained marginally higher than conventional concrete at 600°C.

Tufail et al (2017) similarly investigated the effects of high temperatures (between 100°C and 700°C) on the mechanical properties of concrete in which coarse aggregates had been replaced by granite particles, limestone, and quartzite. He found that increases in temperature decreased the compressive strengths of all samples, although quartzite and limestone concretes had lower compressive strengths relative to granite concrete. Limestone and granite had the highest and lowest abrasion and impact-related losses, which serves to show that they have the lowest and highest

compressive strengths, respectively. This is due to the differences in the shapes of their aggregates and mineral compositions, with limestone primarily consisting of calcite and quartzite of quartz. When exposed to temperatures ranging between 300-600°C, significant damages were observed in terms of internal defects, such as transgranular fractures, cracks, and micropores. This observation is consistent with that of Chen et al. (2009), who found microcracks in limestone, and clear cracks and fractures when it was heated up to 300°C and 500°C respectively.

Zhang (2011) investigated how the weight loss affected the residual compressive strength of high performance concrete, which had been exposed to different heating temperatures at different exposure times (4, 8 and 16 hours). There was a consistently higher weight loss as the temperature increased, although, a longer exposure time made the chance of a hygric equilibrium state more likely, particularly for lower heating temperatures. Results indicated that an exposure time of 8 hours was sufficient for temperatures above 300°C, while lower heating temperatures required an exposure of about 16 hours to reach hygric equilibrium.

He also found that the relationship between weight loss and residual compressive existed on two stages. In the first, the evaporating capillary water negatively affected the concrete strength only slightly, while chemically combined and gel water evaporation in the second stage significantly reduced the strength of the concrete.

Adefemi et al (2013) investigated how the fire resistance of conventional portland cement was affected by the use of carbide waste (CW) at different percentages (5, 10, 15, 20, 25 and 30%) and different temperatures (200, 300, 400, 600, 500 and 800°C) for 2 hours. CW is a type of admixture with a whitish color and is a bye-

produce of oxy-acetylene gas used in welding. Results indicate that a 10% CW replacement enhanced the resistance of the concrete to temperatures up to 800°C by 14%, relative to ordinary portland cement. While the compressive strength of the control sample began to decline at 300°C, the CW concrete did not start to experience a reduced compressive strength till about 500°C, although it subsequently decreased up to 800°C. The increased compressive strength is, in part, attributed to the additional CAH and CSH produced from the reaction of the admixture (CW) with the free lime, which is then deposited in the pore system. On the other hand, the lesser Ca(OH)₂ content in the CW concrete also contributed to the relative increase in compressive strength. Fire resistance is known to be improved by higher quantities of lower crystal-like Ca(OH)₂ and gel-like hydration products in the cement matrix (Neville, 1987). Conversely, reductions in fire resistance are attributed to high temperatures and the consequent dehydration of Ca(OH)₂ around 600°C, which produces both H₂O and CaO. At temperatures above 700°C, losses in terms of compressive strength are primarily the result of the dissociation of calcium carbonate and subsequent loss of CO₂ from CaCO₃. Regardless, the reductions in the compressive strengths of the CW concretes are still smaller in comparison to that of the control sample, thus contributing to a reduced Ca(OH)₂ content since the reaction of the admixture consumes the free lime available for the formation of Ca(OH)₂ and makes its carbonation to CaCO₃ easier (Shetty, 2005).

Chapter 3

EXPERIMENTAL WORK

3.1 Introduction

In this thesis, the concrete mixes were composed of blast-furnace slag cement, quartz powder QP, crushed limestone (fine and coarse) aggregates and high range water reducing admixture (superplasticizer). In order to obtain the objectives of the study, fifteen different mixes were prepared to produce specimens by replacing five different percentages (0, 10, 20, 30 and 40%) of quartz powder (QP) for each of the three-characteristic strength (C20/25, C35/45 and C50/60). In this study, 90 cubic specimens for compressive strength test at 28 and 56 days of curing age, 90 beam specimens for flexural strength test at 28 and 56 days, 90 cylindrical specimens for splitting tensile strength test at 28 and 56 days, 15 cylindrical specimens for chloride ion penetration test at 56 days, 45 cylindrical specimens for water absorption test at 56 days, and 45 cylindrical specimens for heat resistance test at 56 days of curing were prepared. The major aim was to specify the influence of QP combined with different characteristic strength on physical and mechanical properties of concrete. For this purpose, various tests have been done, namely: slump test, compressive strength test, flexural strength test, splitting tensile strength test, chloride ion penetration test, water absorption capacity test, and heat resistance test.

This chapter explains the materials and concrete mixes which were used in the above experiments. Also, preparation of materials and testing methods according to ASTM standard or other standards that was used in test procedures.

3.2 Materials Used

In this section, the materials that used in tests are explained in the below:

3.2.1 Cement

CEM II Portland slag cement of 32.5 grade made from of Bogaz (Endusteri and Madencilik) cement factory in North Cyprus. This kind cement has a suitable resistance to sulfate attack in concretes and produce by European standards. The chemical and physical analysis this cement as show in Table 3.1:

Table 3.1: Chemical and Physical Analysis of Cement 32.5

Portland Composite Cement (CEM II/B-M (S-L) 32,5 R)				
PROPERTIES		Analysis Results	Methods	
Chemical Analysis	Insoluble Residue (%)		0.10	
	Loss on ignition (%)		10.88	
	SO ₃ (%)		2.24	
	SiO ₂ (%)		18.72	
	CaO (%)		60.44	
	CaO free (%)		1.00	
	MgO (%)		2.00	
	Al ₂ O ₃ (%)		4.04	
	Fe ₂ O ₃ (%)		2.56	
	Cl (%)		0.00	EN 196-21
PROPERTIES			Methods	
Physical Analysis	Specific Gravity (g/cm ³)		3.00	
	Fineness: specific surface (cm ² /g)		4007	
	90 Micron Sieve Residue (%)		0.26	
	45 Micron Sieve Residue (%)		5.24	
	Water/Cement Ratio (%)		28.00	
	Initial Setting Time (minutes)		185	
	Pressure Strengths (MPa)	2 days	15.78	EN 196-1
		7 days	29.86	
28 days		41.33		

3.2.2 Mixing Water

Natural tap water was used for production all concretes mixtures and curing specimens.

3.2.3 Fine Aggregate

Fine aggregate passing the No. 4 (4.75 mm) sieve (known as sand) was used in this thesis. Sieve analysis carried out to gain gradation according to ASTM C136M-14 and controlled with ASTM C33/C33M-16 standard which is presented in Figure 3.1.

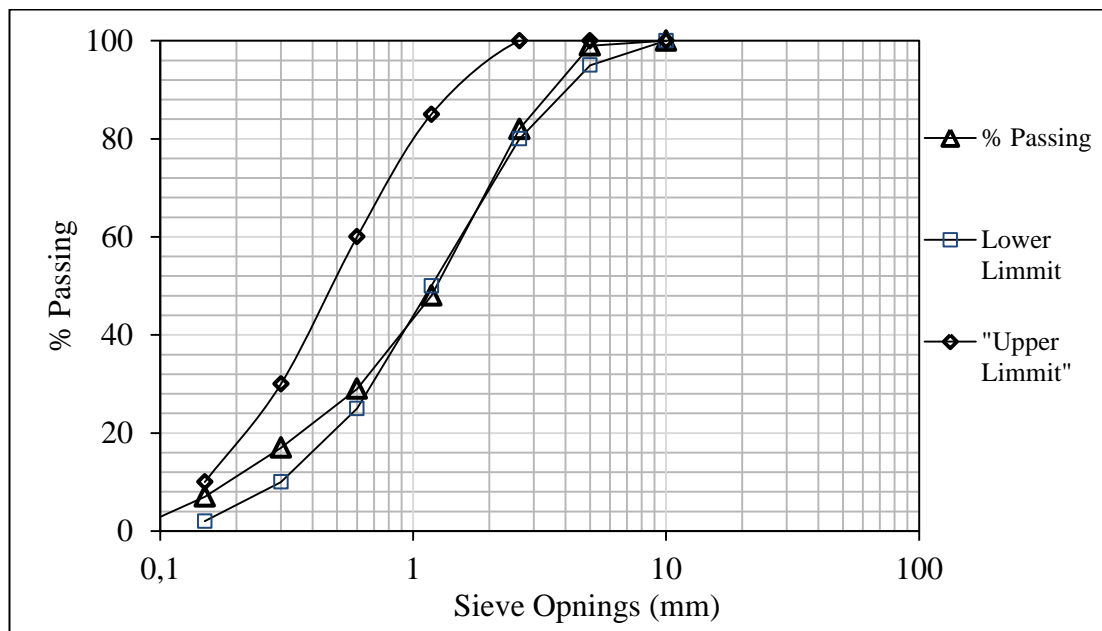


Figure 3.1: Fine Aggregates Sieve Analysis

3.2.4 Coarse Aggregates

Coarse aggregates (gravel) retained on No. 4 (4.75 mm) sieve was used in this study with three various sizes (10, 14 and 20 mm in diameter). ASTM C136M-14 was used to find out the gradation and ASTM C33M-16 was used to check whether the grading of the coarse aggregate is within standard limits (Lower and upper limits) which is illustrated in Figure 3.2.

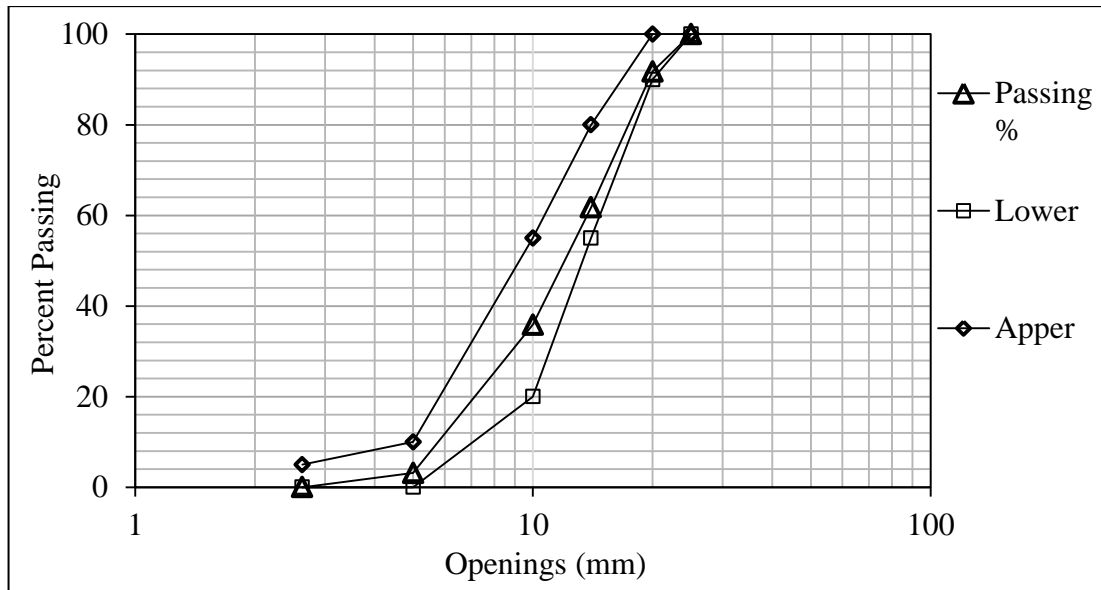


Figure 3.2: Coarse Aggregates Sieve Analysis

3.2.5 Quartz Powder

Quartz powder particle sizes less than 55 μm and high content SiO_2 used in this study. It was prepared from Aydinlar Madencilik factory in Izmir which shows in Figure 3.3.

The Chemical analysis quartz is shown in Table 3.2, particle size distribution of quartz powder according ASTM D422 – 63 (2007) is shown in Figure 3.4, and Table 3.3 is shows percent passing of quartz powder particles in hydrometer analysis.

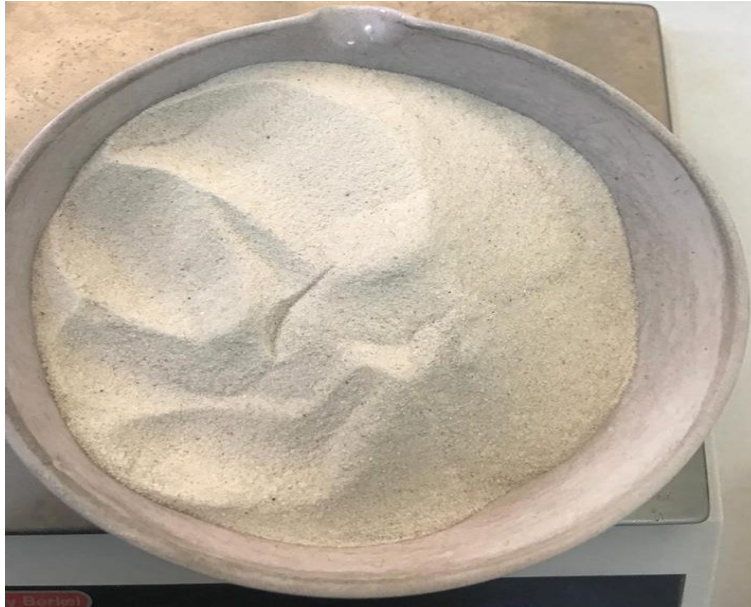


Figure 3.3: Quartz Powder

Table 3.2: Chemical Analysis of Quartz Powder

Property	Amount
SiO ₂ content	89.85%
SO ₃ content	0.25%
LOI at 975 celious degree	-0.53%
MgO content	0.0%
Fe ₂ O ₃ content	0.05%
CaO content	0.0%
Al ₂ O ₃ content	0.0%
Specific gravity	2.64
Specific surface area(cm ² /g)	5670

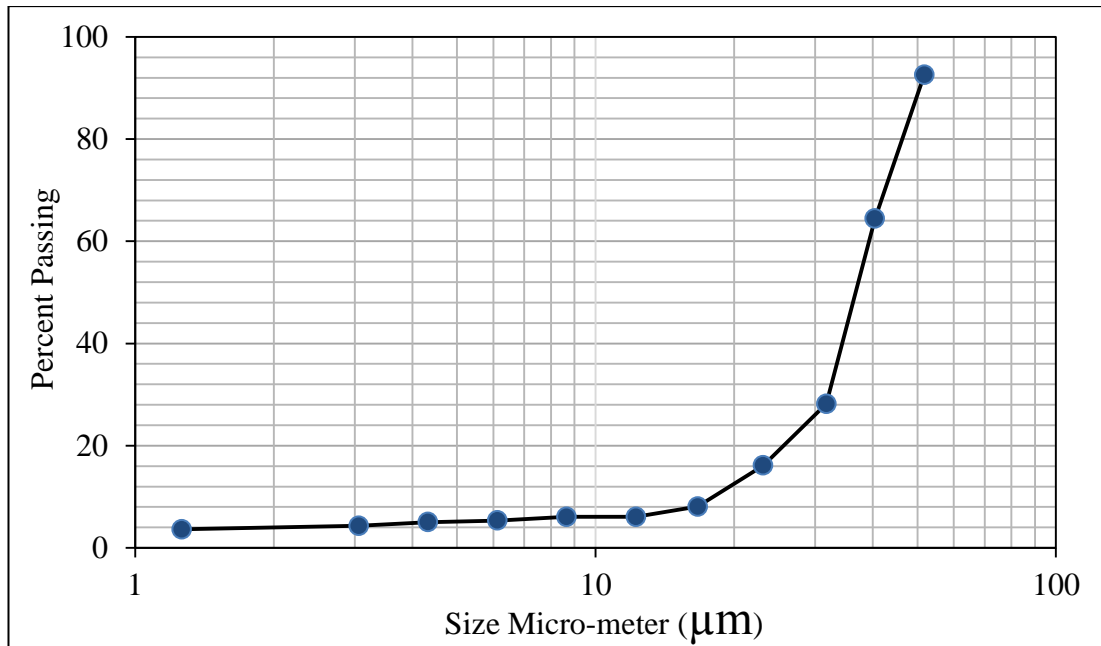


Figure 3.4: Particle Size Distribution of Quartz Powder

Table 3.3: Percent Passing of Quartz Powder Particles in Hydrometer Analysis

(%) Passing	92.58	64.41	28.19	16.12	8.07	6.06	6.06	5.34	5.02	4.30	3.63
D (µm)	51.77	40.43	31.73	23.13	16.67	12.23	8.65	6.12	4.33	3.06	1.26

3.2.6 Superplasticizer

High range water-reducing admixture (Master GLENIUM 27) was used in the experiments for only C50 concrete mixtures in order to achieve the required strength.

