Mechanical Properties of Concrete Containing Quartz Powder as a Filler Instead of Using Silica Fume

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ABSTRACT

The development and usage of concrete as a construction material has been greatly increased and widely accepted all over the world. The most important parameters in concrete that should be considered are: workability, strength and durability. By adding pozzolans and cementitous filler materials, strength and durability of concrete can be improved. Even though it will cause in reduction of workability and it brings up the need of superplastisizer or a w/c ratio more than 0.4, they have been used widely over the past decades. There are lots of known materials which act as pozzolans, and many researchers tried new materials as a cement replacement to test their effects on the concrete. Properties of concrete can be improved by finding the best combination and percentage replacement of cement for these materials in fresh and hardened states.

In this experimental study, the effects of replacing cement by silica fume, quartz powder and combination of them with three different percentage of replacement (10, 15, and 20%) on fresh and hardened states of concrete has been investigated. At the end, by testing the samples, the optimum combination has been figured out by comparing the mixes with the plain sample, which is a sample with no cement replacement. Many experiments has been done in this investigation such as slump test on fresh state and compressive strength, splitting tensile strength, flexural strength, depth of penetration (Permeability), rebound (Schmidt) hammer number and ultrasonic pulse velocity on hardened state. It can be concluded that, replacing cement by combined supplementary materials, increases the compressive strength and reduces the permeability in concrete, but increasing usage of these replacement materials does not have an efficient positive effect on flexural strength.

Keywords: Silica fume, quartz powder, cement replacement, compressive strength, splitting tensile strength, flexural strength, depth of penetration, PUNDIT, rebound hammer.

ÖZ

Beton sürekli gelişmekte olan kullanımı alanınadan dolayı tüm dünyada bilinmekte ve kabul görmektedir. Betonda aranan ve önemsenmesi gereken bazı özellikler şöyle sıralanabilir: işlenebilirlik, mukavemet ve durabilite. Puzolanlar ve diğer katkı malzemeleri ile mukavemet ve durabilitede iyileştirmeler yapılabildiği bir gerçektir. Bu malzemelerin kullanımı ile işlenebilirlik düşmekte ve bundan dolayı da kimyasal katkı kullanımını zorunlu hale gelmektedir. Günümüzde pek çok malzeme puzolan olarak kullanılmakta ve bu konularda yoğun şekilde araştırmalar yürütülmektedir. Doğru oranlarda kullanılırsa bu malzemelerin betonun taze ve kuru özelliklerini iyileştirdiği de bilinmektedir.

Bu tez için yapılan çalışmada, silis dumanı ve kuvarz tozunun ayrı ayrı ve birlikte çimento ikame malzemesi olarak kullanılmasının betonun taze ve kuru özelliklerine olan etkisi araştırılmıştır. Kullanılan oranlar %10, %15 ve %20 olarak değiştirilmiştir. Elde dilen sonuçlara bakılıp en iyi kombinasyon bulunmaya çalışılmıştır. Yapılan çalışmada taze beotn deneyleri olarak çökme deneyi, kuru beton deneyi olarak ise basınç dayanımı, yarmada çekme dayanımı, eğilme dayanımı, penetrasyon derinliği, beton çekiç vurusu ve ultrasonic pals hızı ölçümleri yapılmıştır. Elde edilen sonuçlara bakıldığı zaman ise her iki malzemenin de geçirgenliğin in azaldığı görülmüştür. Diğer taraftan ise eğilme dayanımında önemli bir iyileşme olmadığı ortaya çıkmıştır.

Anahtar kelimeler: silis dumanı, kuvarz tozu, çimento ikamesi, basınç dayanımı, yarmada çekme dayanımı, eğilme dayanımı, penetrasyon miktarı, PUNDIT, beton çekici vuruşu.

To

my dear parents and sister,

and my dear Roxana

with love and respect

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BRE	Building Research Establishment
BS-EN	British Standards- European Norms
SF	Silica Fume
QP	Quartz Powder
PUNDIT	Ultrasonic Pulse Velocity Test
W/C	Water to Cement ratio
GGBS	Ground Granulated Blast Furnace Slag
MPa	Mega Pascal
D	Diameter

Chapter 1

INTRODUCTION

1.1 General

Concrete is a versatile and useful manmade building material, that is useful in various construction purposes and has been widely accepted to use because of some important properties such as fire resistance, being shaped easily, having huge chemical resistance. On the other hand it has a better acceptance between contractors because of its lower financial effects, and it can be easily produced.

Like other materials there are different experiments for controlling the concrete's quality, each one formed to test the properties of concrete. Some destructive experiments which are used to examine the strength of concrete, were done. Compressive strength, splitting tensile strength and flexural strength tests are three essential experiments. Some other non-destructive experiments, such as ultrasonic pulse velocity and rebound hammer test are also used. The results of all experiments can be changed due to some environmental effects or vibration time. For achieving a concrete with higher quality and better properties different techniques were adapted, such as using fibers, different conditions for curing and adding admixtures or additives. One of these additive materials is quartz powder (QP) which is a natural fine material that can be replaced by cement.

Concrete with ordinary Portland cement has lots of voids between fine particles which causes higher permeability and lower durability, so QP with ultra-fine particles can fill the voids and make better resistance to permeability and also because of better bonding it has positive effects on other mechanical properties when it combines with silica fume.

1.2 Objectives and works done

The aim of this experimental study is to test the effect of replacing cement by QP and SF in concrete with different percentages of replacement. The study was done based on experimental work and discussion about results for five series of combinations of supplementary materials which is explained below.

F1: these mixes contain silica fume as cement replacement materials in three different percentages (10, 15 and 20) and have no quartz powder additive.

F2, F3 and F4: these mixes contain silica fume and quartz powder as cement replacement materials in three different percentage (10, 15 and 20) by different ratio of SF/QP which are 1.5/0.5, 1/1 and 0.5/1.5 respectively.

F5: these mixes contain quartz powder as a cement replacement material in three different percentages (10, 15 and 20) and have no silica fume additive. Regarding the objective, sieve analysis for fine and coarse aggregates, and four trial mix designs to find the best mix design, was done. The standards from ASTM and BS-EN were used to cast and cure the samples.

1.3 Works done and achievements

This study is based on experiments and discussion about the results that were achieved from experimental work. The achievements during this study are listed below:

1. Compressive strength, depth of penetration and non-destructive tests on cubic (150* 150* 150 mm) samples, splitting tensile strength on cylindrical specimens and flexural strength on (100* 100* 500 mm) beams were tested.

2. Relations between amount and percentage of substitution of cement by QP and SF were obtained.

3. Considering five mixes with different percentage of cement replacement, the results were compared to each other and discussed.

1.4 Thesis outline

In chapter 2, (literature review), the previous significant works on the properties of concrete have been briefly mentioned and explained.

Chapter 3 (experimental works) explains completely the details about all the experiments and methods, which were performed based on standards.

Chapter 4 (results and discussions) includes the results and the discussion about analyzing them based on previous researches and achievements.

In chapter 5 (conclusions), based on results and of what was done in this study, conclusions are briefly listed.

Chapter2

LITERATURE REVIEW

2.1 Description of cement replacement materials

Since construction industry development improved, the development of new materials for construction was developed, too. In recent years by increasing public knowledge about environmental issues (cement production causes producing 5-7% of the CO2 emissions in the world) (E. Bacarji & R. D. Toledo, 2013); substitution of cement with other materials which has less hazardous effects on world environment has been widely accepted. And many researchers studied about materials that can be replaced by cement (Quanbing Yang & S. Zhang, 2000).It could be better to use some materials which have recycling resources, or byproducts of other industries such as silica fume, fly ash, quartz powder etc.

2.2 Condensed silica fume

Some attention has been given to the silica fume as a possible replacement in cement paste. Silica fume was first used in the USA in 1944. Silica fume in concrete has a more than 60 year history (P. Fidjestol, M. 2002).

Silica fume, as a by-product material in the ferrosilicon industry (as it shown in Figure 2.1) is a very efficient pozzolanic material, though it has some problems with its use in concrete due to its very fine particles (Houssam A. Toutanji b, Z. B. 1999).

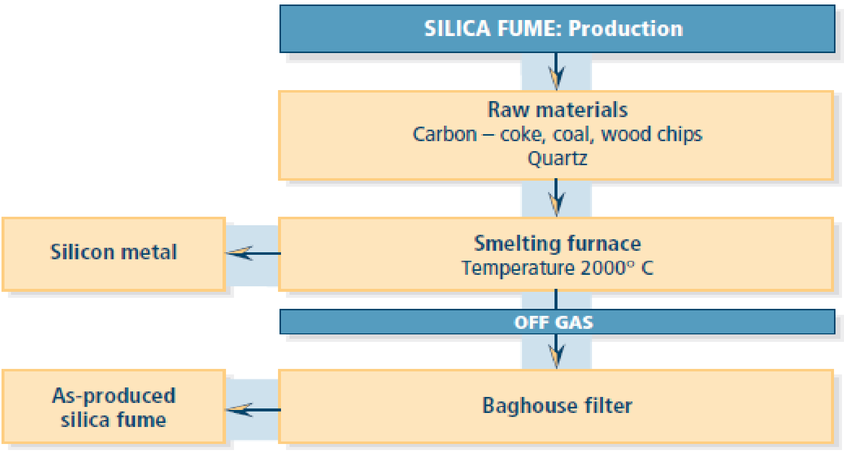

Figure 2.1: Silica Fume Production

Silica fume can have an effect on cement paste in two ways, chemical and physical. In a chemical way, silica fume as a pozzolan increases the compressive strength and other hardened properties like tensile strength (flexural and splitting tensile strength), by combination with lime and producing siliceous hydrates. In a physical way, fine particles have filler effect and make a more dense paste due to its ultra-fine particles, so pore size and porosity will be reduced by filling the holes, and it makes for lower permeability, so durability may be increased (A. Rashad & R. Zeedan, 2011), (M. A. Megat Johari & J. J. Brooks, 2011).Silica fume has a great effect on strength of concrete at early ages; this effect is due to influence of acceleration in hydration and also micro filler effect (M. A. Megat Johari & J. J. Brooks, 2011).

Almost all researchers, after replacing cement with various percentages of silica fume and testing it in 28 days, concluded that concrete with substitution of silica fume with 20% of cement has a highest compressive strength. Modulus of elasticity of the concrete at 28 days could be called as a function of concrete compressive strength; silica fume addition can improve the modulus of elasticity indirectly as well. But in general the effect of supplementary materials on elastic modulus of concrete is small and negligible compared to other effects (M.A. Megat Johari, 2011). And up to 10% of this replacement can improve the workability of fresh concrete. Silica fume addition also has a good effect on flexural and splitting tensile strength of concrete (A. Rashad & R. Zeedan, 2011), (M. A. Megat Johari & J. J. Brooks, 2011). Although silica fume is a perfect replacement material, cement paste in presence of silica fume has a low workability and much water is required, and from economic point of view, silica fume needs superplastisizer for better workability, but superplastisizers may have negative effects in laboratory conditions such as unreal compressive strength, unnecessary workability and also it is expensive, so combination of silica fume with other natural fillers such as quartz powder (QP) may improve concrete properties (M.I. Khan & C.J. Lynsdale, 2002).

