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M.Sc. in Civil Engineering

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STRENGTH AND PERMEABILITY OF SELF-COMPACTING CONCRETE INCORPORATING PVC DUST

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MOHAMMED WADI ALJUMAILY

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Strength and Permeability of Self-Compacting Concrete Incorporating PVC Dust

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Mohammed Wadi ALJUMAILY

ABSTRACT

STRENGTH AND PERMEABILITY OF SELF-COMPACTING CONCRETE INCORPORATING PVC DUST

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The present study is an effort to investigate the effects of (PVC) dust, at various replacement levels, on the durability of self-compacting concrete. Large-scale production of cement is causing environmental problems. This concern has led researchers to make use of supplementary cementitious materials for making concrete. PVC dust is a waste material produced in the plastic pipe industry, and is used as a filler material towards waste utilization. Self-compacting concrete is a kind of concrete that does not require internal or external pressure because it becomes soft and compacted under its own weight. Six mixes of concrete with one control were prepared in the study and mix designs were carried out according to Khayat. The impact of PVC dust on durability was studied by replacing cement ratios by weight at 5%, 10%, 15%, 20%, and 25%. The durability and strength of SCC was found by using different tests: water sorptivity, dry shrinkage, restrained shrinkage, gas permeability, water permeability, and compressive strength at 56 and 90 days. Results showed that addition of 25% PVC dust into the concrete mixture has given the best values of the applied durability tests. It has been pointed out that shrinkage and permeability properties of concrete will be improved by using less cement and more PVC dust.

Keywords: Permeability, PVC dust, self-compacting concrete, shrinkage.

ÖZET

PVC TOZLARI İLE ÜRETİLMİŞ KENDİLİĞİNDEN YERLEŞEN BETONLARIN MUKAVEMET VE GEÇİRGENLİĞİ

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67 sayfa

Bu çalışma, farklı yerleşme seviyelerinde PVC tozunun, kendiliğinden yerleşen betonlar üzerinde dayanıklılık etkilerini araştırmak üzere ortaya konulmuş bir çabadır. Büyük ölçekte çimento üretiminin çevresel sorunlara neden olması, araştırmacıları beton yapımında ilave çimento esaslı malzeme kullanmaya zorlamıştır. PVC tozu plastic boru endüstrisinde üretilen atık bir malzemedir ve atık dolgu malzemesi olarak kullanılmaktadır. Kendiliğinden yerleşen beton, kendi ağırlığı altında yumuşaması ve sıkışması nedeniyle iç veya dış basınç gerektirmeyen bir beton türüdür. Bu deneysel çalışmada, bir control olmak üzere altı karışım hazırlanmış ve karışım hesabı Khayat (2000)'e göre tasarlanmıştır. Ağırlıkça çimentonun, 5%, 10%, 15%, 20% ve 25% farklı yerleşme oranlarında PVC tozlarının betonun dayanıklılığı üzerindeki etkileri çalışılmıştır. Kendiliğinden yerleşen betonun dayanıklılık özellikleri şu testler ile hesaplanmıştır: su sorptivitesi, kuru büzülme, sınırlı büzülme, su geçirgenliği ve 56 ile 90 günlük kür altında basınç dayanımları. Deneysel sonuçlar, farklı PVC tozu oranlarının kendiliğinden yerleşen beton özelliklerini önemli ölçüde değiştirdiğini göstermiştir. %25 PVC toz oranı eklenmesi ile uygulanan dayanıklılık testleri en iyi sonuçları vermiştir. Sonuçta, daha az çimento ve daha fazla PVC tozu kullanarak betonun büzülme ve geçirgenlik özelliklerinin iyileştirileceğine dikkat çekilmiştir.

Keywords: Geçirgenlik, PVC tozu, kendiliğinden yerleşen beton, büzülme.

To my beloved family

ACKNOWLEDGEMENTS

Now, as I am reaching the end of my thesis, I would like to express my sincere thanks to my supervisor, Assistant Professor **Dr. Nihat ATMACA** for his invaluable guidance, advice, and supervision. I also appreciate the advice of the committee members.

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My deep appreciations are to my father and my mother. They have been always my source of happiness. Their love and support have encouraged me to complete my M.Sc. degree. I will always be grateful to my beloved family.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BAC	Bituminous Asphalt Concrete
CC	Conventional Concrete
CKD	Cement Kiln Dust
ESP	Eggshell powder
EPS	Expanded Polystyrene Foam
FA	Fly Ash
GRP	Glass Reinforced Plastic
HDPE	High Density Polyethylene
HRWRA	High Range Water Reducing Admixture
LDPE	Low-density polyethylene
MSW	Municipal Solid Waste
NAPSS	Polystyrenesulfonate
PC	Portland Cement
PE	Polyethylene
PETE	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene

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PVC	Polyvinyl Chloride
SP	Superplasticizer
SCC	Self-Compacting Concrete
SEM	Scanning Electron Microscope
SF	Silica Fume
SPC	Self Compacting Polyvinyl Chloride Powder Concrete
W/b	Water per binder ratio
W/c	Water Per Cement Ratio
RPC	Reactive Powder Concrete
RHBA	Rice Husk Bark Ash
IPC	Inorganic Polymer Concretes
HSCC	High Strength Self-Compacting Concrete
MSCC	Medium Strength Self-Compacting Concrete
VMA	Viscosity Modifying Admixtures
HVFA	High Volume Fly Ash
MK	Metakaolin
RCA	Recycled Coarse Aggregates
RFA	Recycled Fine Aggregates
PFA	Pulverized Fuel Ash
POFA	Palm Oil Fuel Ash