3.3 Mix Design

Mix design is a process of determination of suitable materials proportions to produce economical concrete which have certain strength and durability for a specific workability as possible. Tables 3.4, 3.5 and 3.6 illustrated this thesis mix designs.

For control groups (0% QP) without cement replacement the mix design proportions were as in the following:

- For C20/25 the proportions were 1:2.76:2.76 for cement sand and gravel respectively.
- For C35/45 the proportions were 1:1.77:2.0 for cement sand and gravel respectively.
- For C50/60 the proportions were 1:1.1:1.45 for cement sand and gravel respectively.

Table 3.4 Table 3.5 and Table 3.6 list the (mixing design) proportions of three different characteristics strength for this study. With these mixing proportions, the compressive strength of concrete is approximately 20 MPa and 35 MPa for normal strength concrete and 50 MPa at 28 days after casting with curing.

Table 3.4: Proportions of Mixing Materials for C20/25 Concrete Mixes

Concrete Type	QP (%)	C (kg/m ³)	QP (kg/m ³)	W (kg/m ³)	FA (kg/m ³)	CA (kg/m ³)	SP. (kg/m ³)
Control	0	330	0	225	912	913	0
QP10	10	297	33	225	912	913	0
QP20	20	264	66	225	912	913	0
QP30	30	234	99	225	912	913	0
QP40	40	198	132	225	912	913	0

QP: Quartz Powder; C: Cement; W: Water; FA: Fine Aggregate; CA: Coarse Aggregate;

Sp: Super plasticizer.

Table 3.5: Proportions of Mixing Materials for C35/45 Concrete Mixes

Concrete Type	QP (%)	C (kg/m ³)	QP (kg/m ³)	W (kg/m ³)	FA (kg/m ³)	CA (kg/m ³)	SP. (kg/m ³)
Control	0	450	0	225	796	899	0
QP10	10	405	45	225	796	899	0
QP20	20	360	90	225	796	899	0
QP30	30	315	135	225	796	899	0
QP40	40	270	180	225	796	899	0

QP: Quartz Powder; C: Cement; W: Water; FA: Fine Aggregate; CA: Coarse Aggregate;

Sp: Super plasticizer.

Table 3.6: Proportions of Mixing Materials for C50/60 Concrete Mixes

Concrete Type	QP (%)	C (kg/m ³)	QP (kg/m ³)	W (kg/m ³)	FA (kg/m ³)	CA (kg/m ³)	SP. (kg/m ³)
Control	0	600	0	225	680	865	0.5
QP10	10	540	60	225	680	865	0.5
QP20	20	480	120	225	680	865	0.5
QP30	30	420	180	225	680	865	0.5
QP40	40	360	240	225	680	865	0.5

QP: Quartz Powder; C: Cement; W: Water; FA: Fine Aggregate; CA: Coarse Aggregate;

SP: Super plasticizer.

3.4 Experimental Method

3.4.1 Mixing, Casting, and Curing

In this thesis, in order to produce nearly the same specimen properties, all specimens followed the same procedures for material mixing.

All required materials as mentioned and defined in previous section were mixed by a rotary mixer. Before the concrete was poured to molds, they were prepared and lubricated with oil. The mixing procedures were firstly, half of coarse and fine

aggregates were put into the mixer and dry mixed for 30 seconds. Then, the cement and QP were added and mixed for 30 seconds more, after that, another half of fine and coarse aggregates were put into the mixer and dry mixed for 60 seconds more. Secondly, mixed water with superplasticizer was added to the mixer and mixed for at least 2 minutes until a homogeneous mixture was achieved.

After mixing, the ready mixed concrete was casted into molds. For casting, table vibrator was used to compact the specimens. After casting, all specimens left and put in the curing room with a comparative humidity of 99% as shown in Figure 3.5. After twenty-four hours the specimens were demolded. Then immediately the specimens were left in the curing water tank with natural temperature close to 25°C, for 28, and 56 days till ready to testing day.



Figure 3.5: Different Types of Specimens in Curing Room Used in This Research.

3.5 Fresh Concrete Slump Test

For determining the influence of five various percentages of QP (0, 10, 20, 30 and 40%) on workability of fresh concrete as a cement replacement material for three different concrete characteristic strengths C20/25, C35/45 and C50/60, the slump test and mixing procedure performed as a Figure 3.6. The procedures and method were used followed to (ASTM C143/C143M 15a) standard test method for determining the workability of the concrete.



Figure 3.6: Concrete Slump Test

3.6 Testing of Hardened Concrete

In order to determine the effect of QP on mechanical and physical properties of hardened concrete the following experiments were done.

3.6.1 Compressive Strength

This test presented to determine the compressive strength of concrete at 28 and 56 days. To measure the influence of partial cement replacement by QP for three

different characteristic strength (C20/25, C35/45 and C50/60) on the compressive strength, the cube specimens with (150 x 150 x 150 mm) in dimensions were made according to BSEN 12390-3. For each characteristics strength three samples with each different amount of QP were prepared.

3.6.2 Flexural Strength

The effect of QP as a cement replacement material on flexural tensile strength for three different characteristics strength C20/25, C35/45 and C50/60 was investigated by using beam specimens of size 100 x 100 x 500 mm. The beam specimens were prepared and tested at ages of 28 and 56 days as can be seen in Figure 3.7. The test procedure was done as stated by ASTM C78/C78M – 16 Standard Test Method for flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). Three specimens were used for testing each proportion of quartz powder.



Figure 3.7: Flexural Strength Test

3.6.3 Splitting Tensile Strength

The effects of QP as a cement replacement of concrete on tensile strength for three different characteristics strength (C20/25, C35/45 and C50/60) was investigated with cylinder specimens (100 mm diameter \times 200 mm height) and tested at age of 28 and 56 days as can be seen in Figure 3.8. The test procedures were done according to ASTM C496/C496M – 17. Three specimens were used for testing each proportion of quartz powder.

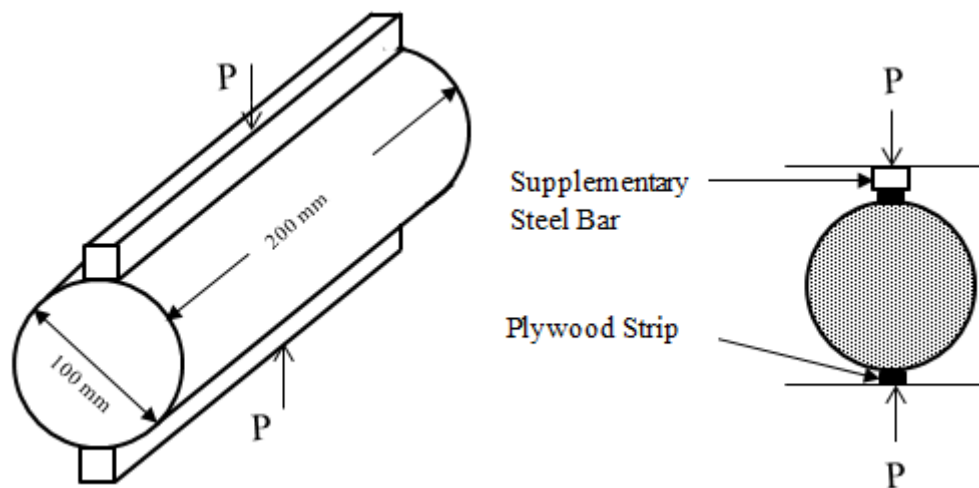


Figure 3.8: Splitting Tensile Strength Test

3.6.4 Rapid Chloride Penetration Test (RCPT)

This test method actually is used for the determination of the electrical conductance of concrete, moreover indicates the resistance to the penetration of chloride ions. ASTM C1202-08 Standard Test Method for Electrical Indication of Concretes (Ability to Resist Chloride Ion Penetration) can be used to determine the relative permeability of the concrete specimens.

The effects of QP proportion on the concrete's ability to resist chloride ion penetration for three different characteristics strength concretes was studied by the

RCPT test. The test method was done according to ASTM C 1202–08 standards. The concrete cylindrical specimens (with 100 mm diameter \times 200 mm length) were cut by a laboratory jigsaw to the size of 100 mm diameter \times 50 mm length. The concrete samples were tested at 56 days. The test procedures were done with total electrical current passing through the specimens. One side of slice submerged in sodium hydroxide and another side of slice in a solution of sodium chloride by provide 60 V dc at each end of the slices as shown in Figure 3.9. For each group, total charge passed through the concrete specimens was evaluated and compared with control group test specimens.



Figure 3.9: Rapid Chloride Penetration Test

3.6.5 Water Absorption Capacity Test

In order to evaluate water absorption capacity for specimens with five different percentages of QP for different characteristic strength (C20/25, C35/45 and C50/60), the cylinder specimens (with 100 mm diameter \times 200 mm height) were prepared.

This test was done according to ASTM C642–13. Three samples were tested for each proportion of quartz powder.

3.6.6 Heat resistance

In fact, there is no any ASTM standard test method or any standard test method for the determination of heat or fire resistance properties of concrete. Nevertheless, a method was adopted to measure and evaluate the effect of different percentages of QP as a partial replacement of cement on the heat or fire resistance of concretes at elevated temperatures. The test temperature adopted was 600°C. The test method adopted was done according to the experimental procedure of the work of Terro (2006) who studied the effect of crushed glass on properties of concrete at elevated temperatures.

In order to understand and analyze the heat resistance of concretes at different replacement percentages of QP (10, 20, 30 and 40%) by the cement, the test specimens were tested in compression and the compressive strength was determined for each specimen after heating up to 600°C. For this purpose, cylindrical specimens (100 mm diameter × 200 mm height) were prepared and tested for the heat resistance according to Terro (2006) test method.

The following heat resistance test procedure is carried out: First, the samples were cured in normal water at temperature of 20–22°C for 56 days prior to heating; directly the sample surfaces were cleaned with a towel in order to remove free surface water and then they were weighed with a sensitive digital balance. Second, heating of specimens was done with using a muffle furnace that can reach a temperature of 600°C. The rate of heating was constant, 2-4 °C per minute, and hold in the muffle furnace. A thermostat built in the furnace can automatically control the

range of heating. The specimens were left in the oven for duration of 7 hours to get a uniform temperature of 600°C in order to eliminate any thermal stresses (see Figure 3.10). After that, the specimens were kept in the oven for 15 hours for cooling and 7 hours more in the air temperature. This slow cooling before testing caused to avoid any thermal shocks that could affect the residual compressive strength. Third, the cylindrical specimens were weighed again to get the oven-dry weight to determine the total water absorption capacity after heat exposure (by subtracting oven-dry weight from fully saturated weight before placing for oven drying). Finally, the cylindrical test specimens were tested in compression to obtain the compressive residual strength after heat exposure.



Figure 3.7: Heating Samples to Test Heat Resistance Testing of Concrete with Different amount of QP

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the effects of five different proportions of QP on the mechanical properties for three different types of concrete C20/25, C35/45 and C50/60 were investigated in order to determine the beneficial and the detrimental effects of QP on concrete. For each test, the specimens modified with quartz powder were compared with the control mixes. The following tests such as compressive strength, flexural strength, tensile strength, water absorption capacity, and heat resistance were performed in order to determine the effects of quartz powder on the mechanical properties of concrete. Also, rapid chloride test was employed to measure the resistance of concrete to chloride ions attack. Eventually, results are demonstrated with different graphs for best understanding and comparison in various aspects.

4.2 The Effects of Various QP Replacement Levels on Workability of Different Concrete Classes

In this study, in order to evaluate the workability of fresh concrete, the slump test was used. The test results of the five various percentages of QP (0, 10, 20, 30 and 40%) as a substitution to cement for three different concretes (C20/25, C35/45 and C50/60) are depicted in Figure 4.1.

In the case of C20/25 and C35/45 concrete mixes, the workability decreased by increasing QP percentage up to 40%. The optimum decreasing was obtained when

QP replacement was 40%. The slump value was decreased by 20.6% and 28.6% in C20/25 and C35/45 concretes, respectively. This implies that increase in percentage of QP results to decrease in the slump of concrete. With the rise in the percentage of QP, the fineness of ingredients increases and in turn, the specific surface of QP particles increases. Thus, more water was needed to wet the risen quantity of surfaces of particles and subsequently, workability declines (Celik & Marar, 1996; Neville, 1987).

In case of C50/60 concrete mixes, the workability increased slightly with increasing percent of QP up to 30%. Beyond 30% replacement level, the workability started to decrease (exactly in 40 % QP replacement level). The optimum increase is obtained when QP percent replacement is 30% which is increased by 8.8% compared to the control slump test result. These changes in workability are because of the superplasticizer used just for C50/60 made a very thin film around all concrete gradients and QP particles as well. As a result, this film mostly affected QP particles to prevent absorbing of water compared to the cement particles during mixing. However, for 40% cement replacement with QP the used superplasticizer was not sufficient to make this film around all QP particles, thus the workability started to decrease.

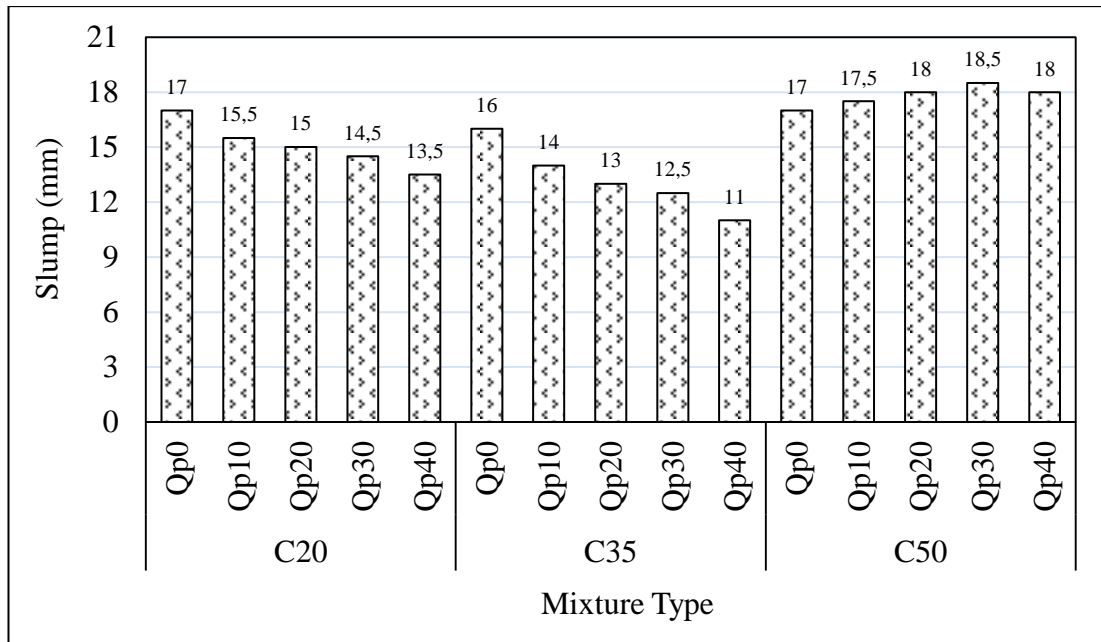


Figure 4.1: Effect of QP as Partial Replacement of Cement on Slump

4.3 The Influence of Various QP Replacement Levels on Compressive Strength of Different Concrete Classes

The average of three cubic ($150 \times 150 \times 150$ mm) specimens test results for compressive strength of fifteen different concrete mixes (five different percentage of quartz powder with three different classes of concretes C20/25, C35/45 and C50/60) are illustrated in Figures 4.2 and 4.3.

As it can be seen from Figures 4.2 and 4.3, for both 28 and 56 days of curing ages, QP has a great influence on concrete compressive strength, in which the concretes with 10% QP achieved the highest compressive strength for all concrete types. The obtained increasing rates for concretes with 10% QP compared to the control group strength (0% QP concretes) were 16.97, 10.78 and 9.93% for 28 days and 16.94, 7.17 and 8.69% for 56 days for concrete classes C20/25, C35/45 and C50/60, respectively. While, the lowest results were achieved with 40% QP concretes, the concrete lost their strength by 54.21, 45.34 and 36.14% for 28 days and 56.90, 46.64 and 38.84%

for 56 days for concrete classes C20/25, C35/45 and C50/60, respectively, compared to the control group strength (0% QP concretes).

The increase of compressive strength at a replacement level of 10 % QP is due to the fact that QP is an inert material, it needs external heat source to encourage and act as a pozzolanic material. In this study, some amount of heat which was produced in the results of chemical reactions of cement particles encouraged the chemical reactions (pozzolanic) activities of QP particles, thus a higher strength concrete was produced. On the other hand, some amounts of QP may act as a filler material, and fill voids between cement particles, thus more dense concrete produced with 10% QP. However, by increasing the amount of QP to replace cement at levels of 20, 30 and 40% the cement amount decrease in the concrete mixes, hence a lesser heat was produced. Therefore, the produced heat was not sufficient to encourage the pozzolanic reaction of all QP particles.