2.3 Crushed Quartz Powder

Since quartz powder is available as a natural material that is made from sawing stones and it is almost useless (T. H. Song & S. H. Lee, 2013), and also by product of industries, it could be a good choice for using as a filler in concrete. By using quartz powder as filler instead of cement, the same strength can be reached more economically. M. Courtial et al. evaluated the variable parameter which was quartz powder to silica fume ratio and superplastisizer amount, he said that replacing condensed silica fume by fine quartz powder particles improved almost all the properties such as compressive strength and flexural strength, with replacing 25% of silica fume by quartz crushed powder, but more than that does not have an efficient effect (M. Courtial & M. Noirfontaine, 2013).

The addition of quartz powder with ultra-fine particles improves the concrete properties for various reasons.

1. Physical effect: as far as fillers affect the concrete based on their size and shape, quartz powder can densify and homogenize the paste so it has a positive effect in fresh state and also hardened state of concrete due to its fine particles. QP in low temperature is a non-reactive additive, and acts just as filler (E. Bacarji & R. D. Toledo, 2013). And in fresh state supplementary materials may retard the high strength concrete setting time (M.A. Megat Johari, 2011)

2. Surface chemical effect: when the particles add and improve hydration by acting as a part of paste and make more specific area (H.Moosberg & B. Lagerblad, 2004). And for sure, by adding quartz in presence of some silica fume, a new grain size between SF grain sizes and cement grain sizes will fill the holes specially when quartz crushed powder particles distributed homogeneously (M. Courtial & M. Noirfontaine, 2013).

3. Chemical effect: when the particles add and react with calcium hydroxide in the cement and make calcium silicate (surface area is the most important factor in QP particles so they should be finer than 5 micron to act as a pozzolan in concrete). But in this step the quartz powder needs autoclave cure with above 90ºC temperature to react as a pozzolan (M. Courtial & M. Noirfontaine, 2013), which is not realistic in huge amounts of concrete like foundations or columns in buildings. The second reason for not using high temperature is, it causes evaporation of the water which is necessary for having a continuous process of hydration and the lack of water can cause bad damage on the fresh concrete. The

third one is high temperature forms steam in middle of the fresh concrete, this steam cannot move out so it causes pressure in hardened concrete and due to this pressure, micro cracks and shrinkage will be occurs in concrete, so the designed concrete lifetime and durability will be reduced (D. R. Grander & R. J. Lark, 2005).

Carbonation is a reaction between carbon dioxide (CO_2) and calcium hydroxide ($CaOH_2$), in hydrated concrete to produce calcium carbonate ($CaCO_3$). Carbonation happen at the surface of concrete with cracks, so to reduce crack sizes pozzolans can help (M. I. Khan & C. J. Lynsdale, 2002).

Alaa. M. Rashad said that replacing quartz powder by cement without silica fume did not change the strength of hardened concrete even with 30% replacement and just increased the slump of fresh paste, and the hydration in early ages (A. Rashad & R. Zeedan, 2011). But in the other research, Q. Yang et al. concluded that QP does not help flexural strength so much but it improves compressive strength and micro structures and adding mineral admixture such as crushed quartz can increase fire resistance in concrete (Quanbing Yang & Shuqing Zhanghuang 2000).

But quartz powder can have a big problem in replacing for cement, which is hazardous alkali-silica reaction that can identify as the most important problem in many structures. Alkali silica reaction (ASR) means a reaction between silicon dioxide (SiO_2) and alkalis (K or Na) which are available in cement paste, in water-saturated condition, producing an amorphous silica gel. This silica gel can react with water and because of reaction expansion will occurs, so surrounding concrete will jeopardize (Nicoletta Marinoni, 2012).

Chapter 3

EXPERIMENTAL WORK

3.1 Introduction

The major purpose of this experimental study is to replace 10%, 15% and 20% of weight of cement by silica fume and evaluate the physical properties of concrete such as workability, compressive strength, splitting tensile strength, flexural strength and permeability improvement. After that, by substitution of silica fume with crushed quartz powder in various ranges (25%, 50%, 75% and 100%); any change in properties of fresh and hardened concrete by combination of these two supplementary materials had been tested. The Ground Granulated Blast Furnace Slag cement, class of 42.5, potable water, crushed limestone aggregate from Beşparmak Mountains of Cyprus (both coarse and fine), crushed quartz powder and silica fume exploited for casting paste specimens.

Cubic samples with size of 150* 150* 150* (mm) were applied for compressive strength test and permeability test, samples with size of 100* 100* 500 (mm) were used for flexural strength test and cylinder samples with size of d = 100 mm and L = 200 mm were used for splitting tensile strength water curing condition was considered for specimens and samples were tested at y and 28 days.

3.2 Materials used

3.2.1 Cement

For casting specimens, Ground Granulated Blast Furnace Slag (GGBS) cement, with the class of 42.5, was used. Physical properties and the details of chemical composition of the cement are shown in Table 3.1 and 3.2.

Table 3.1: Chemical compositions of GGBS cement

Chemical compositions (%)									Loss on ignition	Insoluble material
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl^-		
39.18	10.18	2.02	32.82	8.52	-	1.14	0.3	-	1	0.88

Table 3.2: Physical properties of GGBS cement

Physical properties of GGBS cement	Specific gravity (gr/cm^3)	Fineness: specific surface (cm^2/gr)	Fineness (retained on 90 µm sieve)	Fineness (retained on 45 µm sieve)
	2.87	4250	0	0.8

Table 3.3: Setting time

Initial time (min)	210
Final time (min)	365

3.2.2 Aggregates

Three different size of coarse aggregates (10, 14 & 20 mm), (1:1.5:1.5), and fine aggregate were used. Water absorption and specific gravity of fine and coarse aggregates are shown in Table 3.4, and 3.5 respectively. Dust content in coarse aggregate was 4.2% and in fine aggregates 16.5 % (ASTM C 117, 2004)

Table 3.4: Water absorption of fine and coarse aggregate (SSD based)

Aggregate	Water absorption (% of dry mass)
Fine	1.12
D10	1.64
D14	0.97
D20	0.58

Table 3.5: Specific gravity of aggregates

Aggregates	Bulk specific gravity		Apparent specific gravity
	DRY	SSD	
Fine	2.51	2.57	2.67
D10	2.42	2.45	2.51
D14	2.55	2.57	2.62
D20	2.54	2.56	2.62

And also sieve analysis for each size were done and shown in Tables 3.6, 3.7, 3.8 and 3.9 respectively and grading curves shown in Figures 3.1 and 3.2 based on the standard (ASTM C 33, 2008).

Table 3.6: Sieve analysis of 20 mm max size aggregates

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
28	0.00	0.00	0.00	100.00
20	1.07	23.77	23.77	76.23
14	2.56	56.89	80.66	19.34
10	0.56	12.44	93.10	6.90
6.3	0.22	4.89	97.99	2.01
5	0.05	1.12	99.11	0.89
3.35	0.04	0.89	100.00	0.00
pan	-	-	-	-
	4.5			

Table 3.7: Sieve analysis of 14 mm max size aggregates

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
14	0.30	7.57	7.57	92.43
10	2.39	60.15	68.98	31.02
6.3	1.17	29.51	98.49	1.51
5	0.04	0.88	99.37	0.63
3.35	0.03	0.63	100.00	0.00
pan	-	-	-	-

Table 3.8: Sieve analysis of 10 mm max size aggregates

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
28	0.00	0.00	0.00	100
20	0.00	0.00	0.00	100
14	0.00	0.00	0.00	100
10	0.05	2.01	2.01	97.99
6.3	1.17	47.08	49.09	50.91
5	0.54	21.53	70.62	29.68
3.35	0.73	29.38	100	9
pan	-	-	-	-
	2.49			

Table 3.9: Sieve analysis of fine (5 mm max size) aggregates

Sieve (mm)	Weight (kg)	% Retained	Cumulative % retained	Cumulative % passing
4.75	0	0	0	100.00
2.36	0.34	11.00	11.00	89.00
2	0.36	12.00	23.00	77.00
0.59	1.27	43.00	66.00	34.00
0.297	0.40	13.00	79.00	21.00
0.149	0.26	9.00	88.00	12.00
0.075	0.23	8.00	95.00	5.00
pan	0.14	5.00	100.00	0.00
Total	3.00			

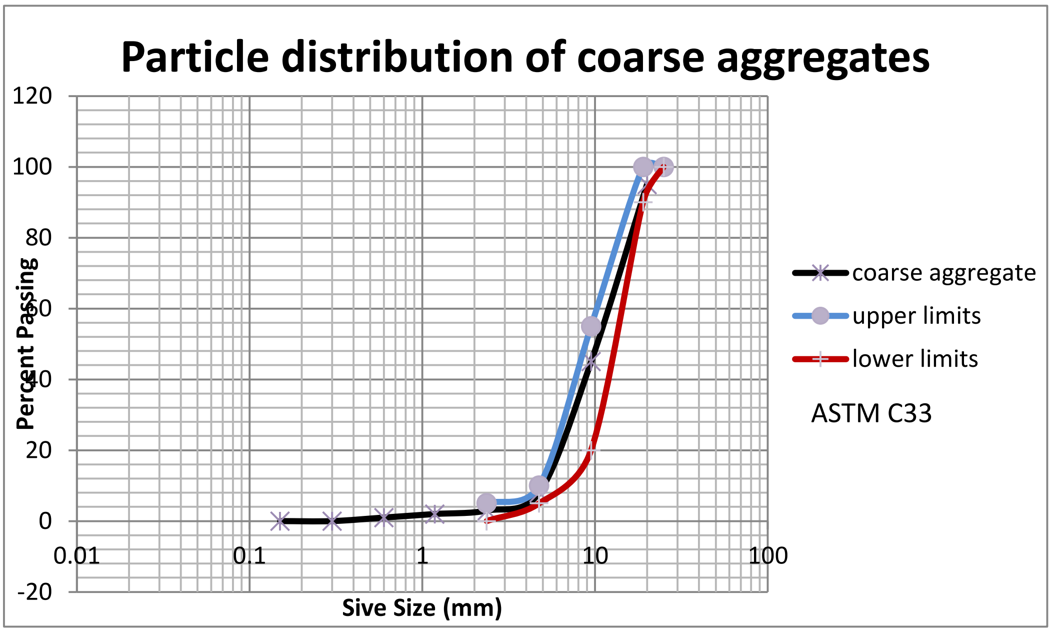

Figure 3.1: Particle size distribution of coarse aggregates

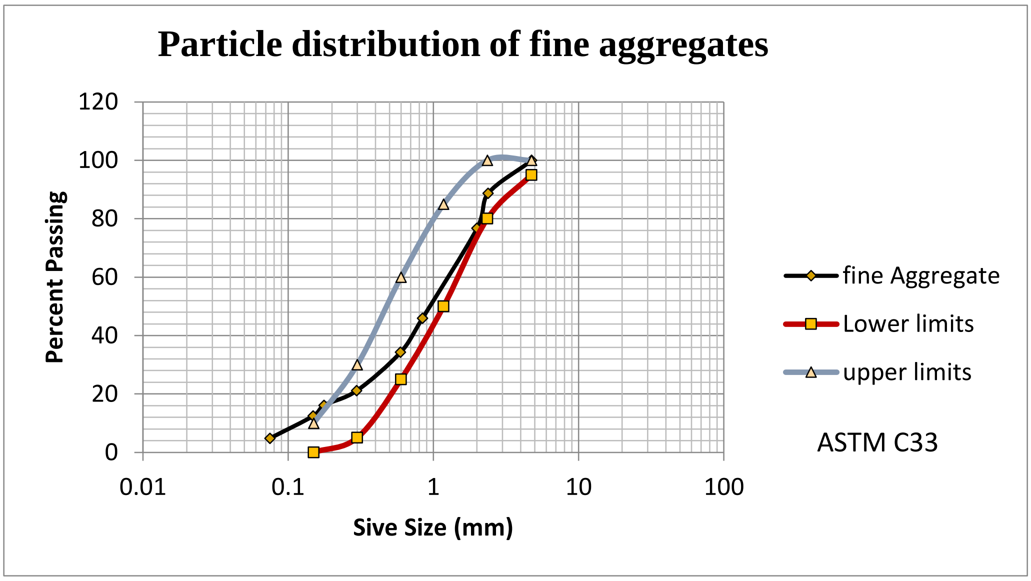

Figure 3.2: Particle size distribution of fine aggregate

3.2.3 Water

The drinking-quality water was considered for making and curing the specimens.