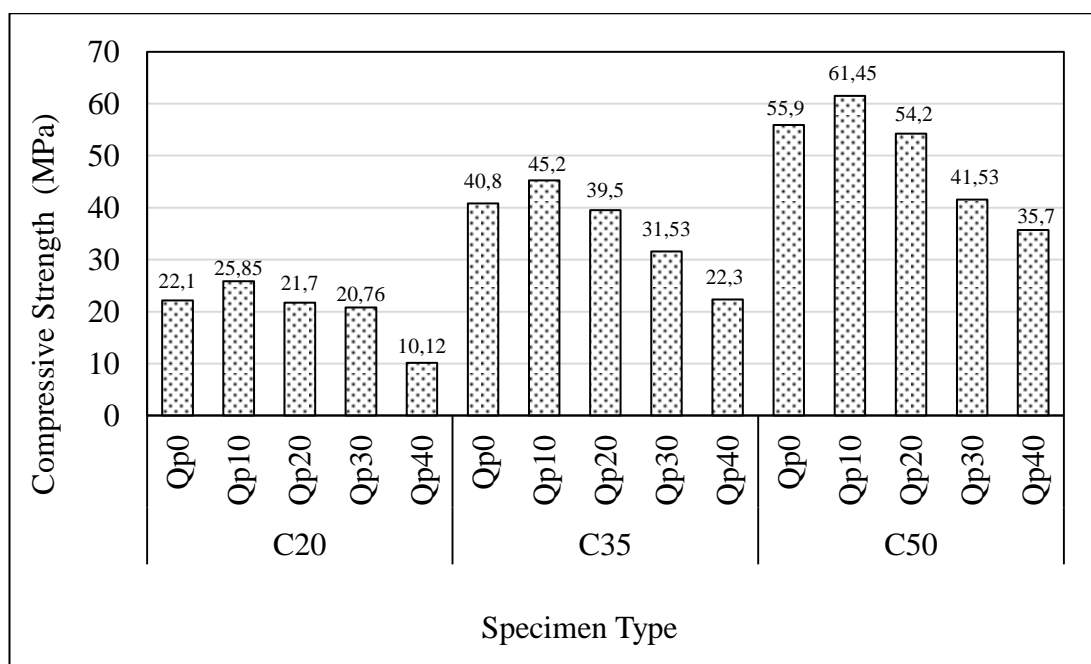


Figure 4.2: Effect of QP on the 28 – Days Compressive Strength

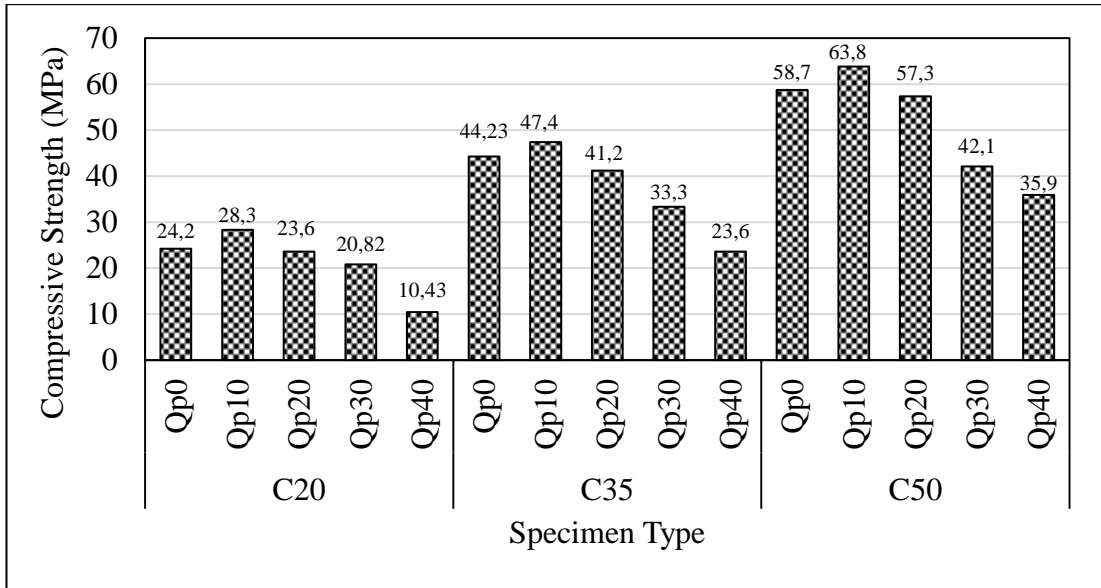


Figure 4.3: Effect of QP on the 56 – Days Compressive Strength

The compressive strength of concretes with 10% QP replacement level for C20/25 concretes was more affected by age of curing (see Figure 4.4). For example, in C20/25 concrete, the compressive strength increased by 9.48%, while, for the same level of cement replacement with QP in C35/45 and C50/60 concretes, the compressive strength increased just 4.87 and 3.82%, respectively.

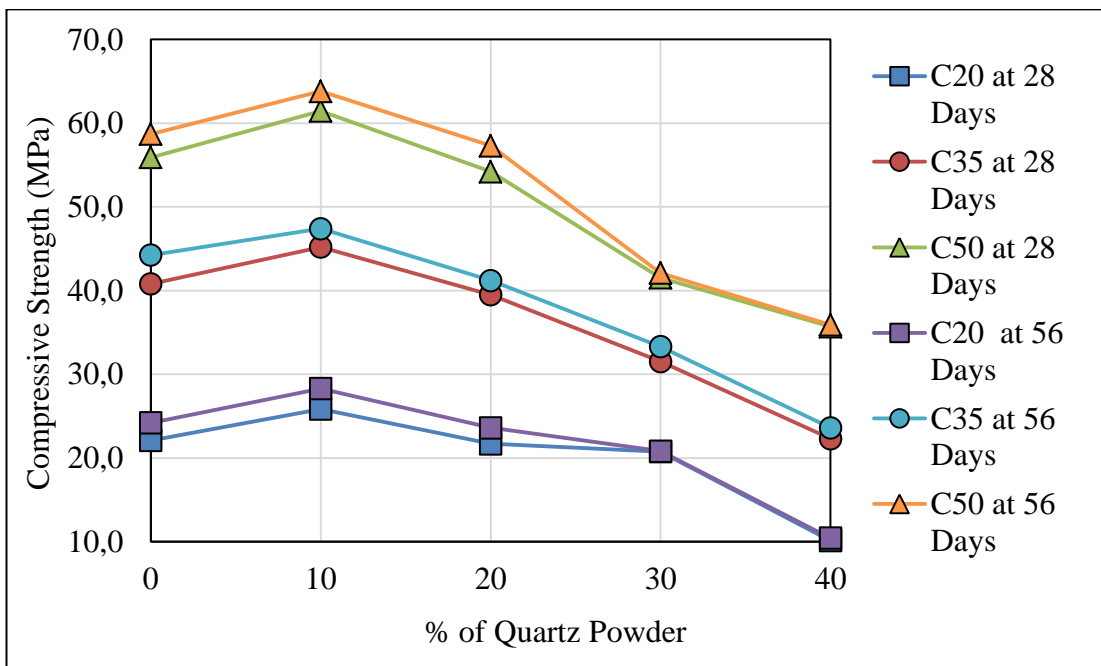


Figure 4.4: Effect of QP on both 28 and 56 – Days Compressive Strength

4.4 The Effects of Different QP Replacement Levels on Flexural Strength of Different Concrete Classes

In order to investigate the effect of QP on flexural strength, the average of three beams (100 mm width × 100 mm depth × 500 mm length) test results for flexural strength of fifteen different concrete mixes (five different percentage of quartz powder for three different classes of concretes C20/25, C35/45 and C50/60) are shown in Figures 4.5 and 4.6.

As it can be seen from Figures 4.5 and 4.6, for both 28 and 56 days of curing ages, QP has a good influence on the concrete flexural strength, in which the concretes with 10% replaced cement with QP achieved highest flexural tensile strength for all concrete types (C20/25, C35/45 and C50/60). The obtained increase for concretes with 10% QP compared to control group strength (0% QP concretes) were 6.16, 6.59 and 7.10% for 28 days and 5.84, 4.87 and 8.23% for 56 days for C20/25, C35/45 and C50/60, respectively. Whereas, the lowest results were achieved with 40% cement replacement with QP, the concrete lost their flexural tensile strength by 24.63, 24.4 and 21.71% for 28 days and 25.56, 28.54 and 23.3% for 56 days for C20/25, C35/45 and C50/60, respectively, compared to control strength (0% QP concretes).

The gained increases in flexural tensile strength by using 10% QP is attributed to the good bonding between aggregates and cementitious materials, moreover, above 10% QP replacement level flexural strength decreased for all strength grades. Also, the mentioned reasons, in section 4.3, that affected the compressive strength may have affected the flexural strength in as well.

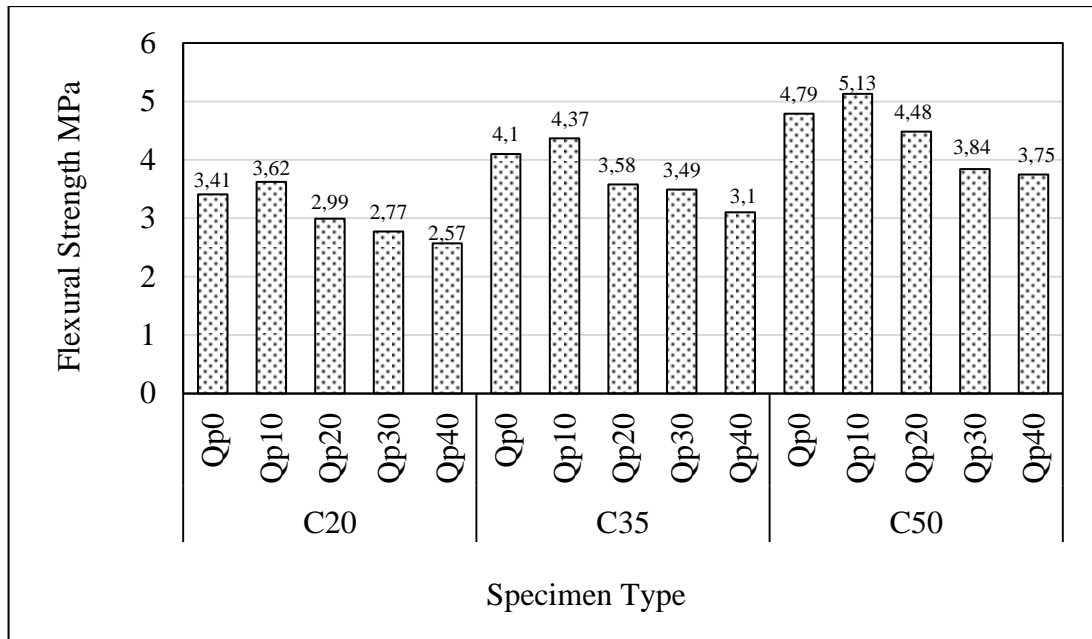


Figure 4.5: Effect of QP on 28 – Days Flexural Strength

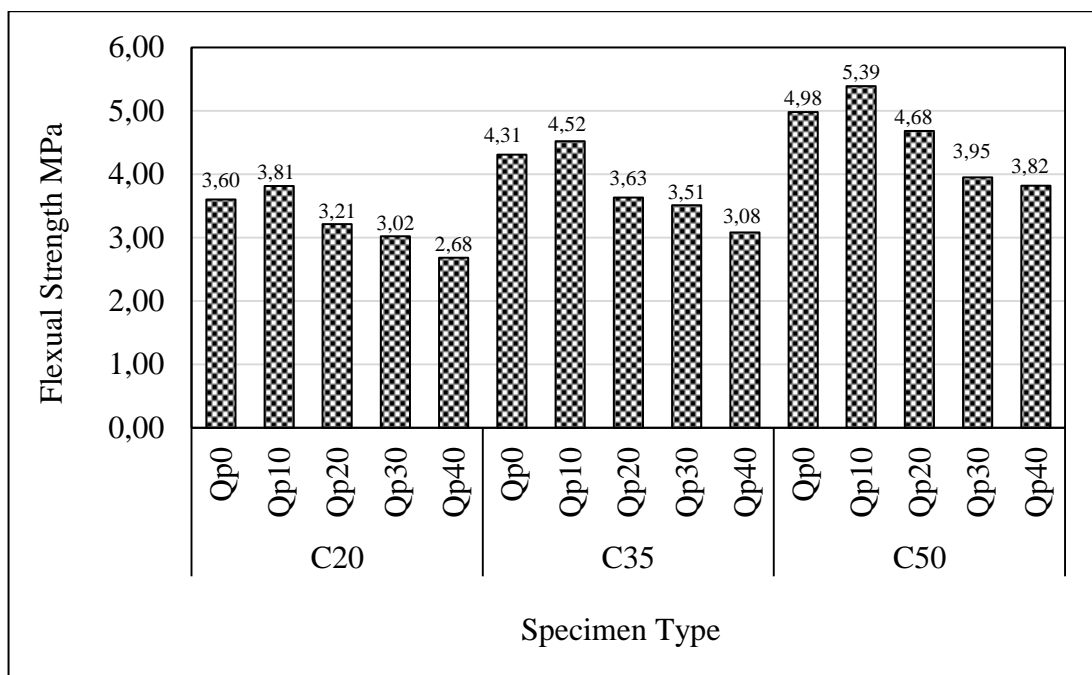


Figure 4.6: Effect of QP on 56 – Days Flexural Strength

The flexural strength of C35/45 concretes was less affected by age of curing (see Figure 4.7). For example, in C20/25 and C50/60 concretes, increase in flexural strength is found to be 5.25 and 5.06 %, respectively, while in C35/45 concrete mixtures increased just 3.43 %.

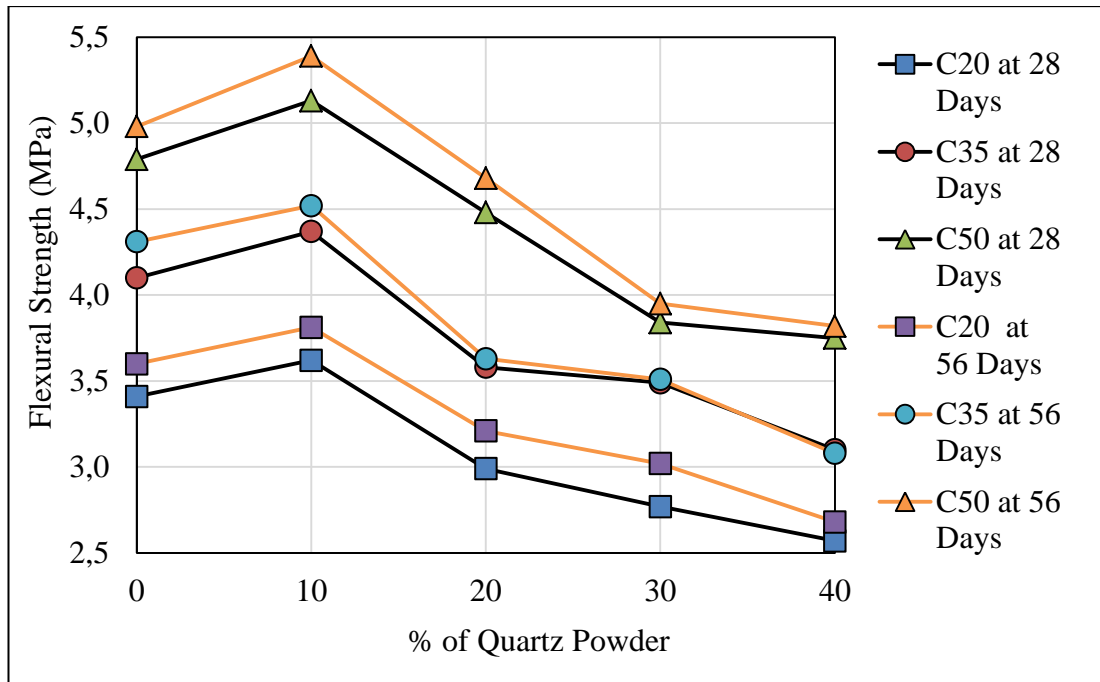


Figure 4.7: Effect of QP on both 28 and 56 – Days Flextural Strength

In order to quantify the variation of flexural tensile strength of the concrete mixes as a function of compressive strength for both 28 and 56 days of curing age; for each concrete class, different regression forms were applied to the models with correlation factors R^2 as it is presented in Table 4.1 and Table 4.2. It can be observed from the tables, with respect to regression R^2 the best relation for each class of concretes for both 28 and 56 days is highlighted. Figures 4.8 and 4.9 show the relation of flexural strength with compressive strength for all concrete classes Figure 4.10: Relation between flexural strength and compressive Strength for cement replacement concretes with QP for 28 days of curing age, as it is clear from figures, when the compressive strength increased the flexural strength increased as well.

Table 4.1: Relationship Equations between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age

Concrete Type	Regression Type	Equation	R ²	Standard Deviation
C20/25	Exponential	$y = 2.0299e^{0.0202x}$	0.70580	
	Linear	$y = 0.0609x + 1.8474$	0.67770	
	Logarithmic	$y = 0.9239\ln(x) + 0.3423$	0.60230	
	Polynomial (2 nd order)	$0.0066x^2 - 0.1666x + 3.5735$	0.8276	
	Power	$y = 1.2252x^{0.3084}$	0.635	0.437
C35/45	Exponential	$y = 2.2376e^{0.014x}$	0.8702	
	Linear	$y = 0.0514x + 1.8837$	0.8462	
	Logarithmic	$y = 1.6102\ln(x) - 1.9888$	0.8043	
	Polynomial (2 nd order)	$y = 0.0019x^2 - 0.0743x + 3.8514$	0.8923	
	Power	$y = 0.7719x^{0.4415}$	0.8358	0.505
C50/60	Exponential	$y = 2.3387e^{0.0125x}$	0.9656	
	Linear	$y = 0.0545x + 1.6875$	0.9553	
	Logarithmic	$y = 2.5356\ln(x) - 5.4583$	0.9292	
	Polynomial (2 nd order)	$y = 0.0016x^2 - 0.0984x + 5.2226$	0.9861	
	Power	$y = 0.4491x^{0.5851}$	0.9433	0.597

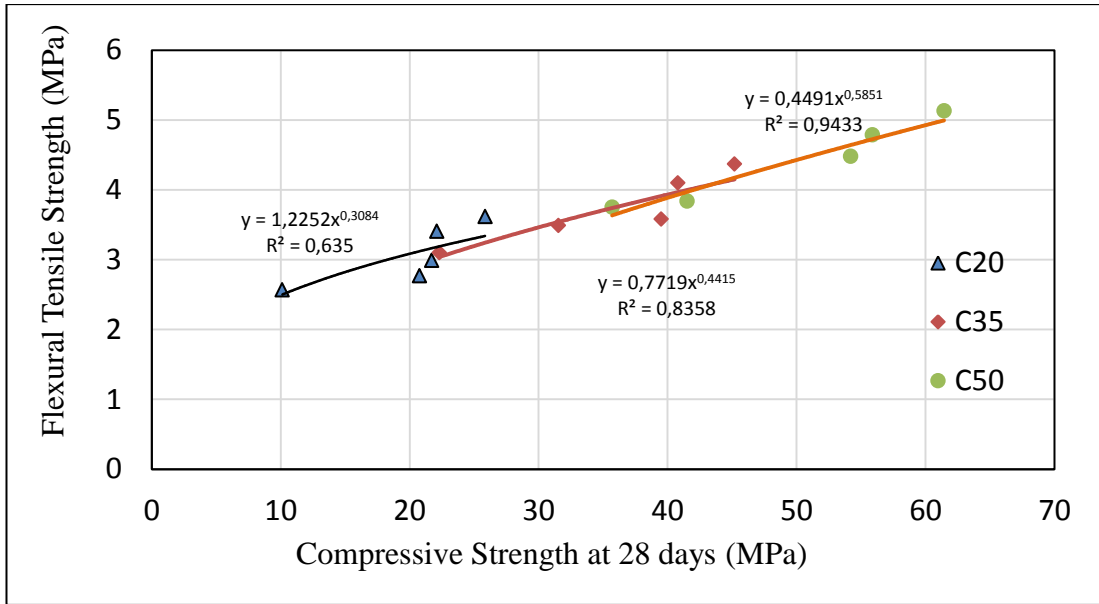


Figure 4.8: Relationship between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age

Table 4.2: Relationship Equations between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age

Concrete Type	Regression Type	Equation	R2	Standard Deviation
C20/25	Exponential	$y = 2.1335e^{0.0194x}$	0.871	
	Linear	$y = 0.0616x + 1.9413$	0.8414	
	Logarithmic	$y = 1.0127\ln(x) + 0.212$	0.7634	
	Polynomial (2 nd order)	$y = 0.0035x^2 - 0.0709x + 3.0261$	0.9191	
	Power	$y = 1.2275x^{0.3219}$	0.8019	0.451
C35/45	Exponential	$y = 2.0998e^{0.0154x}$	0.8906	
	Linear	$y = 0.0576x + 1.6238$	0.8639	0.593
	Logarithmic	$y = 1.9046\ln(x) - 3.0591$	0.8184	
	Polynomial (2 nd order)	$y = 0.0023x^2 - 0.1046x + 4.3037$	0.9218	
	Power	$y = 0.5926x^{0.5133}$	0.8527	0.593
C50/60	Exponential	$y = 2.4073e^{0.0122x}$	0.9666	
	Linear	$y = 0.0549x + 1.7337$	0.952	
	Logarithmic	$y = 2.6196\ln(x) - 5.7034$	0.9258	
	Polynomial (2 nd order)	$y = 0.0019x^2 - 0.1284x + 6.0564$	0.9907	
	Power	$y = 0.4563x^{0.5853}$	0.9442	0.670

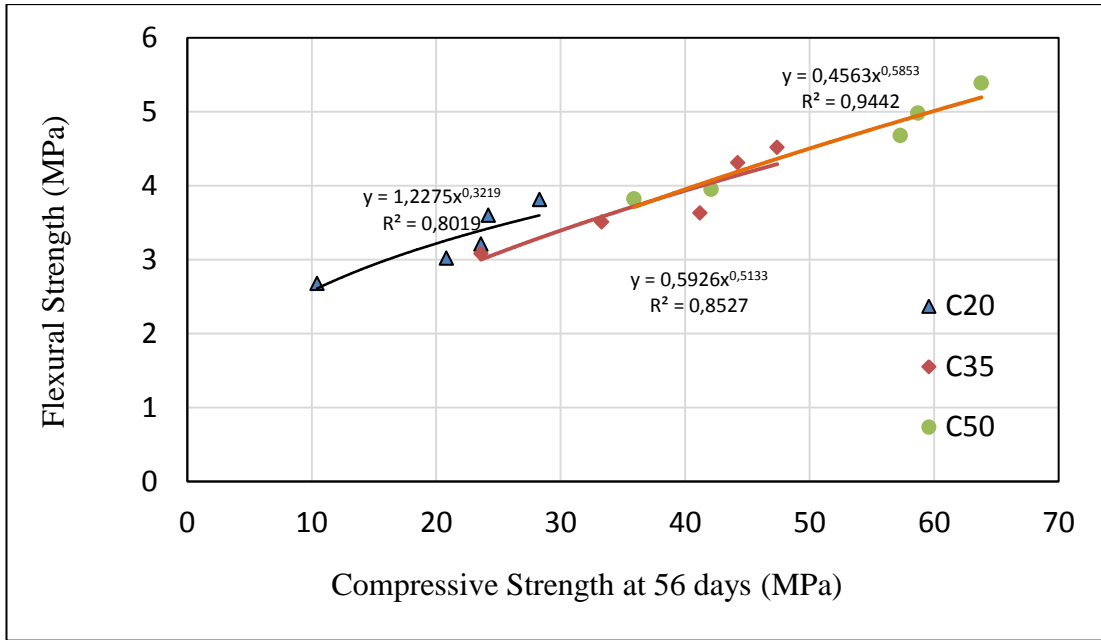


Figure 4.9: Relation between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age

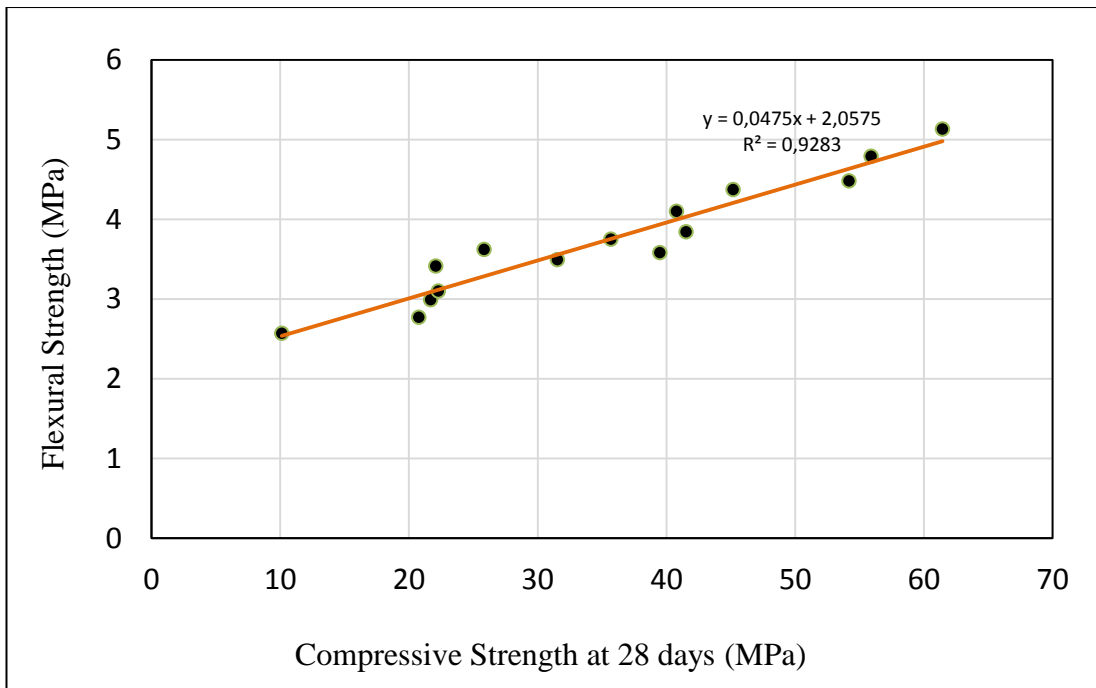


Figure 4.10: Linear Relation between Flexural Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age

4.5 The Influence of Various QP Replacment Levels on Splitting Tensile Strength of Different Concrete Classes

The average of three cylindrical specimens (100 mm diameter × 200 mm height) test results for splitting tensile strength of fifteen different concrete mixes (five different percentage of quartz powder for three different classes of concretes C20/25, C35/45 and C50/60) are shown in Figures 4.11 and 4.12.

As it can be seen from Figures 4.11 and 4.12, for both 28 and 56 days of curing ages QP has a low influence on concrete mixtures C50/60 and negative influence on splitting tensile of C20/25 and C35/45 concretes. C20/25 and C35/45 concretes with 0% QP had highest splitting tensile strength, however, the C50/60 concrete with 10% QP achieved the highest splitting tensile strength. The obtained percentages for concretes with 10% QP compared to control group strength (0% QP concretes) were -7.3, -12.2 and 2.7% for 28 days and -6.27, -7.10 and 4.56% for 56 days for C20/25, C35/45 and C50/60 concrete mixtures, respectively. While, the lowest results were achieved with 40% QP for all concrete types, the concretes lost their splitting tensile strength by 45.7, 45.8 and 23.3% for 28 days and 48.73, 46.22 and 23.75% for 56 days for C20/25, C35/45 and C50/60, respectively, compared to the control concrete strength (0% QP concretes).

These decrements in splitting tensile strength for C20/25 and C35/45 concretes is because of the increasing brittleness of concretes as a result of replacing cement with QP, and this brittleness was increased with increasing the QP replacement level.

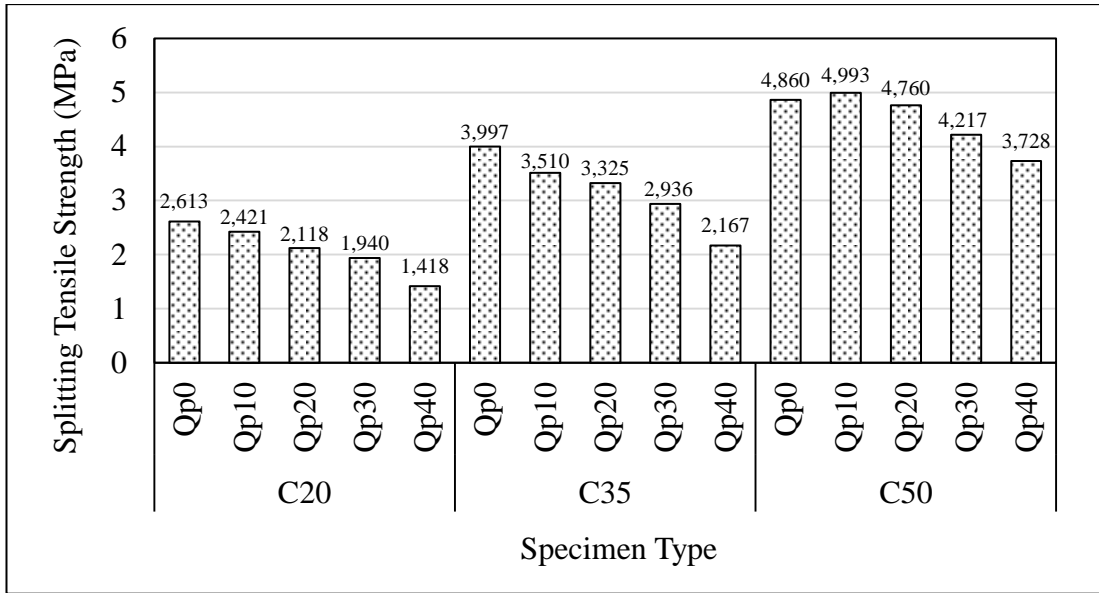


Figure 4.11: Effect of QP on 28 – Days Splitting Tensile Strength

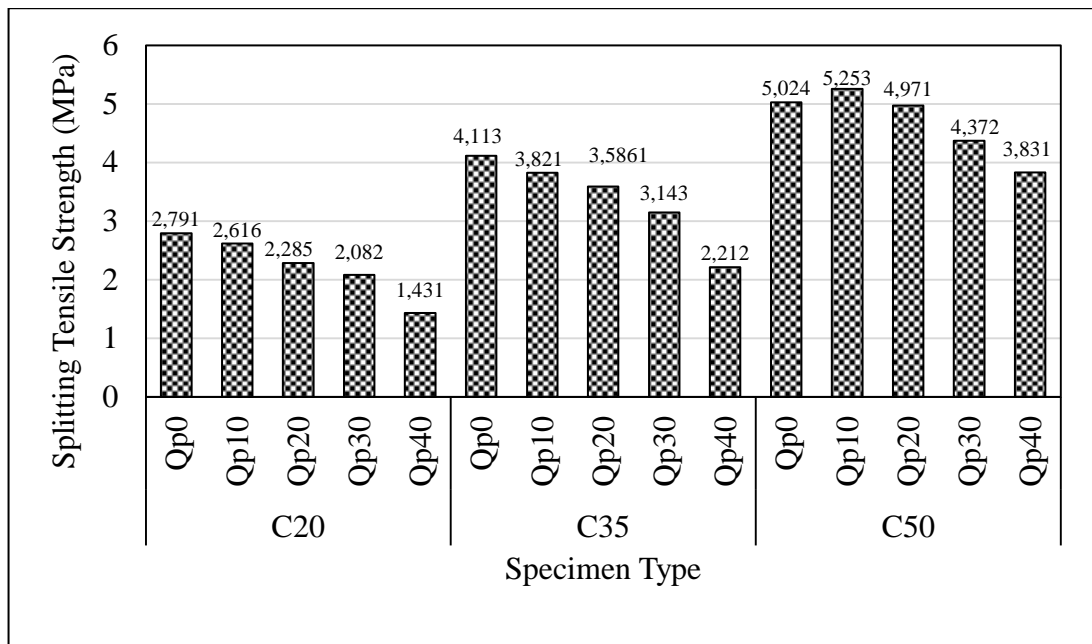


Figure 4.12: Effect of QP on 56 – Days Splitting Tensile Strength

The splitting tensile strength of concretes with 10% QP replacement of C50/60 concretes was less affected by age of curing see Figure 4.13. For example, in C20/25 and C35/45 concretes, increase in splitting tensile strength is found to be 8.05 and 8.86%, respectively, while in C50/60 concrete increased just 4.9%.