3.2.4 Silica fume

The Silica fume that was considered for this study was an available by-product of alloys. It was added as a supplementary material to the cement to make the concrete properties better. Silica fume was added at 3 different percentages (10, 15 and 20 %) by weight of cement. Physical and chemical properties of the silica fume that were used in the all samples are shown in Table 3.10.

Table 3.10: Chemical and physical characteristics of silica fume

Property	Amount
SiO_2 content	82.20 %
Al_2O_3 content	0.50 %
Fe_2O_3 content	0.42 %
CaO content	1.55 %
MgO content	0.00 %
SO_3 content	3.03 %
Loss of ignition	5.66 %
Fineness as surface area	29000 (m^2/kg)
Specific gravity	2.2

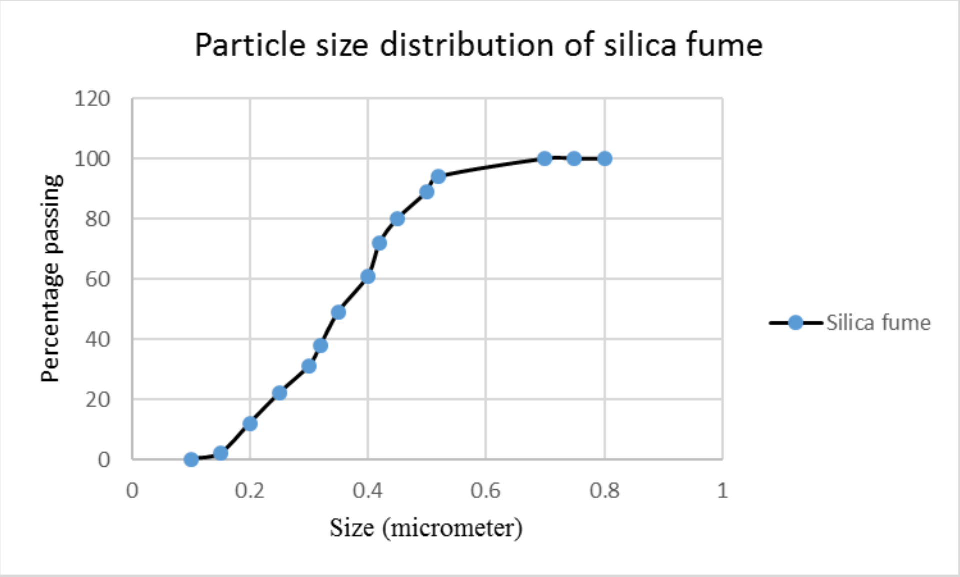

Figure 3.3: Particle size distribution of silica fume

3.2.5 Crushed quartz powder

Quartz is one of the most common mineral on the Earth. It is found in almost every geological environment and also it is at least one component of almost every rock type. In this study, it was added as a supplementary material with silica fume to the cement with very fine particles to test its influence on concrete properties. The quartz powder is shown in Figure 3.3. The physical and chemical properties of the quartz powder that is used in the all samples are shown in Table 3.11.

Table 3.11: Properties of quartz powder

Property	Amount
SiO_2 content	99 %
$MgCO_3$ content	0.01 %
Fe_2O_3 content	0.03 %
CaO content	0.03 %
Al_2O_3 content	0.05 %
SO_3 content	3.03 %
Specific gravity	2.55

Figure 3.4: Quartz Powder

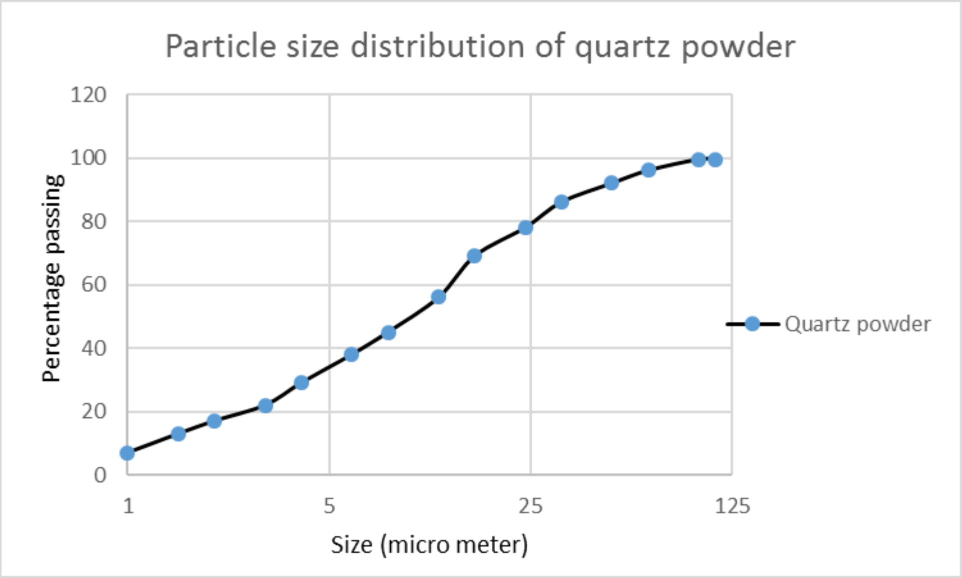

Figure 3.5: Particle size distribution of quartz powder

3.3 Methodology

The concrete mix design was based on the standard (BRE 331, 1988). The water to binder (cement, silica fume, quartz powder) ratio that had been used in all of samples of this study is 0.45, and just the cement replacement amount by silica fume and quartz powder changed. The details of mix design and different samples shown in Table 3.12 and 3.13, respectively. This mix design was accepted after making 4 different trial mixes with different W/C, which were 0.55, 0.50, 0.45 and 0.40 due to its acceptable compresive strength design and workability results.

Table 3.12: Mix design

	Binder	water	Coarse (20mm) aggregate	Coarse (14mm) aggregate	Coarse (10mm) aggregate	Fine aggregate
kg/m^3	500	225	345	345	230	750

Table 3.13: The amount of cement, silica fume and quartz powder in each mix

Concrete type	Cement (kg)	Silica fume (kg)	Quartz powder (kg)
Plain	500	0	0
F1(10%)	450	50	0
F1(15%)	425	75	0
F1(20%)	400	100	0
F2(10%)	450	37.5	12.5
F2(15%)	425	56	19
F2(20%)	400	75	25
F3(10%)	450	25	25
F3(15%)	425	37.5	37.5
F3(20%)	400	50	50
F4(10%)	450	12.5	37.5
F4(15%)	425	19	56
F4(20%)	400	25	75
F5(10%)	450	0	50
F5(15%)	425	0	75
F5(20%)	400	0	100

3.3.1 Casting concrete

The batching, weighing and mixing process of this study were done based on British Standard. In each batch, at first aggregates, cement, silica fume and quartz powder mixed together in laboratory mixer, and after about for 30 seconds, water was added to mixer slowly and mixing process continued for approximately 3 minutes to achieve a homogenous paste. In this step workability test (slump test) was evaluated from fresh concrete. After testing the workability, used concrete was put back in to the batch and remixed for a few seconds for filling the molds. (BS 1881: Part 125: 1986, 2009).

3.3.2 Curing

The molds were compacted by vibrating table, that can vibrate samples in a perfect way. The vibbrate table was shown in Figure 3.4. After compacting, samples were moved to the curing room which had more than 90% humidity and 20ºC temperature, the samples were remoulded after one day and were put in a water tank with 20ºC tempreture for 28 days. After 28 days curing they were ready for tests.

Figure 3.6: Vibrating table

Figure 3.7: Water tank for curing

3.4 Fresh concrete tests

3.4.1 Workability test

The test that was performed for evaluating workability in fresh concrete was slump test. Figure 3.6 shows the slump test apparatus.

Figure 3.8: Slump test

3.5 Tests on hardened concrete

Totaly six tests were performed on samples in hardened state, as below:

Compressive strength, permeability, splitting tensile strength, flexural strength, rebound hammer and PUNDIT.

3.5.1 Compressive strength

The cubic samples (150mm*150mm*150mm) were choosed for compressive strength tests at 7 and 28 days acording to BS EN 12390-3:2009 . The loading speed during the compressive test was 0.4 MPa/s, as it should be 0.6 ± 0.2 MPa/S based on (BSEN 12390-3:2009, 2009). Perpendicularly load was applied to the casting as it shown in Figures 3.7 and 3.8.

Figure 3.9: Compression test system

Figure 3.10: Crushed sample under compression load

3.5.2 Splitting tensile strength

Cylinder specimens (d= 100mm, L= 200mm) were performed for splitting tests after 28 days water curing, acording to BS EN 12390-6:2000, 2009. After removing the specimens from the water tank, they were carefully put on the testing machine with the axially applied load, as it is shown in Figure 3.9 and 3.10.

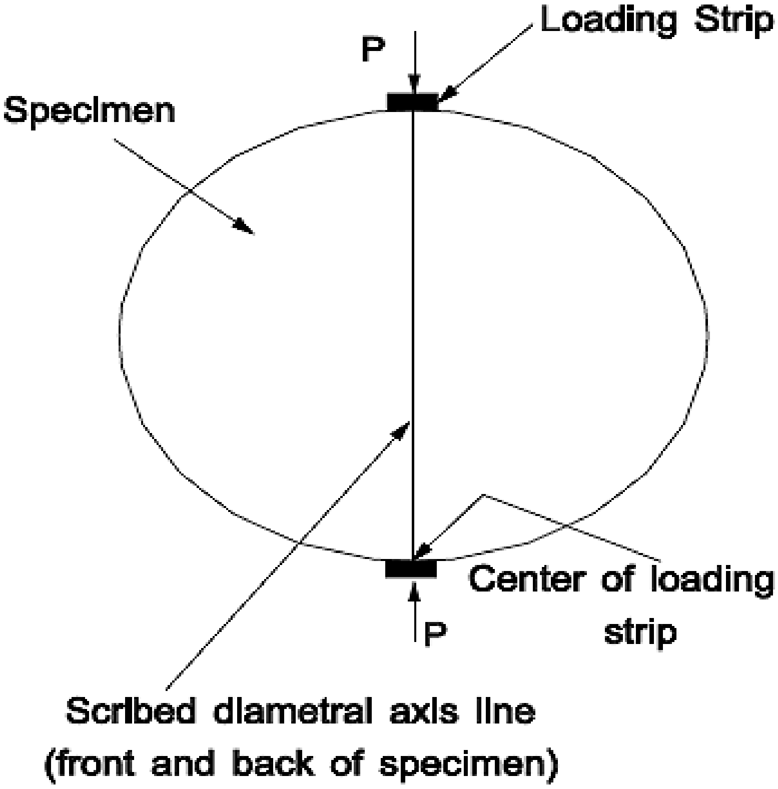

Figure 3.11: Cylindidrical specimen under the load

Figure 3.12: Crushed specimen after splitting test

3.5.3 Flexural strength test

The beams (100* 100* 150 mm) were tested for this study with a third-point load machine at a constant deformation rate (0.05 mm/min), based on standard (ASTM C

1609, 2010). The pressure was started without shock and increased constantly until the first crack, and no more load can be applied. The maximum load that samples withstand before first crack, were used to evaluate the flexural strength (Figure 3.11 and 3.12).