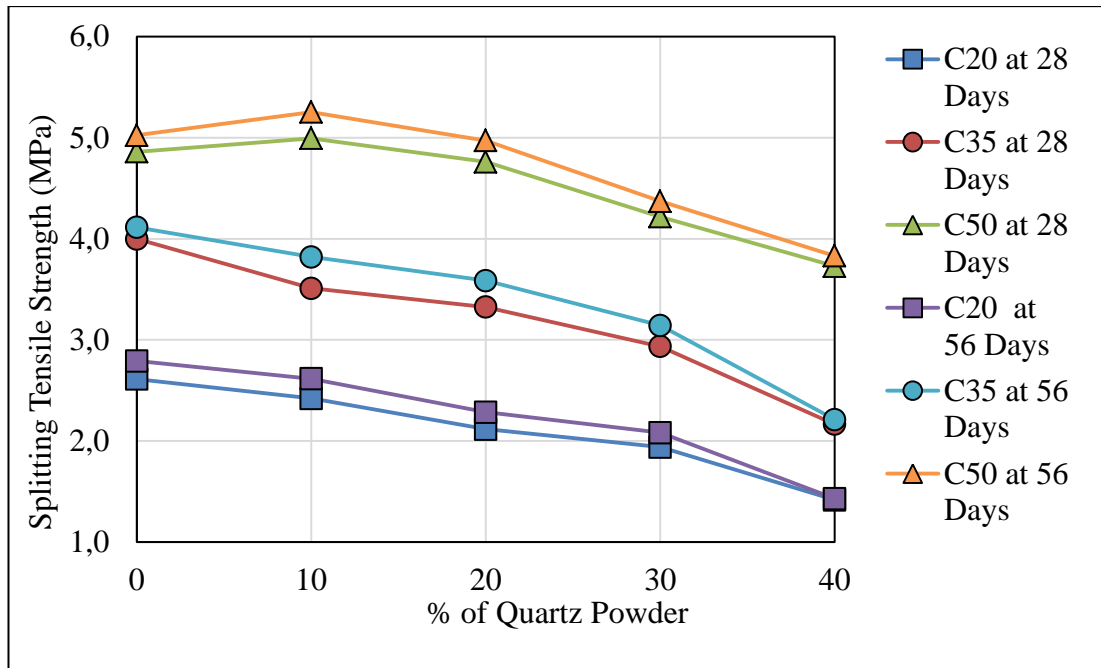


Figure 4.13: Effect of QP on both 28 and 56 – Days Splitting Tensile Strength

In order to calculate the variation in splitting tensile strength of the concrete mixes modified with QP as a function of compressive strength for both 28 and 56 days of curing age; for each concrete class, different regression forms were applied to the model with correlation factor R^2 as it is presented in Table 4.3 and Table 4.4. It was observed from the tables, with respect to regression R^2 the best relation for each class of concretes for both 28 and 56 days is highlighted. Figures 4.14 and 4.15 show the variation of splitting tensile strength with compressive strength for all concrete classes and Figure 4.16 shows the linear relationship between splitting tensile strength and compressive strength for cement replacement concretes with QP for 28 days of curing age, as it is clear from figures, the compressive strength increase the splitting tensile strength increase as well.

Table 4.3: Relationship Equations of Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP at 28 Days of Curing Age

Concrete Type	Regression Type	Equation	R ²	Standard Deviation
C20/25	Exponential	$y = 0.9822e^{0.0368x}$	0.8341	
	Linear	$y = 0.0687x + 0.7197$	0.77	
	Logarithmic	$y = 1.1013\ln(x) - 1.1519$	0.7632	
	Polynomial (2nd order)	$y = -0.0004x^2 + 0.083x + 0.6113$	0.7705	
	Power	$y = 0.3578x^{0.592}$	0.8348	0.462
C35/45	Exponential	$y = 1.3347e^{0.0237x}$	0.8521	
	Linear	$y = 0.0685x + 0.7297$	0.8165	0.572
	Logarithmic	$y = 2.2345\ln(x) - 4.7463$	0.842	
	Polynomial (2 nd order)	$y = -0.0025x^2 + 0.2356x - 1.8849$	0.8608	
	Power	$y = 0.1984x^{0.7762}$	0.8864	0.686
C50/60	Exponential	$y = 2.5771e^{0.0111x}$	0.9585	
	Linear	$y = 0.0486x + 2.0956$	0.9711	0.830
	Logarithmic	$y = 2.311\ln(x) - 4.4719$	0.9877	
	Polynomial (2nd order)	$y = -0.0013x^2 + 0.1704x - 0.7216$	0.9962	
	Power	$y = 0.5688x^{0.5313}$	0.9791	0.528

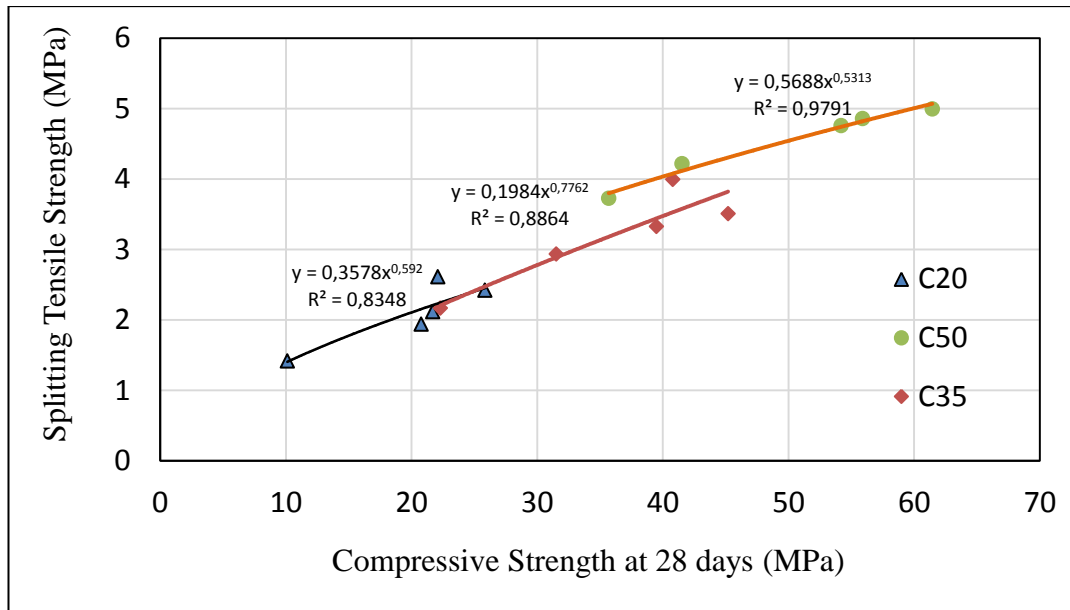


Figure 4.14: Relationship between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age

Table 4.4: Relationship Equations between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age

Concrete Type	Regression Type	Equation	R2	Standard Deviation
C20/25	Exponential	$y = 0.9492e^{0.0414x}$	0.8699	
	Linear	$y = 0.081x + 0.6134$	0.8125	
	Logarithmic	$y = 1.2987\ln(x) - 1.5962$	0.8077	
	Polynomial (2 nd order)	$y = -0.0007x^2 + 0.1057x + 0.4256$	0.8137	
	Power	$y = 0.3028x^{0.6687}$	0.8746	0.530
C35/45	Exponential	$y = 1.3163e^{0.0256x}$	0.8993	
	Linear	$y = 0.0774x + 0.5984$	0.8944	
	Logarithmic	$y = 2.5234\ln(x) - 5.584$	0.9213	
	Polynomial (2 nd order)	$y = -0.0026x^2 + 0.2537x - 2.1589$	0.9367	
	Power	$y = 0.1672x^{0.8401}$	0.9363	0.740
C50/60	Exponential	$y = 2.5888e^{0.0118x}$	0.9625	
	Linear	$y = 0.0535x + 2.0291$	0.9761	
	Logarithmic	$y = 2.5418\ln(x) - 5.1905$	0.99	
	Polynomial (2 nd order)	$y = -0.0012x^2 + 0.1662x - 0.5777$	0.9939	
	Power	$y = 0.5226x^{0.5629}$	0.9811	0.580

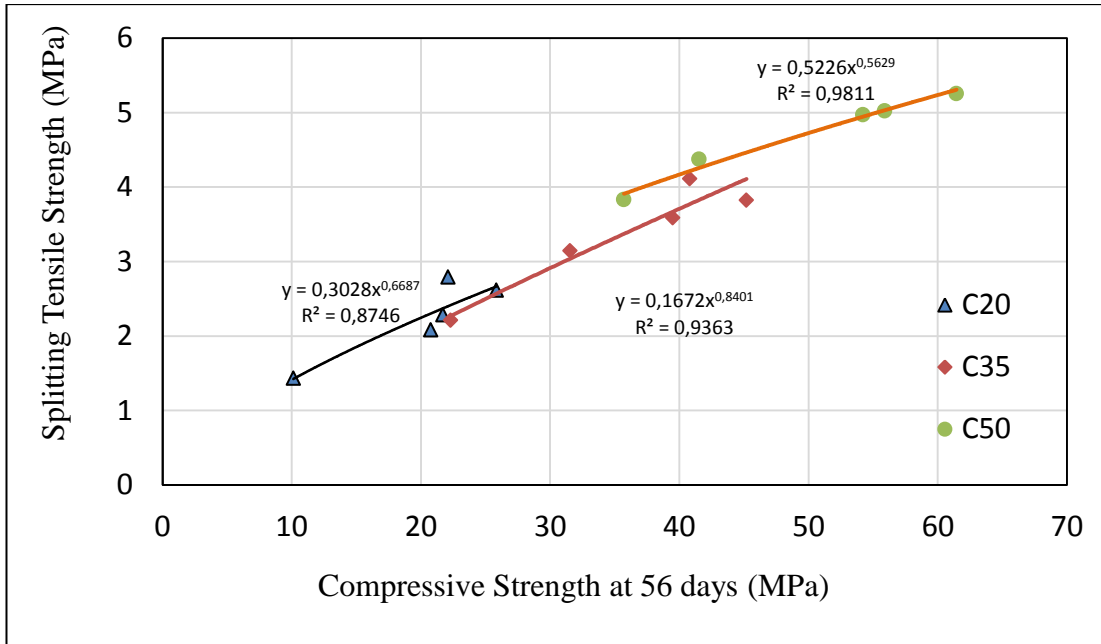


Figure 4.15: Relationship between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age

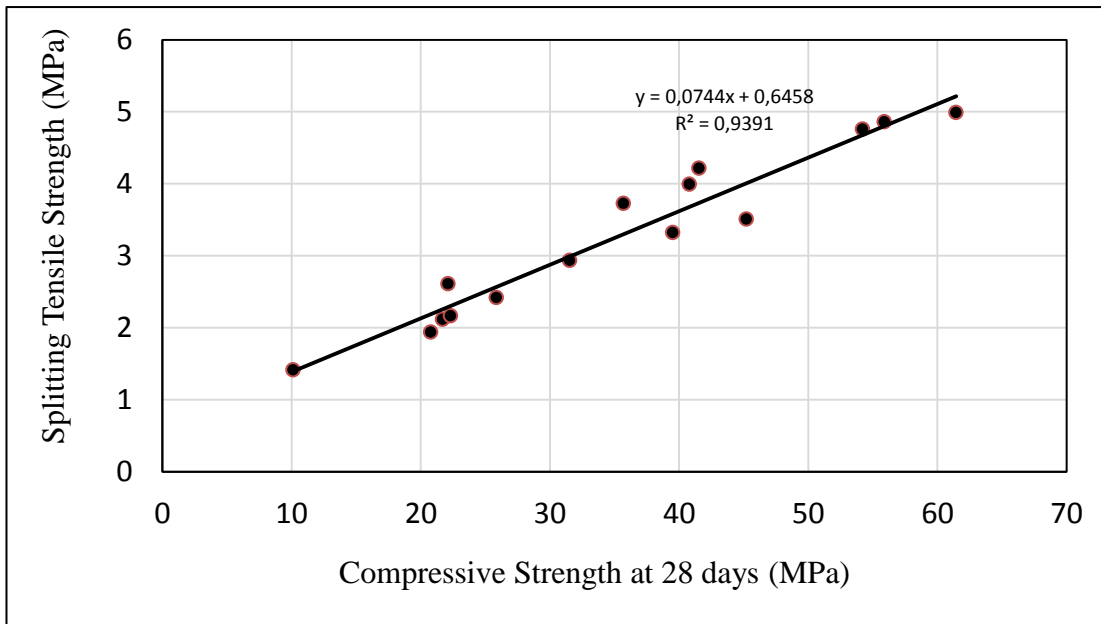


Figure 4.16: Linear Relationship between Splitting Tensile Strength and Compressive Strength for Cement Replacement Concretes with QP for 28 Days of Curing Age

4.6 The Effects of Different QP Replacement Levels on Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

Rapid chloride penetration test performed on concrete specimens modified with QP as a cement replacement material with 5 different percentages (0, 10, 20, 30 and 40%) for three different concrete types (C20/25, C35/45 and C50/60) at 56 days. The test results illustrated, with 10% QP replacement level, the resistance of concretes against to ionic penetration was increased and reached to highest values, while the resistance of concretes up to 40% QP was more than the control mixture for all types of concretes.

It can be seen from Table 4.5, the passed charged classification of control groups was high for C20/25 concrete and moderate for both C35/45 and C50/60 concretes, while, with 10% QP replacement level, the passed charged was decreased by 63.82, 42.25 and 39.61% for C20/25, C35/45 and C50/60 and they became moderate, low and low classes, respectively. The classification of the resistance to penetration of chloride ions test results were according to ASTM C1202-08 (see Table 4.6). Generally, QP replacement level improved concretes resistance against ionic penetration. The higher the passed charge the lower is the resistance to penetration of chloride ions which means the higher permeability of concrete. This can be attributed to the fact that QP particles are smaller than cement particles, hence they fill the empty voids i.e., quartz particles acted as a filler. Also, from all test results, it is founded that QP possessed little pozzolanic behavior up to 10% because of having sufficient heat at this level of cement replacement with QP which is explained in section 4.3.

With rise is the percentage of QP as a partial replacement to cement, because of some factors like absence of cohesion between cement paste and fine aggregate, thus the result gives weaker concrete by low compressive strength that caused high permeability.

Table 4.5: Chloride Ion Penetration Results of Cement Replacement Concretes with QP for Different Type of Strength at 56 Days

Quartz Prop.	Concrete Types					
	C20/25		C35/45		C50/60	
	Charged Passed (MA)	Classification	Charged Passed (MA)	Classification	Charged Passed (MA)	Classification
Qp0	8655	High	3396	Moderate	2797	Moderate
Qp10	3131	Moderate	1961	Low	1689	Low
Qp20	3519	Moderate	2303	Moderate	2212	Moderate
Qp30	6230	High	2711	Moderate	2323	Moderate
Qp40	7797	High	3049	Moderate	2682	Moderate

Table 4.6: Chloride Ion Penetrability Based on Charge Passed (ASTM C1202-08)

Charge Passed (coulombs)	Chloride Ion Penetrability
>4,000	High
2,000–4,000	Moderate
1,000–2,000	Low
100–1,000	Very Low
<100	Negligible

4.7 The Effects of Various QP Replacement Levels with Different Concrete Strength on Water Absorption Capacity

The results of water absorption capacity test for 5 different percentages of QP (0, 10, 20, 30 and 40%) replacement levels with cement for three various strength grades C20/25, C35/45 and C50/60 at 56 days are presented in Figure 4.17.

As it can be seen in the Figure 4.17, QP replacement has a positive effect on water absorption capacity, in which the concretes with 10% QP had the lowest water absorption capacity, the obtained decreases were 12.88, 7.2 and 19.62% for C20/25, C35/45 and C50/60, respectively.

In C20/25 concretes, the water absorption capacity up to 30% QP replacement level was less than control concrete mixture, on the other hand, for 40% QP replacement with cement nearly had the same water absorption capacity as it was in control concrete mixture. For C35/45 concretes, the water absorption capacity up to 20% QP replacement level was less than in control concrete mixtures. For 30% and 40% QP replacement with cement had greater water absorption capacity compared to control concrete mixtures. In C50/60 concretes, the water absorption capacity up to 40% QP replacement level was less than control concrete mixtures.

The reduction in the capacity of water absorption is because QP acted like filler material that reduced the total voids in the concrete. On the other hand, when the quantity of QP raised and the cement content declined a weaker concrete is produced because weaker concrete absorbs more water. Furthermore, the increase in water

absorption resulted from the formation of excessive voids attributable to dehydration of C-S-H gel in the mixes with high percentage of QP replacement levels.