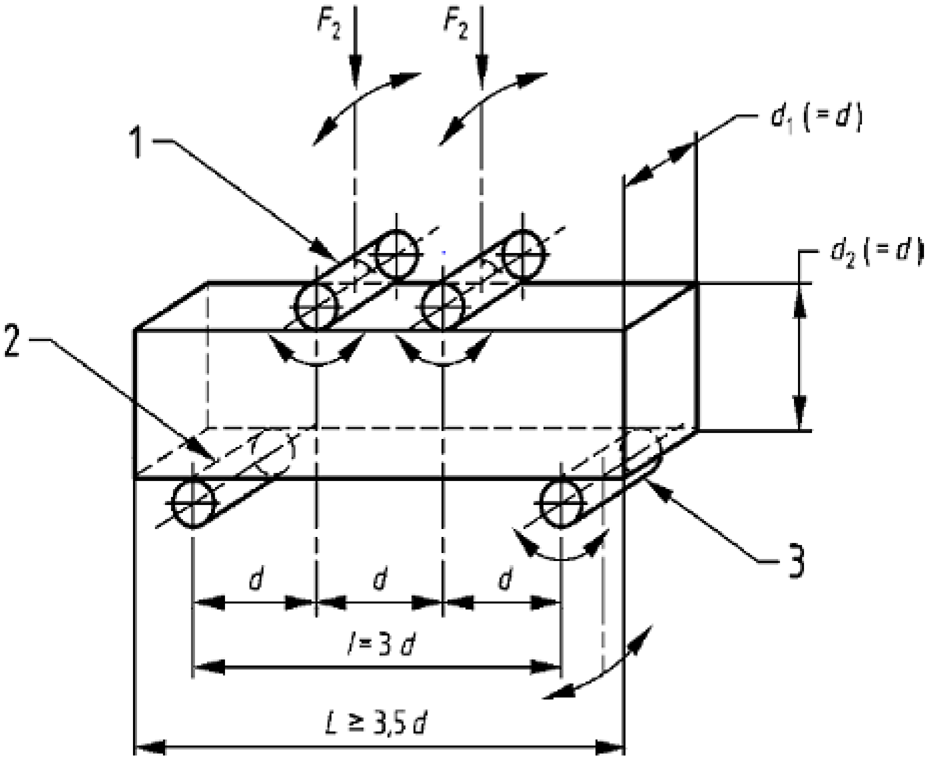

Figure 3.13: Third point loading system

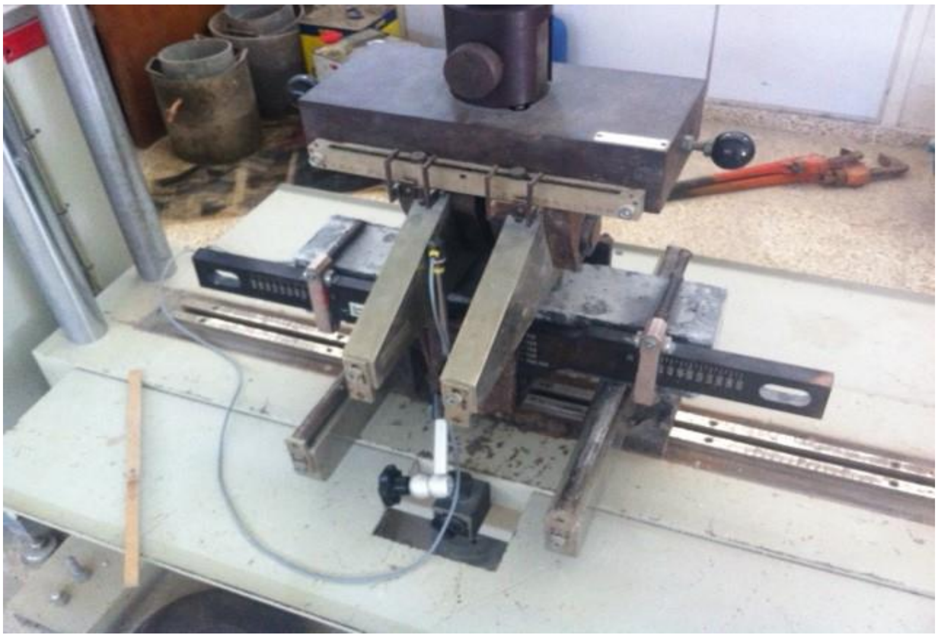

Figure 3.14: Flexural strength test machine

3.5.4 Depth of penetration of water under pressure

Durability is one of the main factors in concrete and it is a concern in aggressive environments. The cubic samples (150* 150mm) were tested after 28 days curing according to standards (BSEN-12390-8, 2002). Each specimen was placed into the permeability test machine in the opposite direction of which it was cast. The constant 500 kN/mm^2 water pressure was applied into each specimen surface from the top of its cell according to the standard (BSEN-12390-8, 2002) as it shown in Figure 3.13 and 3.14. The pressure were applied for 72 hours, then samples were split and maximum depth of penetration were recorded. The samples should be tested as soon as their surface has been dried.

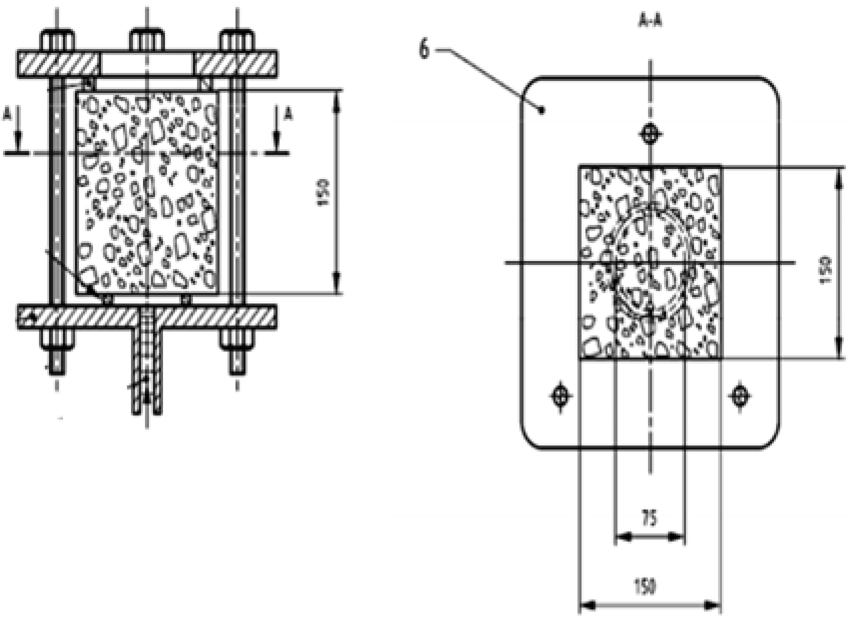

Figure 3.15: Permeability test details

Figure 3.16: Permeability test apparatus

3.5.5 Ultrasonic Pulse Velocity Test (PUNDIT)

PUNDIT test, was performed to predict compressive strength of concrete without destructing the specimens.

This test, evaluates the time that an ultrasonic wave takes to travel through the concrete sample between two probes placed on opposite surfaces of the specimen. The wave’s velocity will be evaluated by determining the travel time, based on standard (BS 1881: Part 201, 2009). The cubic specimens were made for this test and tested after 28 days. In Figure 3.15, the PUNDIT performance is shown. The relevant equipment must be calibrated before any test. After that, the points in the center of opposite sides of cube samples were marked. The surfaces of samples were greased, after that the sticks were placed on center of two adverse sides. The time of ultrasonic pulse (micro seconds) were appeared on the screen. Pulse velocity (km/sec) was calculated by dividing the time (seconds) to the length (km) of specimen.

Figure 3.17: PUNDIT test

3.5.6 Rebound hammer test

Rebound hammer (Schmidt hammer) test is known as a compressive strength predictor and it is placed in non-destructive tests category. The cubic samples (150* 150mm) after 28 days were used for this experiment and they were placed in the compressive strength machine with constant load of 100 kN, and during the experiment, each specimen was subjected to ten impacts which was punched with hammer to the surface of the concrete, and the number of the hammer was read on a scale attached to the instrument according to (BS 1881: Part 201, 2009). Some factors such as moisture condition of the surface or cement type can affect the results of the tests.

Based on the ASTM C 805/C 805M (2008), true number of hammer can be calculated as follows: At first, the average of 10 results was calculated, then those numbers, that have difference more than 6 units with the average amount were removed. After that, average of the remained numbers were calculated and called as the rebound number. Rebound hammer is shown in Figure 3.16.

Figure 3.18: Schmidt hammer

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

How to perform the experiments was explained in the previous chapter. And the results of them will be shown in chapter 4 as tables and figures. Discussions about the experiments will be done for outcomes as well. Results reached from the experiments including the slump test in fresh state, and compressive strength, splitting tensile strength, flexural strength, permeability, PUNDIT and Rebound hammer on hardened state were displayed.

4.2 Fresh concrete

4.2.1 Slump test

The workability for fresh states was investigated by slump test, and for each specimen with different percentages of silica fume and quartz powder and constant W/C (0.45), slump test was performed. The results are shown in Table 4.1.

It is obvious that, due to very fine particles and more water requirement of silica fume and quartz powders, by increasing the cement replacement amount, the slump were reduced. And slump value is lower when using silica fume compared to quartz powder at the same percentage. Because slump value has a direct relation with size of particles. It means that concretes which contain finer particles will have less slump value, and silica fume has finer particles than quartz powder.

Table 4.1: Slump test results

Concrete type	Slump (mm)
Plain	140
F1(10%)	110
F1(15%)	105
F1(20%)	75
F2(10%)	110
F2(15%)	110
F2(20%)	90
F3(10%)	115
F3(15%)	120
F3(20%)	95
F4(10%)	135
F4(15%)	120
F4(20%)	90
F5(10%)	135
F5(15%)	130
F5(20%)	110

4.3 Hardened concrete tests

4.3.1 Compressive strength

The samples that were used for compressive strength were cubic samples, and compressive test were tested for the plain and all the other mixes in 7 days and 28 days. The results are presented in Table 4.2 and 4.3.

Table 4.2: Compressive strength test results at 7 days (MPa)

Concrete type	Compressive strength (MPa)	Changes in compressive satrength (%)
Plain	32.3	-
F1 (10%)	38.5	+19.20
F1 (15%)	41.4	+28.20
F1 (20%)	41.6	+28.80
F2 (10%)	38.5	+19.20
F2 (15%)	42.9	+32.80
F2 (20%)	43.2	+33.70
F3 (10%)	38.1	+18.00
F3 (15%)	41.8	+29.40
F3 (20%)	42.2	+30.60
F4 (10%)	36.2	+12.10
F4 (15%)	39.5	+22.30
F4 (20%)	39.9	+23.50
F5 (10%)	34.3	+6.20
F5 (15%)	38.3	+18.60
F5 (20%)	39	+20.70

Table 4.3: Compressive strength test results at 28 days (MPa)

Concrete type	Compressive strength (MPa)	Changes in compressive satrength (%)
Plain	45.1	-
F1 (10%)	53.9	+19.50
F1 (15%)	56.3	+24.80
F1 (20%)	58.1	+28.80
F2 (10%)	54.3	+20.40
F2 (15%)	57.1	+26.60
F2 (20%)	58.8	+30.40
F3 (10%)	53.2	+18.00
F3 (15%)	55.8	+23.70
F3 (20%)	57.4	+27.30
F4 (10%)	51.5	+14.20
F4 (15%)	50.2	+11.20
F4 (20%)	51.5	+14.40
F5 (10%)	48.4	+7.30
F5 (15%)	50.8	+13.10
F5 (20%)	52.6	+16.10

The results that were reached at 28 days show that replacing cement by supplementary materials up to 20%, improved the compressive strength, and it could be due to filling the voids between cement particles with finer particles, and make the pastes denser and also pozzolanic reaction of silica fume particles. But with increasing the quartz powder amount instead of silica fume after 25% substitution, the compressive strengths were reduced in all cement replacement percentages, and it is because of increasing non-pozzolanic quartz powder particles amount. And as it is shown in Figure 4.1 and 4.2, the highest value of compressive strength for all of the replacement percentages, is for the specimens with 25% substitution of silica fume by quartz powder. And the lowest value is for F5 with 10% cement replacement, but at least it has higher value than plain. The other point is the rate of hydration in early age specimens compare to plain, is higher than the specimens in 28 days, and it is because of filling the voids between cement particles by finer particles. And the percentage changes for seven days and twenty eight days of compressive strength compared to the plain were shown in Figure 4.3 and 4.4, respectively.

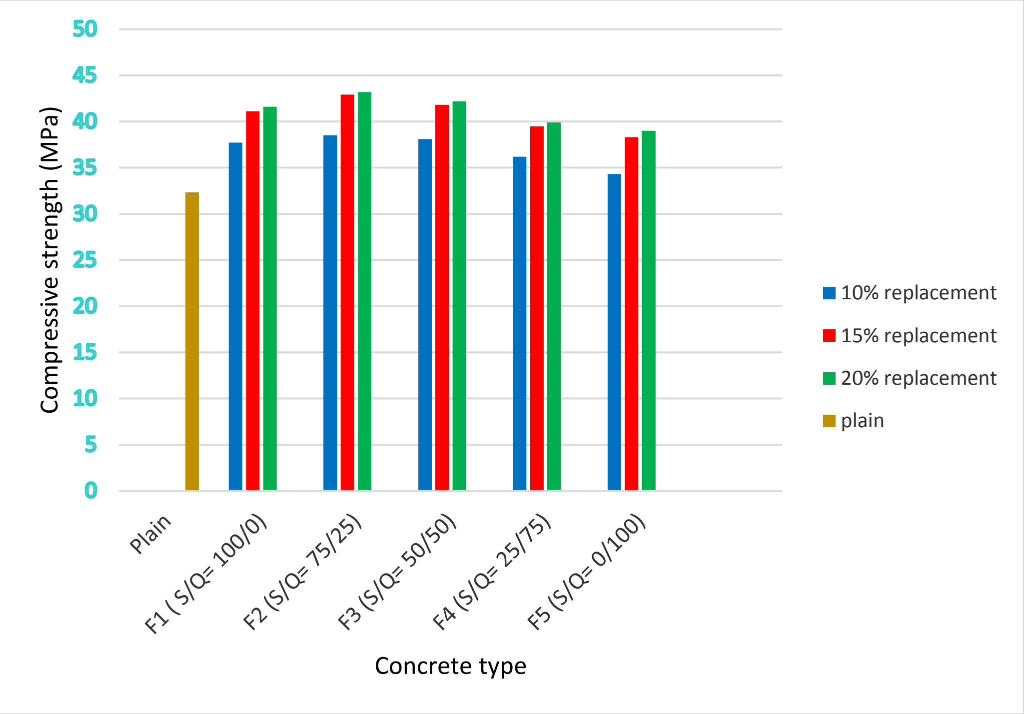

Figure 4.1: Compressive strength test results at 7 days

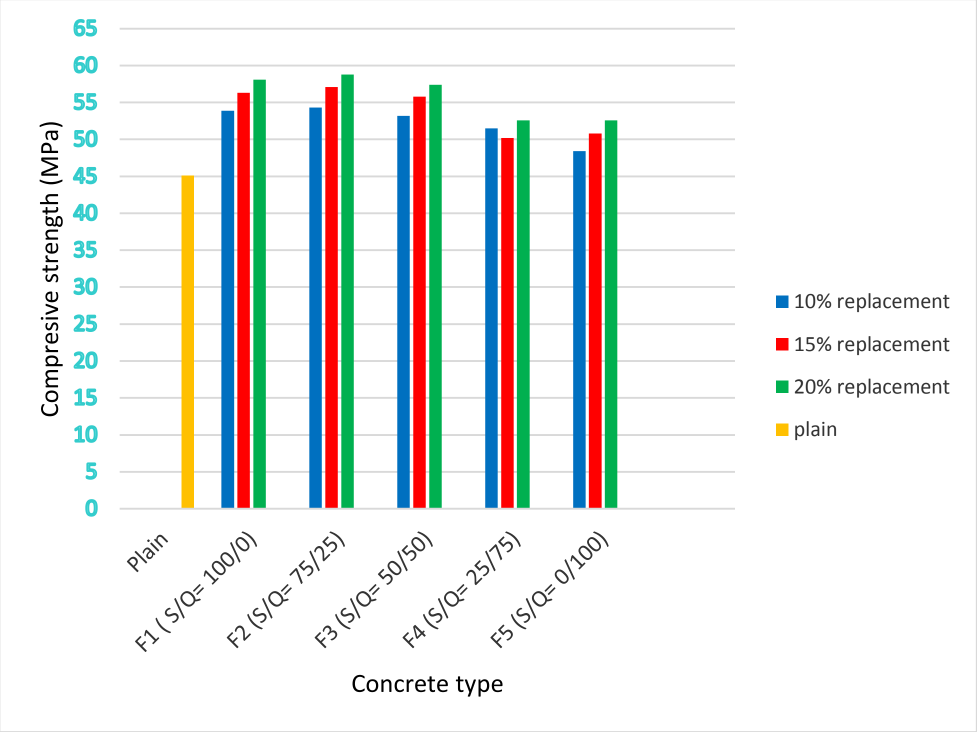

Figure 4.2: Compressive strength test results at 28 days

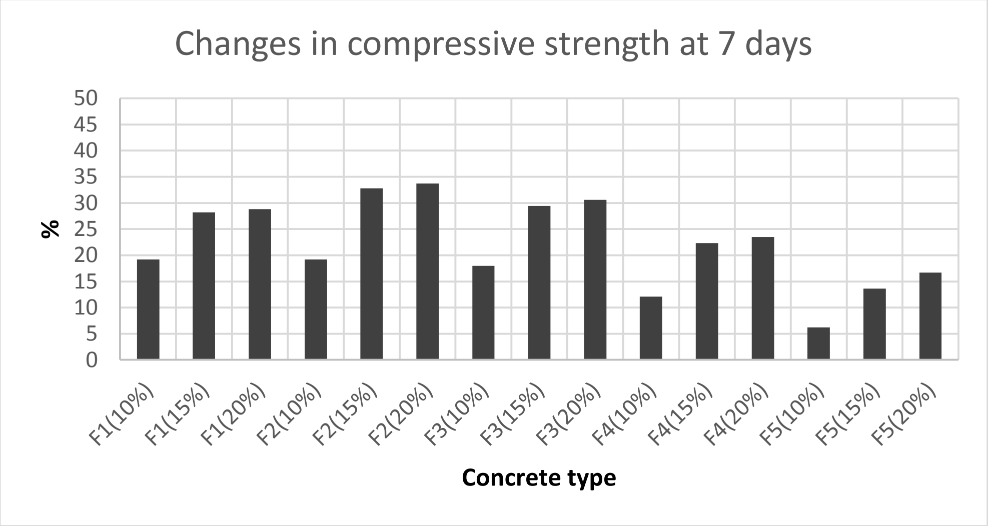

Figure 4.3: Percentage of changes for compressive strength at 7 days

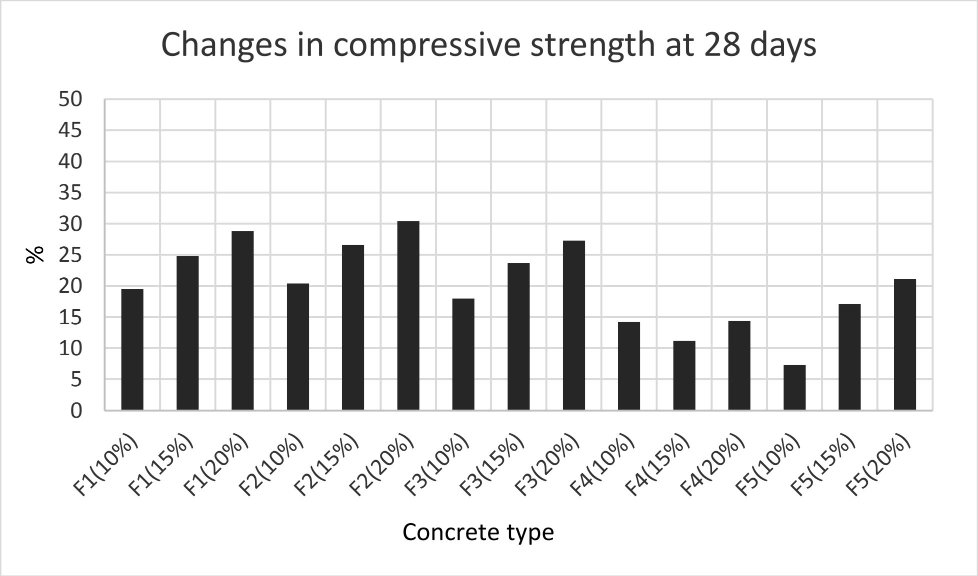

Figure 4.4: Percentage of changes for compressive strength at 28 days

4.3.2 Splitting tensile strength

Splitting tensile strength was tested on cylindrical samples (d= 100mm, l= 200mm) at 28 days after curing, and the results are shown in Table 4.4. In Figure 4.5 and 4.6, the results were compared to each other in different ways. Previous researchers have been concluded that at lower than 60MPa strengths, splitting tensile strength can be assumed as ten percent of compressive strength, but it can be five percent for higher strengths (Caldarone, 2009). In this study as it shown in Figure 4.6, splitting tensile strength is lower than 10% of compressive strength, and by increasing cement replacement material, the splitting tensile strength were increased up to 8% of compressive strength. The highest value of tensile strength is for F1 (20%) which is 23% higher compared to plain sample and reached to 4.61 MPa. But after increasing presence of quartz powder particles in the paste, tensile strength was reduced even lower than the plain specimen result. The lowest value is for F5 (10%), which is 5.6% lower than plain, with 3.54 MPa value. Silica fume acts as a pozzolanic material and helps to reach better bonding between aggregate particles, but quartz powder acts just as a filler in normal temperature. When cement is substituted by quartz powder in concrete, the concrete has a poor bonding between its particles. So splitting tensile strength of concrete with silica fume will be higher than the one with quartz powder.