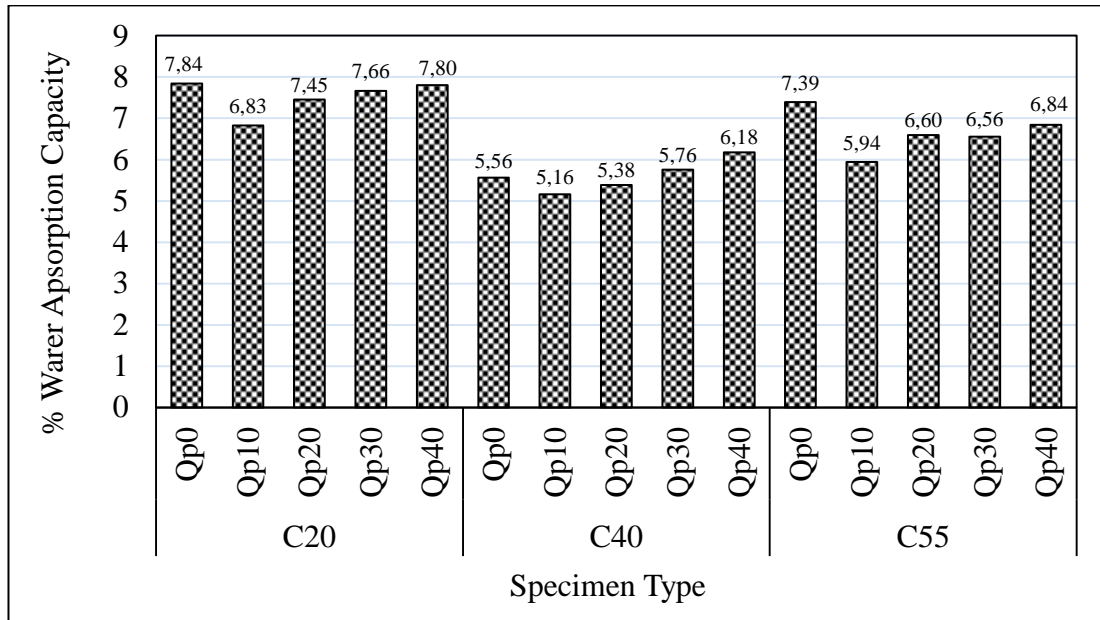


Figure 4.17: Effect of QP on Water Absorption Capacity at 56 Days

In order to study the relation between water absorption capacity and chloride ion penetration of concretes modified with QP at 56 days, for each concrete class, different regression forms were applied to the models with correlation factors R^2 as it is shown in Table 4.7. As it can be observed from the tables, the best relation for each class of concrete is highlighted. Figure 4.18 shows the best relationships for each class of concrete between water absorption capacity and chloride ion penetration for cement replacement concretes with QP and Figure 4.19: linear relationship between water absorption capacity and chloride ion penetration for cement replacement concretes with QP for 56 days of curing age, also it can be observed when absorption capacity increased, the chloride ion penetration increased as well however with a weak correlation.

The results of this experiment agree with Zhangh & Zong (2014) test results that permeability mainly depended on the surface water absorption of concrete, and there was a significant linear correlation between permeability and surface water absorption. However, internal water absorption presented little relationships to permeability.

Table 4.7: Relationship Equations between Water Absorption Capacity and Chloride Ion Penetration for Cement Replacement Concretes with QP for 56 Days of Curing Age

Concrete Type	Regression Type	Equation	R2	Standard Deviation
C20/25	Exponential	$y = 6.6981e^{2E-05x}$	0.7276	
	Linear	$y = 0.0001x + 6.6743$	0.7427	
	Logarithmic	$y = 0.7931\ln(x) + 0.6998$	0.7884	
	Polynomial (2 nd order)	$y = -3E-08x^2 + 0.0005x + 5.7415$	0.8034	
	Power	$y = 2.9787x^{0.1075}$	0.7748	0.413
C35/45	Exponential	$y = 4.499e^{8E-05x}$	0.4594	
	Linear	$y = 0.0005x + 4.3944$	0.4422	
	Logarithmic	$y = 1.2469\ln(x) - 4.2143$	0.4942	
	Polynomial (2 nd order)	$y = -9E-07x^2 + 0.0053x - 1.833$	0.7478	
	Power	$y = 0.9555x^{0.2244}$	0.5133	0.388
C50/60	Exponential	$y = 4.4324e^{0.0002x}$	0.9197	
	Linear	$y = 0.0011x + 3.9937$	0.9062	
	Logarithmic	$y = 2.4836\ln(x) - 12.566$	0.8897	
	Polynomial (2 nd order)	$y = 3E-07x^2 - 0.0002x + 5.4252$	0.9135	
	Power	$y = 0.3559x^{0.3781}$	0.9083	0.524

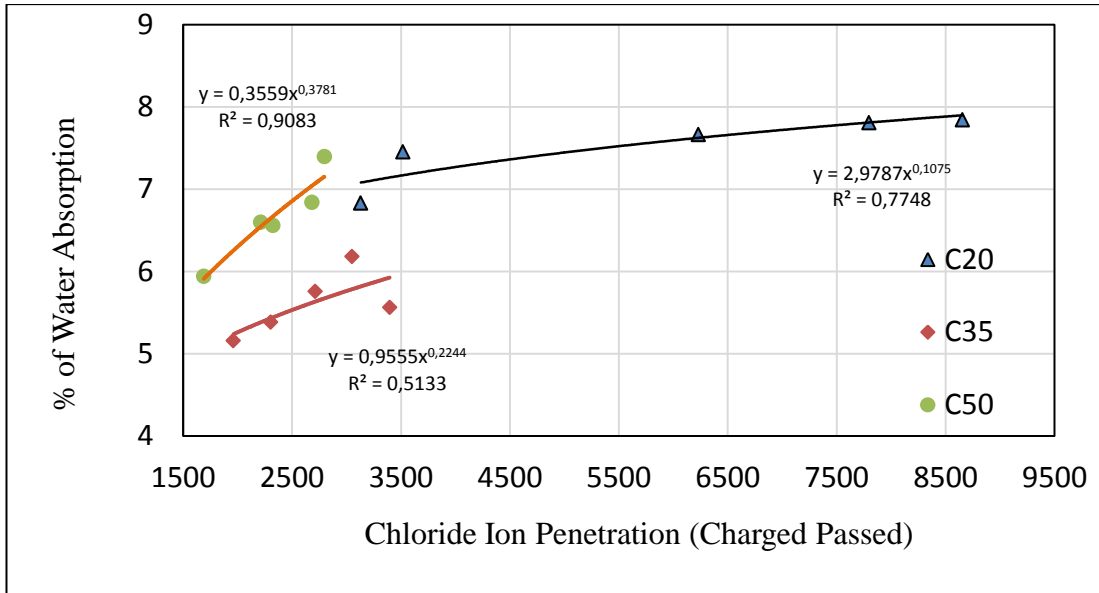


Figure 4.18: Relationship between Water Absorption Capacity and Chloride Ion Penetration for Cement Replacement Concretes with QP for 56 Days of Curing Age

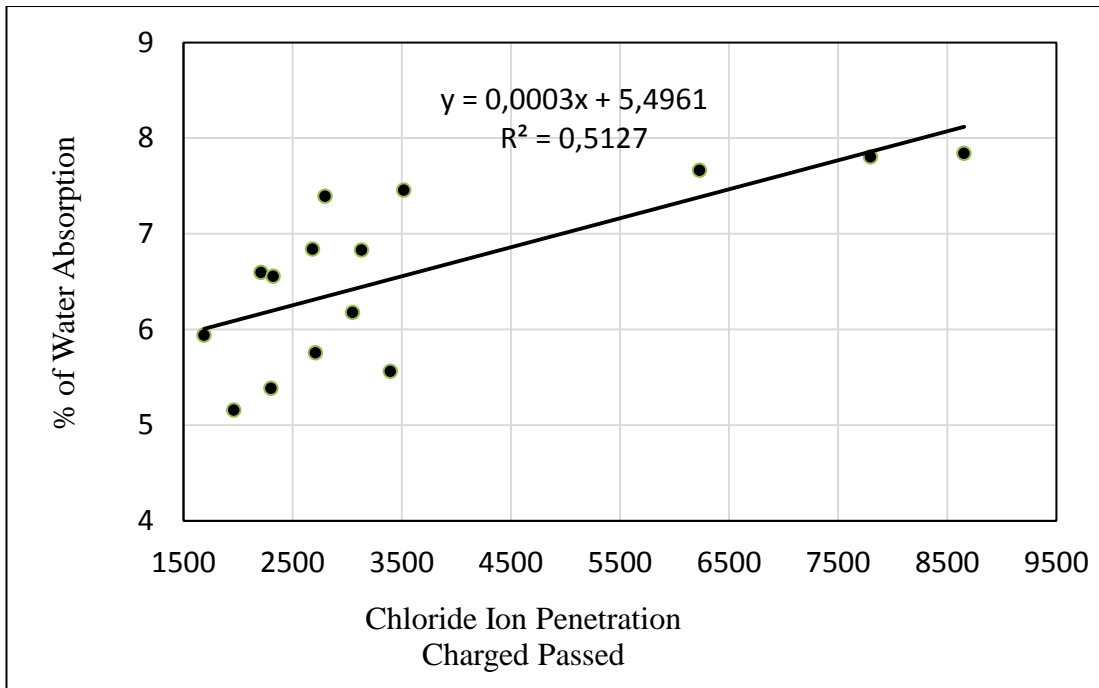


Figure 4.19: Linear Relationship between Water Absorption Capacity and Chloride Ion Penetration for Cement Replacement Concretes with QP for 56 Days of Curing Age

In order to calculate the variation of water absorption capacity of the concrete mixes modified with QP as a function of 56 days compressive strength for each concrete class, different regression forms were applied to the models with correlation factors

R^2 as it is presented in Table 4.8. As it is shown in table, the best relation for each class of concretes was highlighted with respect to regression R^2 . Figure 4.20 shows the variation of water absorption capacity with compressive strength for all concrete classes. As it can be seen, when compressive strength increase water absorption decrease with weak correlations,

Table 4.8: Relationship Equations between and Water Absorption Capacity and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age

Concrete Type	Regression Type	Equation	R2	Standard Deviation
C20/25	Exponential	$y = 8.4387e^{-0.005x}$	0.4184	
	Linear	$y = -0.0399x + 8.3736$	0.4201	
	Logarithmic	$y = -0.607\ln(x) + 9.3465$	0.3269	
	Polynomial (2 nd order)	$y = -0.0069x^2 + 0.2172x + 6.2689$	0.7689	
	Power	$y = 9.6313x^{-0.083}$	0.3239	0.413
C35/45	Exponential	$y = 7.2395e^{-0.007x}$	0.8974	
	Linear	$y = -0.0386x + 7.0714$	0.9056	
	Logarithmic	$y = -1.309\ln(x) + 10.329$	0.9032	
	Polynomial (2 nd order)	$y = 0.0001x^2 - 0.0479x + 7.2256$	0.906	
	Power	$y = 12.81x^{-0.23}$	0.8907	0.388
C50/60	Exponential	$y = 7.2645e^{-0.002x}$	0.0673	
	Linear	$y = -0.0102x + 7.1882$	0.0532	
	Logarithmic	$y = -0.446\ln(x) + 8.4143$	0.0439	
	Polynomial (2 nd order)	$y = -0.0031x^2 + 0.3018x - 0.1672$	0.2364	
	Power	$y = 8.9601x^{-0.076}$	0.0563	0.524

According to Table 4.8, it seems that there is no clear relation between water absorption capacity and compressive strength for all class of concrete mixes.

Figure 4.21 shows that there is no good relation between compressive strength and water absorption capacity at 56 days of curing age, the figure just shows when the compressive increase water absorption decrease.

As stated by Zhang & Zong (2014), both of surface water absorption and internal water absorption had no clear relationship with compressive strength, which indicated that the strength may not be simply evaluated with water absorption.

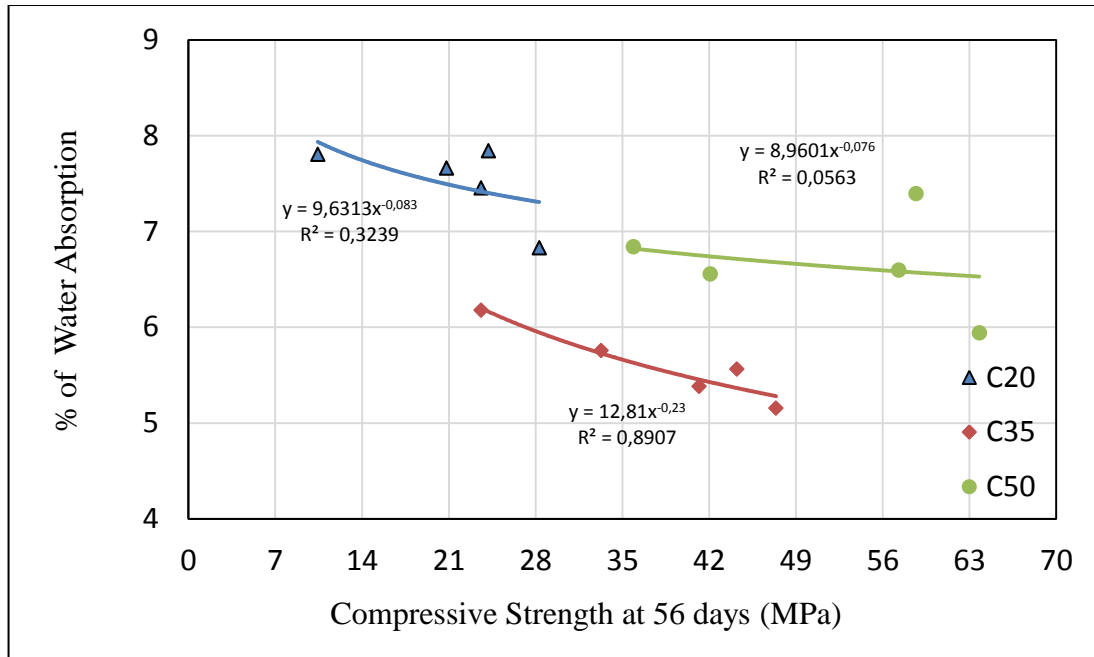


Figure 4.20: Relationship between Water Absorption Capacity and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age

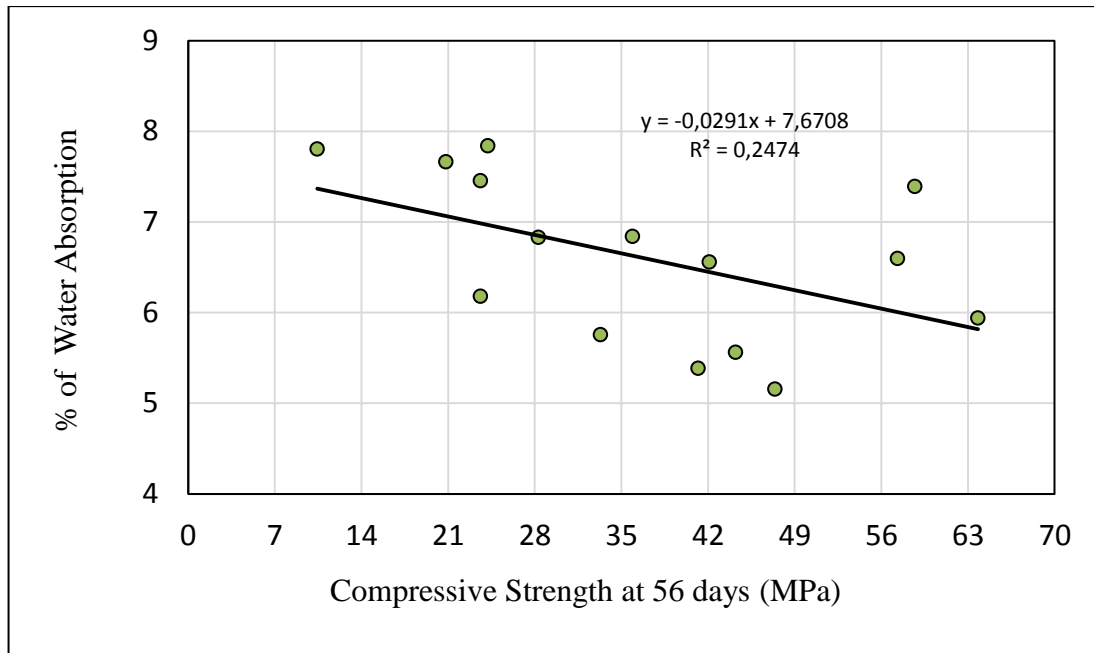


Figure 4.21: Linear Relationship between Water Absorption Capacity and Compressive Strength for Cement Replacement Concretes with QP for 56 Days of Curing Age

4.8 The Effects of Various QP replacement Levels on Heat Resistance of Different Concrete Classes at 600°C

Three test cylindrical specimens (100 mm diameter × 200 mm height) were tested for the residual compressive strength after heat exposure up to 600°C at five different QP replacement levels for three different classes of concrete C20/25, C35/45 and C50/60 at 56 days. The test results are shown in Figure 4.22.