Table 4.4: Splitting tensile strength test results at 28 days

Concrete type	Splitting tensile strength (MPa)	Changes in splitting tensile satrength (%)
Plain	3.75	-
F1 (10%)	4.51	+20.30
F1 (15%)	4.57	+21.90
F1 (20%)	4.62	+23.20
F2 (10%)	4.13	+10.10
F2 (15%)	4.22	+12.50
F2 (20%)	4.28	+14.10
F3 (10%)	4.04	+7.70
F3 (15%)	4.14	+10.40
F3 (20%)	4.2	+12.00
F4 (10%)	3.82	+1.90
F4 (15%)	3.96	+5.60
F4 (20%)	4.04	+7.70
F5 (10%)	3.57	-5.60
F5 (15%)	3.6	-4.00
F5 (20%)	3.7	-1.30

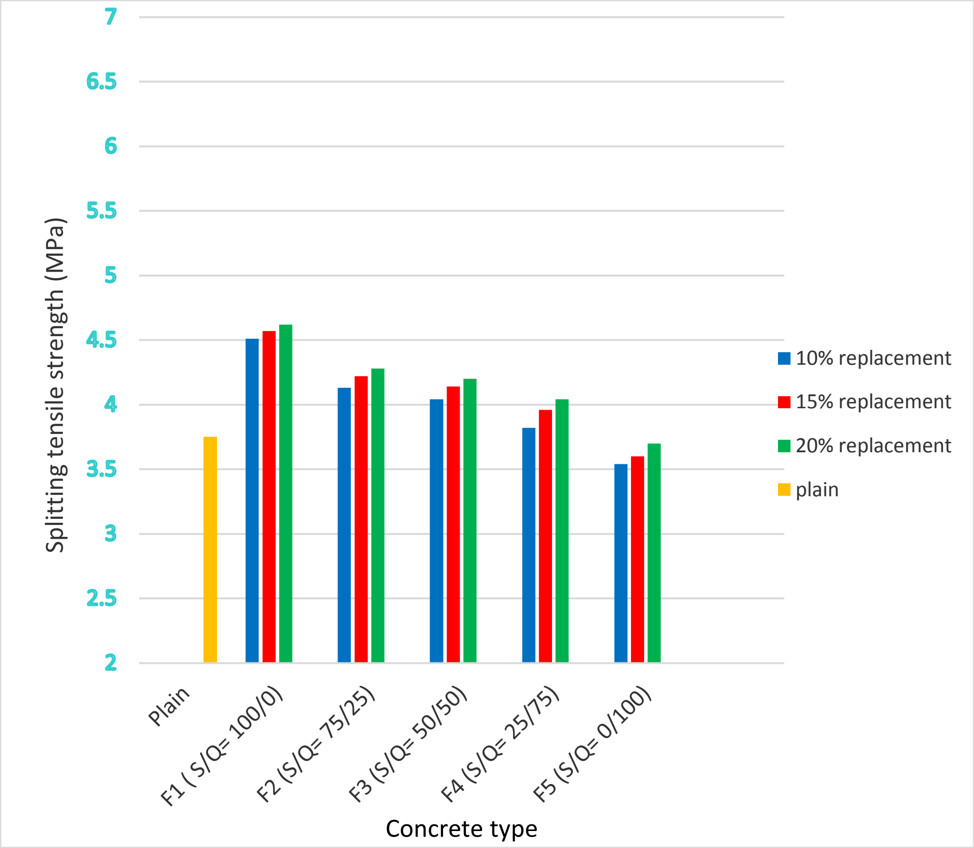

Figure 4.5: Splitting tensile strength test results

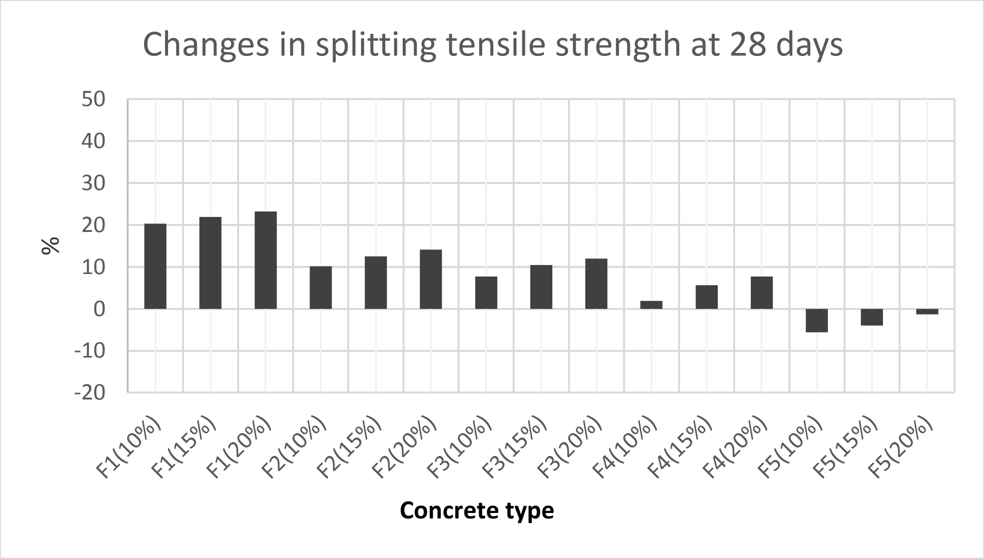

Figure 4.6: Percentages of changes for splitting tensile strength at 28 days

It can be concluded that, increasing quartz particles, does not have efficient positive effect on splitting tensile strength, but it can be in paste up to 75% of supplementary materials, and it does not have bad effect. It acts just as filler.

4.3.3 Flexural strength

Flexural strength was tested on beam samples (100*100*500 mm) at 28 days after curing, and the results are shown in Table 4.5. In Figure 4.7 and 4.8. The results were compared to each other in different ways. This investigation has shown that, although the flexural strength had a small amount of improvement by increasing cement replacement, it is not a big change and it can be concluded that, increasing supplementary materials specially quartz powder, does not have an efficient effect on flexural strength. The small improvement can be due to better bonding between cementitioues materials and aggregates. For improving flexural strength, concrete needs something like fibers to make a bridge on micro cracks, to continue surviving under applying more loads after first crack.

Table 4.5: Flexural strength test results at 28 days

Concrete type	flexural strength (MPa)	Changes in flexural satrength (%)
Plain	5.92	-
F1 (10%)	6.5	+9.80
F1 (15%)	6.76	+14.20
F1 (20%)	6.8	+14.80
F2 (10%)	6.81	+15.00
F2 (15%)	7.02	+16.50
F2 (20%)	7.09	+17.70
F3 (10%)	6.42	+8.40
F3 (15%)	6.79	+14.70
F3 (20%)	6.86	+14.90
F4 (10%)	6.12	+3.40
F4 (15%)	6.6	+11.50
F4 (20%)	6.65	+12.33
F5 (10%)	5.97	+0.85
F5 (15%)	6.36	+7.40
F5 (20%)	6.3	+6.40

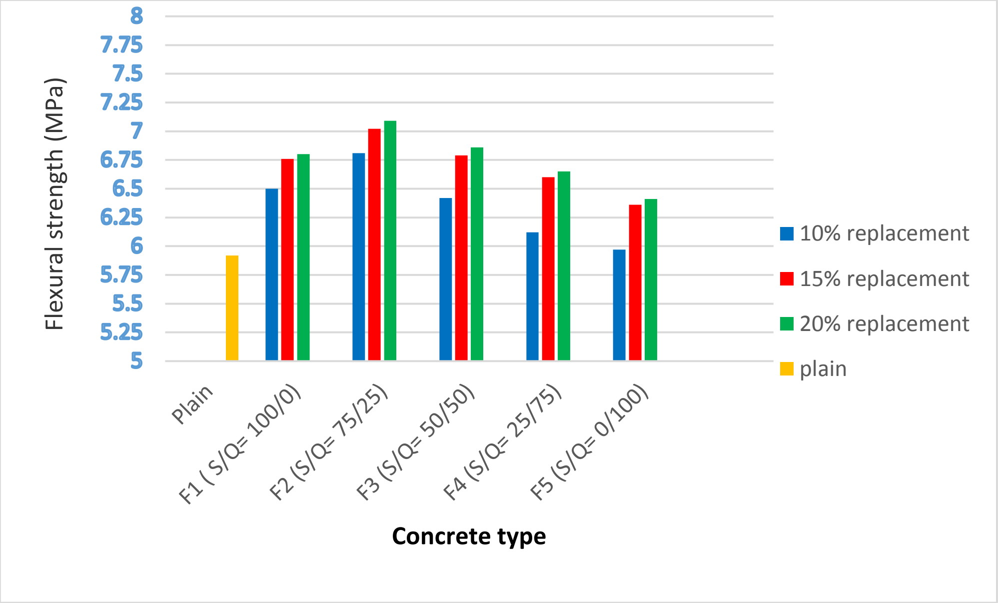

Figure 4.7: Flexural strength test results

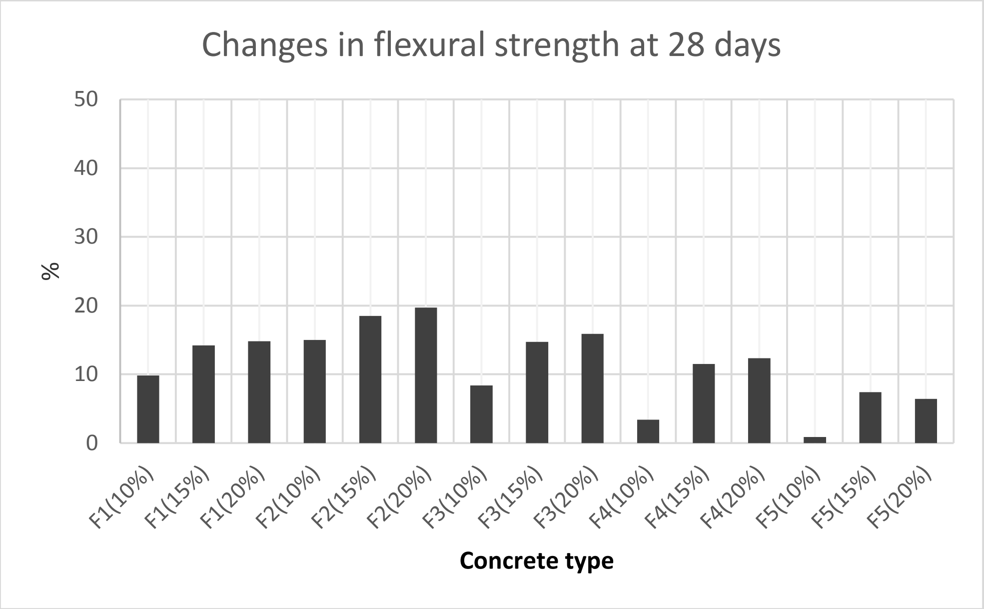

Figure 4.8: Percentage of changes for flexural strength

As it is shown, the percentage of changes of flexural strengths, compares to plain, in Figure 4.8, the highest change is for F2 (20), (using 20% cement replacement in sample with combination of silica fume and quartz powder with the same amount), by 19% and value of 7.9 MPa. And the lowest value is 5.97 which is a little bit higher than plain with 0.85% change for F5 (10) (using 10% cement replacement in sample which is just quartz powder and no silica fume). In general, by increasing the amount of fine particles (supplementary materials including silica fume and quartz powder), the flexural strength value was improved in all specimens, but by increasing the amount of quartz powder instead of silica fume the improvement is not as much as adding silica fume. Quartz powder has a few positive effects on flexural strength of concrete, due to its very fine particles.