As it can be seen from Figure 4.22, after heating specimens up to 600°C, it is appeared that QP as a partial replacement with cement had a negative influence on concrete compressive strength, in which the concretes with 0% QP obtained the highest residual compressive strength for all concrete classes. The decreasing rates of concretes for each of 10 , 20, 30 and 40% QP replacement with cement compared to control concrete strength (0% QP concretes) were 23.44, 6.61, 35.46 and 39.42% for

C20/25 concretes, 30.12, 11.32, 38.5 and 52.14% for C35/45 concretes, 25.23, 1.55, 27.12 and 45.28% for C50/C60 concretes.(see Table 4.9).

Table 4.9: Strength Loss of Concretes with Different Percentages of QP as a Partial Replacement of Cement Subjected to 600°C at 56 Days of Curing Age

Concrete Type	Quartz Proportion	% Loss of Strength
C20/25	Qp0	0
	Qp10	23.44
	Qp20	6.61
	Qp30	35.46
	Qp40	39.42
C35/45	Qp0	0
	Qp10	30.12
	Qp20	11.32
	Qp30	38.5
	Qp40	52.14
C50/60	Qp0	0
	Qp10	25.23
	Qp20	1.55
	Qp30	27.12
	Qp40	45.28

This decrease in residual compressive strength emanates from the fact that increases in temperature leads to loss of capillary water and water on the surface of concrete. This process is accelerated by the decreased cohesive forces between water molecules because of water expansion (Hager, 2013) which results to definite loss of strength. The hydrated hardened concrete contains a substantial proportion of free calcium hydroxide (Ca(OH)_2) which loses its water by more than 400°C leaving calcium oxide (CaO). The CaO rehydrates to Ca(OH)_2 and expand in volume if it is

exposed to moist air or gets wet. The expansion decomposes the concrete (Neville, 1987).

Tufail (2017) disclosed that, with further rise in temperature, decomposition of portlandite happens between 400°C and 540°C. Increase in temperature above 400°C brings about rapid decrease in the concrete strength owing to degradation of calcium–silica–hydrate (C–S–H).

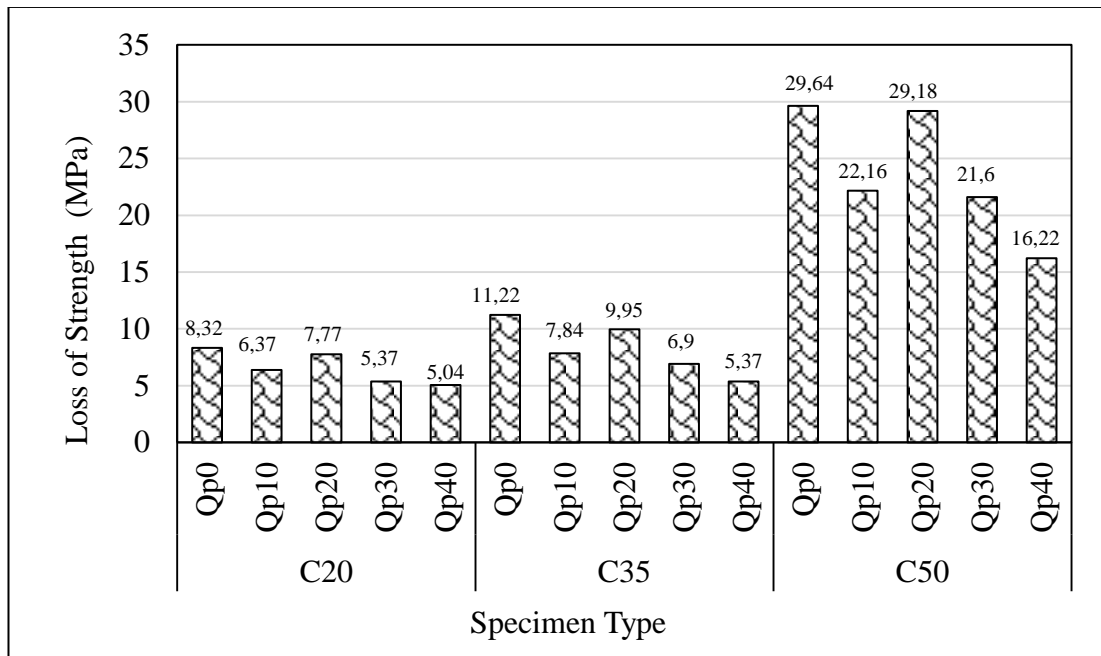


Figure 4.22: Effect of QP After Heat Resistance Up to 600°C on Loss of Strength at 56 Days

As can be seen in Figure 4.22, the residual compressive strength of the three concrete classes are decreased, but this reduction of residual compressive strength of C50/60 less than other two concrete classes (C20/25 and C35/45) after exposure to very high temperature.

The findings in this study conforms to Husem (2006), he concluded that concrete strength is inversely related to high temperature. That is, concrete strength decreases with increase in temperature. Meanwhile, the reduction in the strength of ordinary concrete is more than that in high strength concrete. Zhang et al (2000), reported that this phenomenon implies that more energy is needed to break the surface of concrete and to overcome the cohesive force resulting from aggregate bridging, aggregate interlocking, frictional forces and other mechanisms in the integration process zone of C50/60 than those of C20/25 and C35/45 specimens as the temperature level increased.

4.9 Application and Cost of Quartz Powder (QP)

Quartz is an indispensable mineral for industrial construction required in glass manufacturing industries (industries producing transparent glasses, transparent flat plate glass, fiber glass, and ceramic manufacturing industries as well as solar-industry (solar panels).

Quartz sand is used as filler in the production of rubber, putty and paint, traction in the railroad and mining industries and recreation (volleyball courts, baseball fields, golf courses, children's sand boxes and beaches). Also, quartz sand is intensively use primarily as bathroom countertop, bar tops, kitchen tops, floor and outside walls.

Quartz powder and grains are vital minerals essentially used in construction, blasting, Abrasive, Foundry (sand blasting, scouring cleansers, grinding media, and grit for sanding and sawing). Similarly, recent studies showed the use of quartz powder as admixture or partial replacement cement on physical as well as mechanical properties of concrete.

4.9.1 Cost of Cement and Quartz Powder

Quartz powder (QP) is produced in great amounts in India, China and Turkey, and exported to Europe, Australia, USA, Russia, Middle East and Asia. Table 4.10 shows the prices of quartz in some countries and compared to cement prices in same countries.

Table 4.10 : Cost Analysis of QP and Blast Furnace Slag Cement

Countries	BFS Cement price \$ Per ton	QP (75 μ m) price \$ Per ton	Average cost of QP* concrete \$ Per ton	Cost reduction percent (%)
India	42	16	39.4	6.2
China	45	18	42.3	6.0
Turkey	46	25	43.9	4.5

* 10 % QP as a partial replacement with cement

According to Table 4.10, in these countries the price of QP is less than cement price, so, it has economic benefit and from environmental point of view, hence, it has great impact to reduce of environmental pollution. Cement industry produces huge amounts of CO₂ into the earth's atmosphere which is largely responsible for the increase in greenhouse gas effects.

It can be observed from the above experimental test results that up to 10% replacement level of QP generally improved different properties of concrete. On the other hand, for higher replacement levels with cement than 10%, compressive strength, flexural strength and splitting tensile strength decreased gradually. As mentioned in Chapter 2, in 2016, around 4.2 billion metric tons of cement was produced all over the world, hence the amount of cement incorporated into about 34 billion metric tons of concrete. One can say that, when 10% of QP is used to replace

4.2 billion metric tons of cement, this means that 0.42 billion tons of QP is used, hence the total production of cement in the world would be 3.78 billion metric tons. As a result, 10% QP as a replacement level with cement will cause a reduction in emission of CO₂ gas of about 0.8% (CO₂ reduction from 8 % to 7.2%).

Chapter 5

CONCLUSION

5.1 Conclusions

In this research, three different classes of concrete namely C20/C25, C35/C45 and C50/C60 modified with five various percent of quartz powder (QP) namely 10, 20, 30 and 40% as a partial replacement of cement were investigated in order to study the effect of QP on different properties of fresh and hardened concrete. From the experimental test results the following conclusions are drawn for fresh and hardened concretes:

- a) As the percentage of QP as a partial replacement with cement increased for concrete classes C20/C25 and C35/C45 the concrete slump test result is decreased. This reduction is because QP particles compared to cement particles absorb more water for its chemical reaction. However, for C50/C60 concrete mixtures up to 30% QP increased the slump test result and at 40% of QP replacement level led to a decrease in the slump. This increase is because of 0.5% superplasticizer admixture which made a film around the QP particles.
- b) Using 10% QP to cement replacement for all various classes of concrete lead to increase in the compressive strength, and the maximum increase is obtained with C50/C60 concrete mixture. Beyond 10% of QP replacement with cement the compressive strength started to decrease and it reached the

lowest compressive strength value with 40% of QP. For instance, for concrete class of C20/C25 when using 40% QP as a partial replacement level with cement, the test specimens lost more than 50% of their compressive strength.

- c) Replacing 10% cement by QP with various classes of concretes improved the flexural tensile strength of these concretes. Beyond 10% QP replacement level, the flexural tensile strength started to decrease and it reached its lowest test with 40% of QP replacement level.
- d) According the experiments in this study, QP had no positive effect on splitting tensile strength. This is because the QP does not have a good pozzolanic reaction at normal room's curing temperature (low temperature) and also quartz is an oxide mineral with a brittle tenacity. However for C50/C60 class of concrete (with 0.5% superplasticizer) by replacing 10% QP with cement little positive effect on tensile strength was gained.
- e) By replacing 10% cement with QP for all classes of concrete i.e. C20/C25, C35/C45 and C50/C60, the resistance of concrete to chloride penetration is increased, this increment is due to the fact that QP act as a filler material.
- f) Replacing cement with QP had a positive affect on water absorption capacity up to 40% QP replacement level for each of C20/C25 and C50/C60 concrete classes. On the other hand, concrete class of C35/C45 up to 20% QP replacement level had a positive affect. Generally, at 10% QP replacement level the water absorption capacity significantly decreased of all classes of concrete.

- g) Residual compressive strength for all cylindrical samples exposed to 600°C temperature is decreased. But, just at a 20% QP replacement level had a little positive effect on the residual compressive strength compared with the rest of the proportions of QP.
- h) From the environmental point of view, up to 20% QP can be used to replace cement as it is concluded from compressive strength, rapid chloride penetration and water absorption capacity test results.
- i) The statistical correlation among results was studied and the followings were found:
- The relationship between compressive strength and flexural strength for both 28 and 56 days of curing age is high for all concrete classes except in concrete class C20/25 at 28 days, it is observed to be low.
 - The relationship between compressive strength and splitting tensile strength for both 28 and 56 days of curing age is high for C50/60 and moderate for C20/25 class moderate, but for C35/45 concrete is moderate at 28 days and high at 56 days.
 - The relationship between water absorption capacity and chloride ion penetration 56 days of curing age is age is high for C50/60, moderate for C20/25 and very low for C35/45 concrete classes.
 - The relationship between water absorption capacity and compressive strength at 56 days of curing age is age is high for C35/45, and very low for both C20/25 and C50/60 concretes classes.

5.2 Recommendations for Further Studies

- 1- Using high temperature curing conditions, for curing concretes with QP as partial replacement with cement instead of normal curing temperature may lead to better influences and improvements on the mechanical properties of concrete.
- 2- Studying the influences of combination of pozzolanic materials and QP as a partial replacement of cement on the physical and mechanical properties of mortars or concretes.
- 3- Studying the influence of different replacement levels of QP on concrete properties such as impact strength and toughness tests where there is little information on these research areas.
- 4- Studying the influence of different replacement levels of QP with cement on the durability aspects of concrete such as freezing and thawing, shrinkage and permeability tests.
- 5- Studying possibilities of increasing the strength of concrete or compensating the strength loss when different replacement levels of QP with cement are incorporated in concrete. Such possibilities include Reducing w/c ratio and use of superplasticizers, use of different pozzolans with QP.
- 6- Studying the influence of different replacement levels of QP with cement on the properties of different types of concretes. These types include ultra-high strength concrete, high performance concrete, high flowable concrete, self-

compacted concrete, self-healing concrete, lightweight concrete and roller compacted concrete.

REFERENCES

- A.M Neville, J. B. (1987). *Concrete Technology*. London: pearson.
- A.M.Neville. (1995). *Properties of concrete*. London: longman.
- Adefemi, A., Muhammad, U., Birnin, K. U. M., & Olugbenga, S. (2013). Effect of admixture on fire resistance of ordinary portland cement concrete. *Civil and Environmental Research*, 3(1), 302-308.
- Aköz, F., Yüzer, N., & Koral, S. (1995). The influence of high temperature on the physical and mechanical properties of ordinary Portland cement and silica fume mortar. *Teknik Dergi-Tmmob Insaat Muhendisleri Odasi*, 6, 287-292.
- Ansari, I., & Sahare, S. (2015). Utilization of Glass Powder as a Partial Replacement of Cement and its effect on concrete strength-A review. In *Proceedings of 45 th IRF International Conference, Pune, India*.
- Arioz, O. (2007). Effects of elevated temperatures on properties of concrete. *Fire safety journal*, 42(8), 516-522.
- Aydın, S., & Baradan, B. (2007). Effect of pumice and fly ash incorporation on high temperature resistance of cement based mortars. *Cement and Concrete Research*, 37(6), 988-995.

- Benhelal, E., Zahedi, G., Shamsaei, E., & Bahadori, A. (2013). Global strategies and potentials to curb CO₂ emissions in cement industry. *Journal of cleaner production*, *51*, 142-161.
- Cable, J. K., Wang, K., & Ge, Z. (2003). *Investigation into improved pavement curing materials and techniques: Part 2 (phase III)* (No. Iowa DOT TR-479).
- Castro, J., Bentz, D., & Weiss, J. (2011). Effect of sample conditioning on the water absorption of concrete. *Cement and Concrete Composites*, *33*(8), 805-813.
- Celik, T., & Marar, K. (1996). Effects of crushed stone dust on some properties of concrete. *Cement and Concrete research*, *26*(7), 1121-1130.
- Chen, D., Deng, M., Mo, L., & He, Z. (2017). Influence of modified quartz tailing on strength and autogenous shrinkage of cement pastes. *Advances in Cement Research*, *29*(1), 11-20.
- Chen, L. J., Jun, H. E., Chao, J. Q., & Qin, B. D. (2009). Swelling and breaking characteristics of limestone under high temperatures. *Mining Science and Technology (China)*, *19*(4), 503-507.
- Chini, A. R., Muszynski, L. C., Acquaye, L., & Tarkhan, S. (2003). Determination of the Maximum Placement and Curing Temperatures in Mass Concrete to Avoid Durability Problems and DEF. *Final Report*, 46-64.

- Cioni, P., Croce, P., & Salvatore, W. (2001). Assessing fire damage to rc elements. *Fire safety journal*, 36(2), 181-199.
- Collins, F., & Sanjayan, J. G. (1999). Effects of ultra-fine materials on workability and strength of concrete containing alkali-activated slag as the binder. *Cement and concrete research*, 29(3), 459-462.
- Courtial, M., de Noirfontaine, M. N., Dunstetter, F., Signes-Frehel, M., Mounanga, P., Cherkaoui, K., & Khelidj, A. (2013). Effect of polycarboxylate and crushed quartz in UHPC: microstructural investigation. *Construction and Building Materials*, 44, 699-705.
- Cwirzen, A. (2007). The effect of the heat-treatment regime on the properties of reactive powder concrete. *Advances in Cement Research*, 19(1), 25-34.
- Dali, J. S., & Tande, S. N. (2012, August). Performance of concrete containing mineral admixtures subjected to high temperature. In *37th Conference on Our World in Concrete and Structures, Singapore, August*.
- De Larrard, F. (1999). *Concrete mixture proportioning: a scientific approach*. CRC Press.
- Demirboğa, R., Türkmen, İ. & Karakoç, M. B. (2007). Thermo-mechanical properties of concrete containing high-volume mineral admixtures. *Building and Environment*, 42(1), 349-354.