4.3.4 Depth of penetration of water

All of the samples had been taken into depth of water penetration test after 28 days curing. The specimens were placed in permeability test system’s cells and kept under constant pressure of 500 kPa. After 72 hours the water permeability was measured as soon as the samples surfaces got dried. And results of this investigation are shown in Table 4.6 and in Figure 4.9 and Figure 4.10. The results are compared to each other.

It can be concluded that by increasing the cement replacement amount, permeability was reduced directly, and it was because of filling the voids between particles by finer particles and both silica fume and quartz powder have very fine particles, so the paste became more homogeneous and penetration of water even in high pressure condition were reduced. The best result is for F1 (20) by minimum penetration, and the plain has a highest penetration but in presence of supplementary materials the maximum penetration is for F2 (10) by 13mm. Penetration is affected directly by particles fineness. As it shown in Figure 4.10, increasing fine particles amount had significant changes on permeability.

Table 4.6: Depth of penetration test results

Concrete type	permeability (mm)	Changes in reducing permeability (%)
Plain	19	-
F1 (10%)	11	-42.00
F1 (15%)	8	-57.90
F1 (20%)	7	-63.20
F2 (10%)	13	-31.60
F2 (15%)	10	-47.36
F2 (20%)	7	-63.20
F3 (10%)	12	-36.80
F3 (15%)	10	-47.40
F3 (20%)	8	-57.90
F4 (10%)	11	-42.10
F4 (15%)	10	-47.40
F4 (20%)	7	-63.20
F5 (10%)	13	-31.60
F5 (15%)	12	-36.80
F5 (20%)	11	-42.10

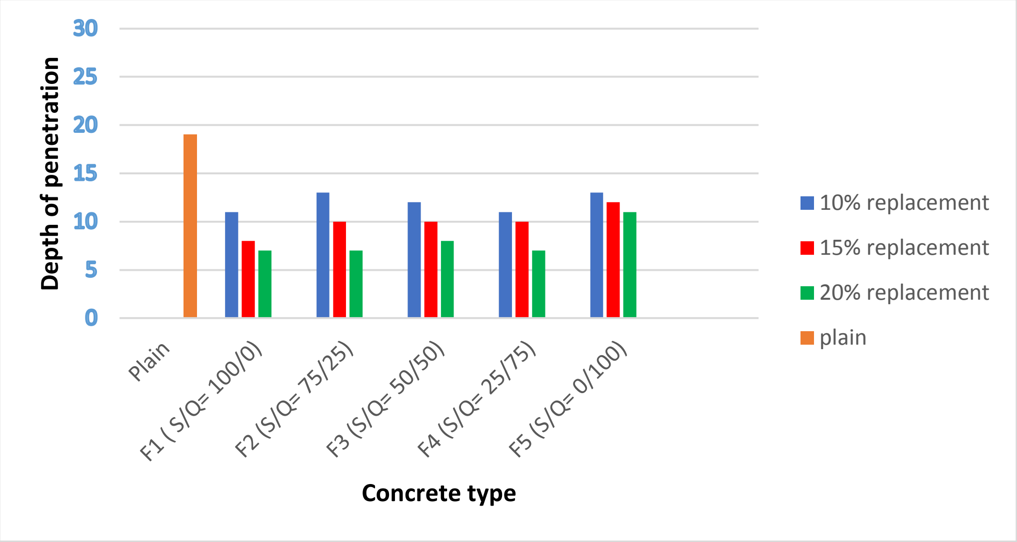

Figure 4.9: Permeability test results

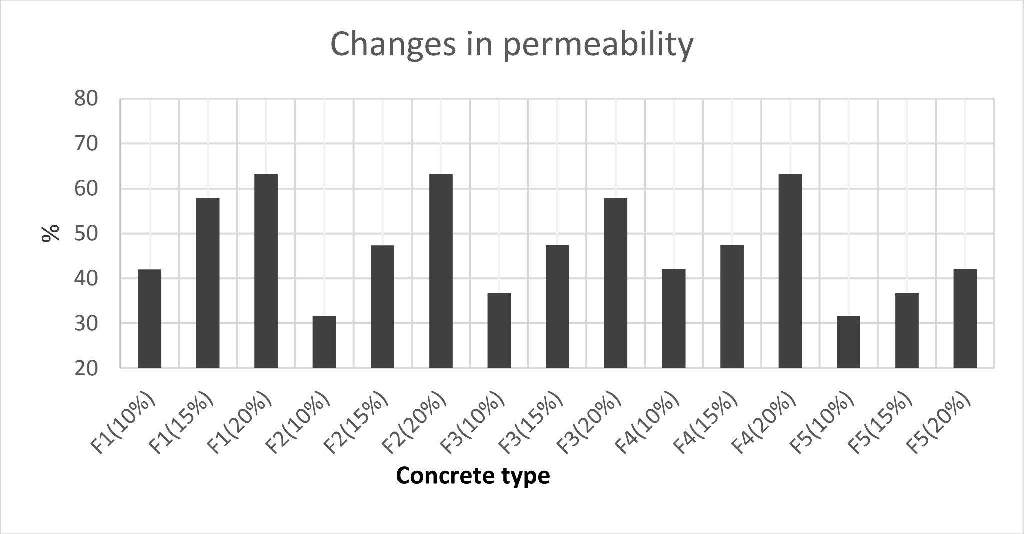

Figure 4.10: Percentage of changes for permeability at 28 days

4.3.5 Ultrasonic pulse velocity (PUNDIT)

PUNDIT test was done on two samples at 28 days for each batch to assess the integrity and homogeneity of concrete. This test is considered as a non-destructive test.

The average of two tests considered as a result was shown in Table 4.7. The changes of pulse velocity results compared to the plain concrete for each mix, and the calculation of them in percentage were shown in Figure 4.11 and Figure 4.12 the results were compared to each other in different kinds of charts.

The samples with higher pulse velocity time mean that, they are denser samples with higher integrity than the samples with lower ones. The results in this investigation illustrate that each mix in presence of supplementary materials, has the pulse velocity value better than the plain sample, and it can be due to finer particles of silica fume and quartz powder, that make the samples denser by even a little bit. As it is shown in results, the best pulse velocity is for F3 (15%) with 4.16 km/s and the highest one is for F1 (10%) with 2.83 km/s after plain. From the results it can be concluded that there is no direct relation between the amount of the cement replacement materials and the ultrasonic pulse velocity.

The ultrasonic pulse velocity can show us the quality of the concrete. The pulse velocity with the value of higher than 4.0 km/sec, shows that the concrete quality is excellent, in 3.5-4.0 km/sec range the concrete quality is defined to be very good, in 3.0-3.5 km/sec range quality of concrete can be called good but less than 3.0 km/sec it has poor quality with loss of integrity (Whitehurst, 1951). According to the Table 4.7, the results obtained from the experiments, are higher than 4 and they all are excellent.

Table 4.7: Pulse velocity test results

Concrete type	Time (µs)	Pulse velocity (km/sec)	Concrete quality	Changes in Pulse velocity (%)
Plain	30.3	4.95	excellent	-
F1 (10%)	31.1	4.82	excellent	-2.6
F1 (15%)	31.5	4.76	excellent	-3.8
F1 (20%)	31.7	4.73	excellent	-4.4
F2 (10%)	30.8	4.87	excellent	-1.6
F2 (15%)	31.1	4.82	excellent	-2.6
F2 (20%)	31.3	4.78	excellent	-3.4
F3 (10%)	31.9	4.7	excellent	-5
F3 (15%)	32.2	4.65	excellent	-6
F3 (20%)	31.5	4.76	excellent	-3.8
F4 (10%)	31.2	4.81	excellent	-2.8
F4 (15%)	31.6	4.75	excellent	-4
F4 (20%)	31.1	4.82	excellent	-2.6
F5 (10%)	32	4.69	excellent	-5.2
F5 (15%)	32.3	4.64	excellent	-6.3
F5 (20%)	31.6	4.75	excellent	-4

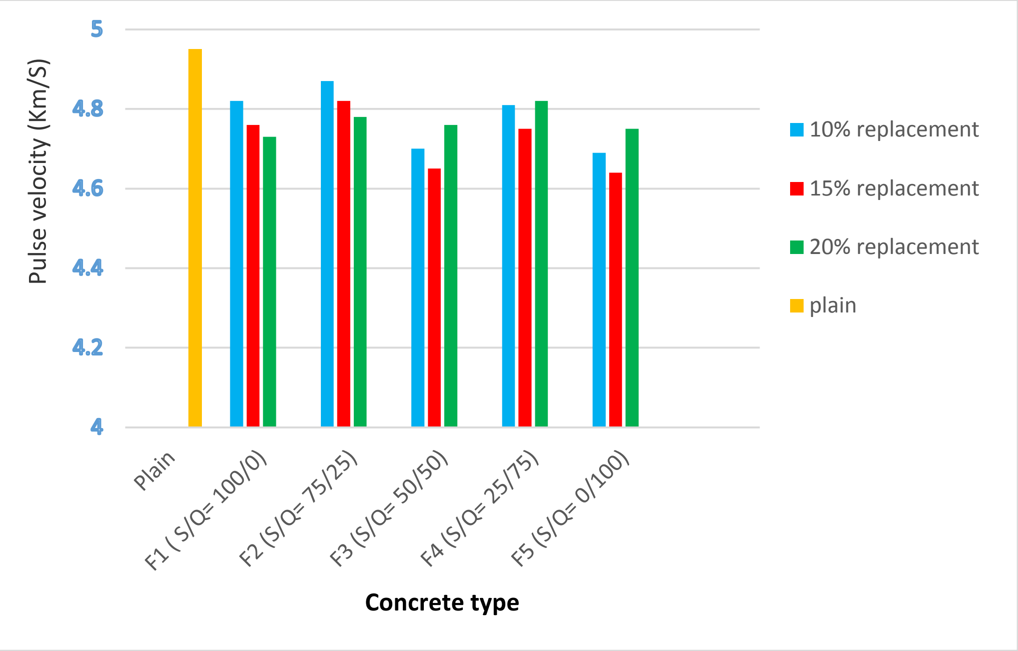

Figure 4.11: Pulse velocity test results

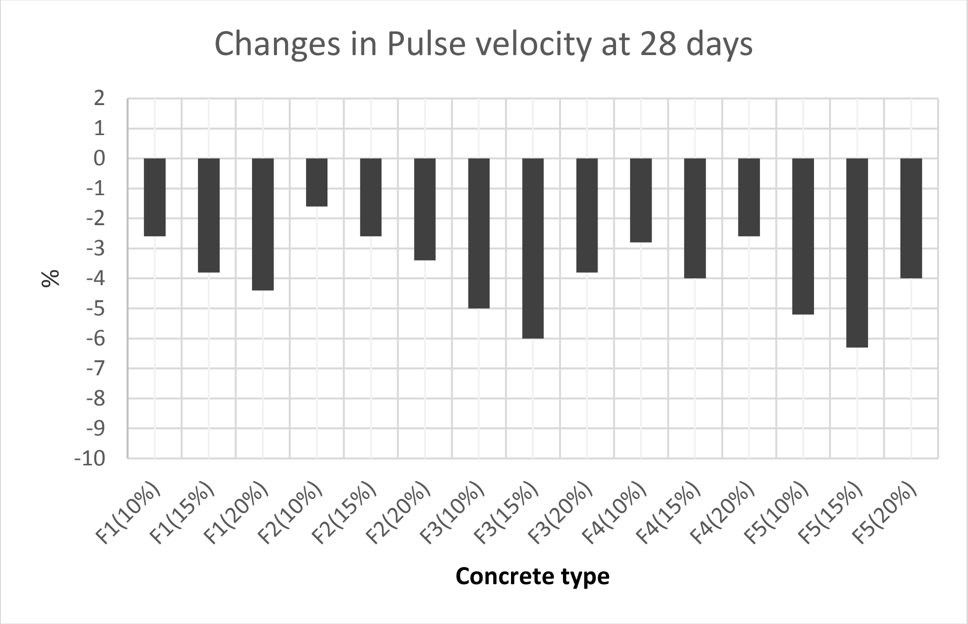

Figure 4.12: Percentage of changes for pulse velocity compared to plain

4.3.6 Rebound hammer (Schmidt hammer) test

Schmidt hammer test was performed on water cured cubic specimens for two samples of each mix after 28 days, before applying for compressive strength test. This test considered as a non-destructive test.