- Diederichs, U., & Schneider, U. (1981). Bond strength at high temperatures. *Magazine of Concrete Research*, 33(115), 75-84.
- G Elkhadiri, I., Palacios, M., & Puertas, F. (2009). Effect of curing temperature on cement hydration. *Ceram Silik*, 53(2), 65-75.
- Gallias, J. L., Kara-Ali, R., & Bigas, J. P. (2000). The effect of fine mineral admixtures on water requirement of cement pastes. *Cement and concrete research*, 30(10), 1543-1549.
- Glanville, W. H. (1947). The grading of aggregates and workability of concrete. *Road Research Technical Paper*, 5.
- Grace, W. R. (2006). Understanding AASHTO T277 and ASTM C1202 Rapid chloride permeability test. *Technical Bulletin*, 100.
- Gutteridge, W. A., & Dalziel, J. A. (1990). Filler cement: the effect of the secondary component on the hydration of Portland cement: part I. A fine non-hydraulic filler. *Cement and Concrete Research*, 20(5), 778-782.
- Hager, I. (2013). Behaviour of cement concrete at high temperature. *Bulletin of the Polish Academy of Sciences: Technical Sciences*, 61(1), 145-15.
- Helmi, M., Hall, M. R., Stevens, L. A., & Rigby, S. P. (2016). Effects of high-pressure/temperature curing on reactive powder concrete microstructure formation. *Construction and Building Materials*, 105, 554-562.

Hossain, M. A., Islam, M. N., & Karim, M. R. (2006, August). Fire resistance of cement mortar containing high volume fly ash. In *31st conference on our world in concrete & structures* (pp. 16-17).

Husem, M. (2006). The effects of high temperature on compressive and flexural strengths of ordinary and high-performance concrete. *Fire Safety Journal*, *41*(2), 155-163.

International Energy Agency (2017 edition). *CO2 Emissions from Fuel Combustion: 1972*. Organization .

Ipek, M., Yilmaz, K., Sümer, M., & Saribiyik, M. (2011). Effect of pre-setting pressure applied to mechanical behaviours of reactive powder concrete during setting phase. *Construction and Building Materials*, *25*(1), 61-68.

Isu, N., Ishida, H., & Mitsuda, T. (1994). Influence of quartz particle size on the chemical and mechanical properties of autoclaved aerated concrete (I) tobermorite formation.. *Cement and concrete research*, *25*(2), 243-248.

Isu, N., Teramura, S., Ishida, H., & Mitsuda, T. (1995). Influence of quartz particle size on the chemical and mechanical properties of autoclaved aerated concrete (II) fracture toughness, strength and micropore. *Cement and concrete research*, *25*(2), 249-254.

- Johari, M. M., Brooks, J. J., Kabir, S., & Rivard, P. (2011). Influence of supplementary cementitious materials on engineering properties of high strength concrete. *Construction and Building Materials*, 25(5), 2639-2648.
- Kamali, M., & Ghahremaninezhad, A. (2016). An investigation into the hydration and microstructure of cement pastes modified with glass powders. *Construction and Building Materials*, 112, 915-924.
- Kjellsen, K. O., & Lagerblad, B. (1995). *The influence of natural minerals in the filler fraction on the hydration and properties of cement-filler mortars*. Cement och Betong Institutet
- Kronlöf, A. (1994). Effect of very fine aggregate on concrete strength. *Materials and Structures*, 27(1), 15-25
- Kumar, S., Gupta, R. C., & Shrivastava, S. (2016). Strength, abrasion and permeability studies on cement concrete containing quartz sandstone coarse aggregates. *Construction and Building Materials*, 125, 884-891.
- Larbi, J. A. (1993). Microstructure of the interfacial zone around aggregate particles in concrete. *NASA STI/Recon Technical Report N, 94*.
- Lawrence, P., Cyr, M., & Ringot, E. (2003). Mineral admixtures in mortars: effect of inert materials on short-term hydration. *Cement and concrete research*, 33(12), 1939-1947.

- Lothenbach, B., Winnefeld, F., Alder, C., Wieland, E., & Lunk, P. (2007). Effect of temperature on the pore solution, microstructure and hydration products of Portland cement pastes. *Cement and Concrete Research*, 37(4), 483-491.
- Malhotra, H. L. (1956). The effect of temperature on the compressive strength of concrete. *Magazine of concrete research*, 8(23), 85-94.
- Mohseni, E., Tang, W., & Cui, H. (2017). Chloride diffusion and acid resistance of concrete containing zeolite and tuff as partial replacements of cement and sand. *Materials*, 10(4), 372.
- Morsy, M. S., Rashad, A. M., & El-Nouhy, H. A. (2009). Effect of elevated temperature on physico-mechanical properties of metakaolin blended cement mortar. *Structural Engineering and Mechanics*, 31(1), 1-10.
- Mostofinejad, D., Nikoo, M. R., & Hosseini, S. A. (2016). Determination of optimized mix design and curing conditions of reactive powder concrete (RPC). *Construction and Building Materials*, 123, 754-767.
- Najimi, M., Jamshidi, M., & Pourkhorshidi, A. (2008). Durability of concretes containing natural pozzolan. *Proceedings of the Institution of Civil Engineers-Construction Materials*, 161(3), 113-118.
- Nikdel, A. (2014). Nikdel, A. (2014). *Mechanical Properties of Concrete Containing Quartz Powder as a Filler Instead of Using Silica Fume* (Master's thesis, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ))

- Noumowe, A. N., Clastres, P., Debicki, G., & Bolvin, M. (1994). High temperature effect on high performance concrete (70-600 C) strength and porosity. *Special Publication*, 145, 157-172.
- Pade, C., & Guimaraes, M. (2007). The CO₂ uptake of concrete in a 100 year perspective. *Cement and Concrete Research*, 37(9), 1348-1356.
- Paillere, A., Buil, M., & Serrano, J. J. (1989). Effect of fiber addition on the autogenous shrinkage of silica fume. *Materials Journal*, 86(2), 139-144.
- Péra, J., Husson, S., & Guilhot, B. (1999). Influence of finely ground limestone on cement hydration. *Cement and Concrete Composites*, 21(2), 99-105.
- Phan, L. T., Lawson, J. R., & Davis, F. L. (2001). Effects of elevated temperature exposure on heating characteristics, spalling, and residual properties of high performance concrete. *Materials and Structures*, 34(2), 83-91.
- Powers, T. C., Copeland, L. E., & Mann, H. M. (1959). *Capillary continuity or discontinuity in cement pastes* (No. 110)
- Powers, T. C., Copeland, L. E., Hayes, J. C., & Mann, H. M. (1954, November). Permeability of Portland Cement Paste. In *Journal Proceedings* (Vol. 51, No. 11, pp. 285-298).

- Rashad, A. M. (2013). A comprehensive overview about the influence of different additives on the properties of alkali-activated slag—a guide for civil engineer. *Construction and building materials*, 47, 29-55.
- Rashad, A. M. (2014). A comprehensive overview about the influence of different admixtures and additives on the properties of alkali-activated fly ash. *Materials & Design*, 53, 1005-1025
- Rashad, A. M. (2014). An exploratory study on alkali-activated slag blended with quartz powder under the effect of thermal cyclic loads and thermal shock cycles. *Construction and Building Materials*, 70, 165-174.
- Rashad, A. M., & Ouda, A. S. (2016). An investigation on alkali-activated fly ash pastes modified with quartz powder subjected to elevated temperatures. *Construction and Building Materials*, 122, 417-425.
- Rashad, A. M., & Zeedan, S. R. (2011). The effect of activator concentration on the residual strength of alkali-activated fly ash pastes subjected to thermal load. *Construction and Building Materials*, 25(7), 3098-3107.
- Rashad, A. M., & Zeedan, S. R. (2012). A preliminary study of blended pastes of cement and quartz powder under the effect of elevated temperature. *Construction and building materials*, 29, 672-681.
- Rashad, A. M., Bai, Y., Basheer, P. A. M., Collier, N. C., & Milestone, N. B. (2012). Chemical and mechanical stability of sodium sulfate activated slag after

exposure to elevated temperature. *Cement and Concrete Research*, 42(2), 333-343.

Rehan, R., & Nehdi, M. (2005). Carbon dioxide emissions and climate change: policy implications for the cement industry. *Environmental Science & Policy*, 8(2), 105-114.

Richard, P., & Cheyrezy, M. (1995). Composition of reactive powder concretes. *Cement and concrete research*, 25(7), 1501-1511.

Roy, D. K. S., & Sil, A. (2012). Effect of partial replacement of cement by silica fume on hardened concrete. *International Journal of Emerging Technology and Advanced Engineering*, ISSN, 2250-2459.

Sadrekarimi, A. (2004). Development of a light weight reactive powder concrete. *Journal of Advanced Concrete Technology*, 2(3), 409-417.

Safiuddin, M., Raman, S. N., & Zain, M. F. M. (2007). Effect of different curing methods on the properties of microsilica concrete. *Australian Journal of Basic and Applied Sciences*, 1(2), 87-95.

Shetty, M. S. (2005). *Concrete Technology Theory & Practice*, Published by S. CHAND & Company, Ram Nagar, New Delh

Siddique, R. (2008). *Cement Kiln Dust*. In *Waste Materials and By-Products in Concrete* (pp. 351-380). Springer, Berlin, Heidelberg.

- Sudarshan, D. K., & Vyas, A. K. (2017). Impact of fire on mechanical properties of concrete containing marble waste. *Journal of King Saud University-Engineering Sciences*.
- Tam, C. M., Tam, V. W., & Ng, K. M. (2012). Assessing drying shrinkage and water permeability of reactive powder concrete produced in Hong Kong. *Construction and Building Materials*, 26(1), 79-89.
- Terro, M. J. (2006). Properties of concrete made with recycled crushed glass at elevated temperatures. *Building and environment*, 41(5), 633-639.
- Tikkanen, J., Cwirzen, A., & Penttala, V. (2014). Effects of mineral powders on hydration process and hydration products in normal strength concrete. *Construction and Building Materials*, 72, 7-14.
- Tikkanen, J., Penttala, V., & Cwirzen, A. (2011). Mineral powder concrete—effects of powder content on concrete properties. *Magazine of Concrete Research*, 63(12), 893-903.
- Tufail, M., Shahzada, K., Gencturk, B., & Wei, J. (2017). Effect of elevated temperature on mechanical properties of limestone, quartzite and granite concrete. *International Journal of Concrete Structures and Materials*, 11(1), 17-28.
- Whiting, D. (1988). Permeability of selected concretes. *Special Publication*, 108, 195-222.

- Xiao, J., & Falkner, H. (2006). On residual strength of high-performance concrete with and without polypropylene fibres at elevated temperatures. *Fire safety journal*, 41(2), 115-121.
- Ye, G., Liu, X., De Schutter, G., Poppe, A. M., & Taerwe, L. (2007). Influence of limestone powder used as filler in SCC on hydration and microstructure of cement pastes. *Cement and Concrete Composites*, 29(2), 94-102.
- Yuan, X. L., Fang, Y. H., & Gu, Y. M. (2013). Effect of Quartz Powder on the Strength and Shrinkage of Alkali-Activated Slag Cement. In *Advanced Materials Research* (Vol. 602, pp. 972-975). Trans Tech Publications.
- Zhang, B. (2011). Effects of moisture evaporation (weight loss) on fracture properties of high performance concrete subjected to high temperatures. *Fire Safety Journal*, 46(8), 543-549.
- Zhang, B., Bicanic, N., Pearce, C. J., & Balabanic, G. (2000). Residual fracture properties of normal-and high-strength concrete subject to elevated temperatures. *Magazine of Concrete Research*, 52(2), 123-136.
- Zhang, S. P., & Zong, L. (2014). Evaluation of relationship between water absorption and durability of concrete materials. *Advances in Materials Science and*

APPENDIX

Mix-design Forms

Concrete mix design form

Job titleC20.....

Stage	Item	Reference or calculation	Values					
1	1.1	Characteristic strength	Specified { 20 N/mm ² at 28 days Proportion defective %					
	1.2	Standard deviation	Fig 3 8 N/mm ² or no data N/mm ²					
	1.3	Margin	C1 or Specified (k =) 8 × 1.2 = 9.6 N/mm ²					
	1.4	Target mean strength	C2 20 + 10 = 30 N/mm ²					
	1.5	Cement strength class	Specified 32.5 42.5/52.5					
	1.6	Aggregate type: coarse Aggregate type: fine	Crushed/uncrushed Crushed/uncrushed					
	1.7	Free-water/cement ratio	Table 2, Fig 4 0.68					
	1.8	Maximum free-water/cement ratio	Specified } Use the lower value 0.68					
2	2.1	Slump or Vebe time	Specified Slump 60-180 mm or Vebe time s					
	2.2	Maximum aggregate size	Specified 20 mm					
	2.3	Free-water content	Table 3 225 225 kg/m ³					
3	3.1	Cement content	C3 225 + 0.68 = 330 kg/m ³					
	3.2	Maximum cement content	Specified kg/m ³					
	3.3	Minimum cement content	Specified kg/m ³					
	3.4	Modified free-water/cement ratio	use 3.1 if ≤ 3.2 use 3.3 if > 3.1 320 kg/m ³					
4	4.1	Relative density of aggregate (SSD) 2.7 known/assumed					
	4.2	Concrete density	Fig 5 2380 kg/m ³					
	4.3	Total aggregate content	C4 2380 - 330 - 225 = 1825 kg/m ³					
5	5.1	Grading of fine aggregate	Percentage passing 600 µm sieve 30 %					
	5.2	Proportion of fine aggregate	Fig 6 50 %					
	5.3	Fine aggregate content	C5 { 1825 × 0.5 = 912 kg/m ³ 1825 - 912 = 913 kg/m ³					
	5.4	Coarse aggregate content						
Quantities		Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg)	14 mm	20 mm	40 mm
per m ³ (to nearest 5 kg)	 330 225 912 166 498 249	
per trial mix of m ³								

Items in italics are optional limiting values that may be specified (see Section 7).
Concrete strength is expressed in the units N/mm². 1 N/mm² = 1 MN/m² = 1 MPa. (N = newton; Pa = pascal).
The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.
SSD = based on the saturated surface-dry condition.

Concrete mix design form

Job title C35

Stage	Item	Reference or calculation	Values				
1	1.1	Characteristic strength	Specified { 35 N/mm ² at 28 days Proportion defective %				
	1.2	Standard deviation	Fig 3 8 N/mm ² or no data 10 N/mm ²				
	1.3	Margin	C1 or Specified (k =) 8 × 1.2 = 9.6 N/mm ²				
	1.4	Target mean strength	C2 35 + 10 = 45 N/mm ²				
	1.5	Cement strength class	Specified 42.5/52.5				
	1.6	Aggregate type: coarse Aggregate type: fine	Crushed/uncrushed Crushed/uncrushed				
	1.7	Free-water/cement ratio	Table 2, Fig 4 0.54				
	1.8	Maximum free-water/cement ratio	Specified 0.5 } Use the lower value 0.50				
2	2.1	Slump or Vebe time	Specified Slump 60 - 180 mm or Vebe time s				
	2.2	Maximum aggregate size	Specified 20 mm				
	2.3	Free-water content	Table 3 225 225 kg/m ³				
3	3.1	Cement content	C3 225 + 0.5 = 450 kg/m ³				
	3.2	Maximum cement content	Specified kg/m ³				
	3.3	Minimum cement content	Specified kg/m ³				
	3.4	Modified free-water/cement ratio	use 3.1 if ≤ 3.2 use 3.3 if > 3.1 450 kg/m ³				
4	4.1	Relative density of aggregate (SSD) 2.7 known/assumed				
	4.2	Concrete density	Fig 5 2370 kg/m ³				
	4.3	Total aggregate content	C4 2370 - 450 - 225 = 1625 kg/m ³				
5	5.1	Grading of fine aggregate	Percentage passing 600 µm sieve 30 %				
	5.2	Proportion of fine aggregate	Fig 6 47 %				
	5.3	Fine aggregate content	C5 { 1695 × 0.47 = 796 kg/m ³ 1695 - 796 = 899 kg/m ³				
	5.4	Coarse aggregate content					
Quantities		Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg)		
					10 mm	20 mm	14 mm 40 mm
per m ³ (to nearest 5 kg)	 450 225 796 163 490 245
per trial mix of m ³							

Items in italics are optional limiting values that may be specified (see Section 7).
 Concrete strength is expressed in the units N/mm². 1 N/mm² = 1 MN/m² = 1 MPa. (N = newton; Pa = pascal).
 The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.
 SSD = based on the saturated surface-dry condition.