The average of two tests (10 times for each), that were considered as a result were shown in Table 4.8. In Figure 4.13 the results were compared to each other in different kinds of charts. And after that in figure 4.14 the changes of rebound hammer results versus compressive strength results compared. It was tried to find correlations between those parameters.

Table 4.8: Schmidt hammer test results

Concrete type	Compressive strength (MPa)	Rebound number
Plain	45.1	30
F1 (10%)	53.9	34
F1 (15%)	56.3	35
F1 (20%)	58.1	35
F2 (10%)	54.3	34
F2 (15%)	57.1	35
F2 (20%)	58.8	36
F3 (10%)	53.2	34
F3 (15%)	55.8	34
F3 (20%)	57.4	36
F4 (10%)	51.5	33
F4 (15%)	54.2	34
F4 (20%)	56.1	34
F5 (10%)	48.4	32
F5 (15%)	52.8	33
F5 (20%)	54.6	35

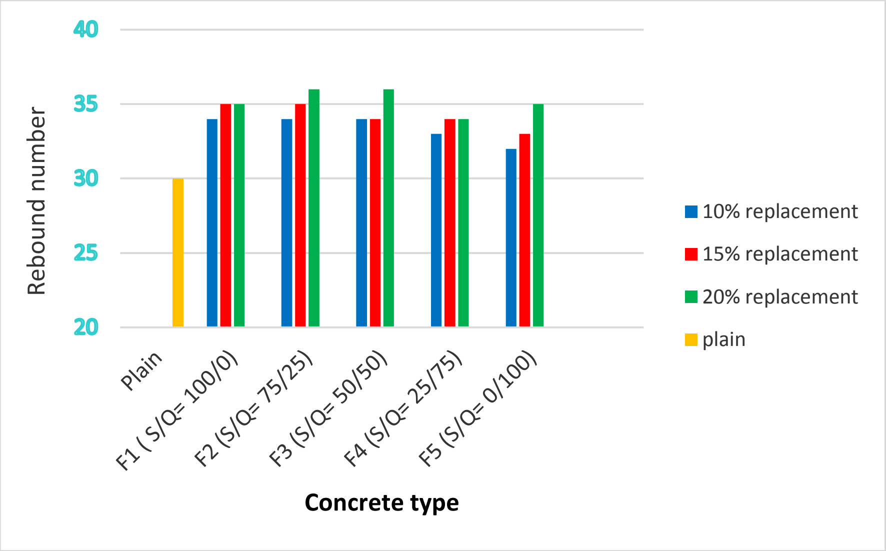

Figure 4.13: Rebound hammer test results

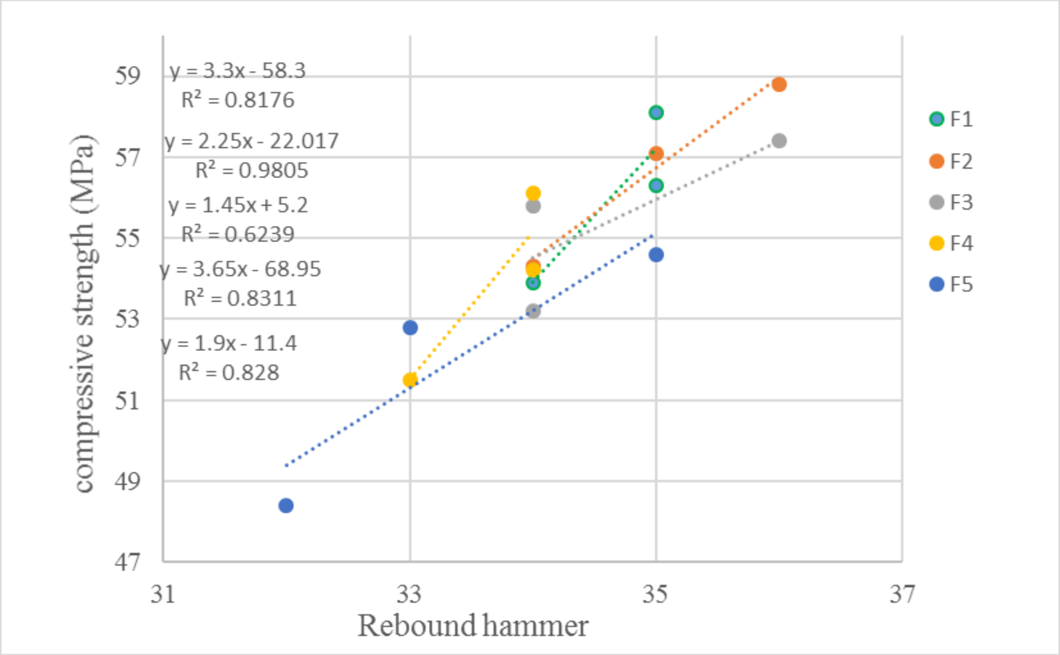

Figure 4.14: Comparison of rebound hammer with compressive strength regression

Relations between compressive strength and rebound numbers are fairly linear as it shown in Figure 4.14. Regression results are shown in Table 4.9

Table 4.9: Regression results for rebound hammer number and compressive strength

Concrete type	Equation	R^2
F1	y = 3.3x - 58.3	$R^2 = 0.8176$
F2	y = 2.25x - 22.017	$R^2 = 0.9805$
F3	y = 1.45x + 5.2	$R^2 = 0.6239$
F4	y = 3.65x - 68.95	$R^2 = 0.8311$
F5	y = 1.9x - 11.4	$R^2 = 0.828$

Based on results, it can be said that for all mixes, the rebound numbers of specimens with 10% cement replacement are averagely lower, like as compressive strength. But rebound hammer test results are not as same as compressive strength results and it could be because of many reasons such as allocation of aggregates, bad vibration or presence of bubbles in surface of the specimens.

The highest value of rebound hammer is for F3 category (35), it seems that F3 series' rebound hammer is constant and have the same value and the difference between values of F3 is not significant, and lowest one is for plain as same as compressive strength. In addition, as it is obvious, rebound hammer test was affected by surface of specimen condition, and aggregate maximum size (BS 1881: Part 201, 2009).

Chapter 5

CONCLUSION

5.1 Conclusion

The following conclusions were achieved based on the results reached from the study.

1. Silica fume, due to its huge specific surface uses too much water for being wet, and when it is used in concrete, the slump test was reduced efficiently and hydration was stopped by lack of water in concrete. So this may cause lower compressive strength.

2. Using quartz powder as a cement replacement material instead of silica fume had less negative effects on slump test results, because it has bigger particles compared to silica fume. So combination of silica fume and quartz powder can have better effect on concrete to achieve higher strength with constant w/b ratio.

3. Using combination of silica fume and quartz powder in concrete as a cement replacement increases the compressive strength. Silica fume in concrete has more efficient effects for achieving higher compressive strength than quartz powder. Because silica fume acts as a pozzolan material in presence of moisture, but quartz powder needs autocloave curing for reaction as

pozzolan. Also adding more supplementary materials up to 20% by weight of cement improved the compressive strength at 7 and 28 days. The combination of two additive materials by S/Q= 75/25 is the best ratio for improving the compressive strength. And the compressive strength changed 30% compared to plain concrete in the best condition.

4. Splitting tensile strength improved by adding just silica fume up to 20%. But there is a reduction in splitting tensile strength by adding quartz powder in the absence of silica fume instead of cement, because quartz powder does not have pozzolanic reaction at low temperature. But there is a point that combination of silica fume and quartz powder by a ratio of 1:3 did not have bad effect on splitting tensile strength. So from the financial point of view, this combination of silica fume and quartz powder can be used for the same strength as it was reached by cement. The improvement in strength by using silica fume can be due to filling the voids between cement particles by finer particles and also acting as a pozzolanic material.

5. The highest splitting tensile strength value is allocated to F1 (20%) by 23% improvement, which means silica fume has a better effect on tensile strength improvement than quartz powder.

6. In terms of flexural strength, although there is a non-efficient improvement by adding and increasing cement replacement materials, results show that all of the combinations of SF and QP has a positive effect in flexural strength. But silica fume has better results than quartz powder and adding supplementary materials were improved the flexural strength up to 18% by

F2 (20%) and the lowest improvement is for F5 (10%) compared to plain. This improvement is due to better bonding between aggregates because of pozzolanic reaction.

7. By looking at the results of flexural strength and splitting tensile strength it can be mentioned that there is no reliable relation between splitting tensile strength and flexural strength. In general flexural strength has higher value than splitting tensile strength, but in this study they have almost same results. It can be affected by many factors such as different environmental condition when the samples were cured or tested. There could also be human errors.

8. Because of adding finer particles to cement paste, the permeability of the mixes had great reduction up to 20% cement replacement. The highest reduction is 6% by F1 (20%) and F2 (20%). It can be due to ultra-fine particles that were filled the voids between cement particles and they were made denser concrete with lower permeability.

9. There is no direct relation between pundit test results and amount of supplementary materials, although as density increased pulse velocity should also be better. Pundit test results can be affected by different properties of materials that are used in specimens such as, vibration time or other factors. For better results it is better to compare the concrete samples at same conditions and use the same materials with the same amounts.

10. Rebound hammer test is for prediction of compressive strength test, but this test was designed for OPC, so it may have different results from compressive strength for other concretes. But the results of rebound hammer was improved by increasing the supplementary materials up to 20%.

5.2 Recommendation

1. This experimental study was performed on two different cement replacement materials. More different pozzolans and natural materials could be replaced by cement.

2. This experimental study had a constant w/b ratio and the combinations of SF and QP was the variable. For finding out how w/b ratio can have effect on concrete, different mix designs with different w/b ratios could be tried.

3. Different percentages of replacing materials by cement could be tried.

4. For more reliable results the environmental condition and the materials which is used in mixes should be the same.

5. Splitting tensile strength and flexural strength should be tested at the same time and the same condition to find out better relations between them.

6. It can be used different types of fibers for having higher values in splitting tensile strength and flexural strength test results.

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