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CHAPTER 1

INTRODUCTION

1.1 General

Incorporating industrial waste materials into the concrete mixture could improve the cement quality and be an acceptable way of disposing these wastes. Different studies were carried out to investigate the incorporation of industrial waste to improve the quality of both types: plain and self-compacting concrete (SCC). This study focuses on the new techniques used in the production of SCC. This includes the incorporation of the industrial waste materials. The work looks over the improvement of the SCC quality due to the newest practices of admixtures and their act; the effect of some in SCC ingredients on the fresh and hardened of properties, which are in debate in this area some applications of various innovative materials as in and there. Being SCC, a specific type of very flow able concrete, it does not require vibrations to place and compact it. Innovative materials are known that its uses for partial replacement of cement, sand, aggregate or some combination of two or more of these replacements. These substances, namely, could be used as additional filler to strength the mechanical and physical SCC properties. The works expected goal is to compile the more recent improvements in SCC of studying their effect on the properties of SCC and based a strong basis on an international benchmarking for many research works [1].

It is known that Self-Compacting Concrete was the first advanced in Japan about 31 years ago to attain durable long-lasting concrete structures. Many experiments have been carried out to clarify and achieve a regular mix design for standard concretes. That is to say, it is very similar to normal concrete. It is achieved that Self-compacting concrete does not have further inner or external vibration and it is necessary for the compaction. It was said that SCC compacts itself because of its own -weight and is abandoned completely until it flows into the formwork.

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According to many tests, mostly, the structural members with a high percentage of Reinforcement can fully fill all voids and gaps. SCC can flow as “honey.” In other words, it can be said that it contains almost a horizontal concrete level after placing [2]. Concrete is consist of many types naturally, cheaply and is known that has easily available some ingredients such as cement, sand, aggregate and water. Cement is the second material on a list of the most globally used materials. Cement is a material that has both adhesive and cohesive properties, which allows it to bond mineral particles into a compact whole. It is created by mixing together ground limestone, iron or alumina, and silica. The mixture is heated to about 1600° C in a rotary kiln, which causes the material to break down and recombine into new compound called clinker. After cooling clinker to an appropriate temperature, it should be grinded to a fine powder named cement. The rapid production of cement process causes large problems for the humanity and the environment. The main environmental problem is the emission of CO_2 during the production of the cement. CO_2 emissions are very harmful and cause big changes in the environment. According to estimations, one ton of CO_2 is released to the atmosphere when the same amount of ordinary Portland cement (PC) is manufactured [3]. There is no alternative building material to fully replace the cement. However, the search for a material to be used as an alternative or a supplementary for cement is still ongoing efforts. The discovery of such a material should lead to sustainable global development and to a reduction in the possible environmental impacts. Cost savings and substantial energy savings can result when industrial byproducts are used as partial replacements for cement.

There are many types of waste materials used to replace cement such as kiln dust, quarry dust, eggshell powder, ceramic waste powder, rice husk ash, and Polyvinyl chloride (PVC) dust.

Being made of petroleum substance, PVC is widely can be the third produced synthetic plastic polymer. Sodium chloride was used in the production process too. Recycled PVC, in addition, is broken into very small chips while the impurities are removed. Then, the product is refined to make purely white PVC. PVC is very light and can be easily exposed to air during the manufacturing of PVC pipes. This exposed PVC is called as PVC Dust. The PVC has to be disposed in a careful manner by an environment friendly way. PVC dust is used

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as a filler material with cement such as an environmental friendly and cost effective construction material.

Because of the growing demand and the urgent need to use PVC, it has continued to accumulate as waste until it became a burden on the environment. The disposal of this plastic is one of the largest environmental problems facing today's world. This problem led to increase the awareness and the emergence of international attention to searching for solutions to reduce the negative effects of the accumulation of plastic waste. Scientists, engineers, and researchers have started thinking about reusing the PVC in construction works without losing it into the environment. There are several methods to dispose the plastic waste. In general, known methods are landfilling, incineration, biodegradable plastics, and finally, recycling.

The process of recycling is the reuse of waste whether home or commercial to minimize the impact of this waste accumulation on the environment. It has been confirmed by practical experience in this area that recycling programs can help reducing the costs of raw material and operating as well as help the environment by reducing environmental pollution. Here, the product of recycled plastic is usually of lower quality than the basic product used for the first time, and it is not used in the same purposes as the basic product. In spite of this, the cost of recycling manufacturing is more expensive than the cost of manufacturing the basic product in terms of raw materials. This makes the process of recycling is logically uneconomical, but a waste of energy. The recycling process of waste PVC is still used as previous studies indicated that rates of recycling range from 1% to 3% and the rest is disposed of by incineration and landfill [4]. The recycling of PVC waste has a lower rate compared to other types of plastic waste. Only 6% of the PVC was recycled in west [5]. The study of research referred that only 4300 tons of PVC was recycled out of a total weight of 4,300,000 tons in USA in 1995, representing only 0.1% from total quantity of generation in USA. In Austria, the rate of recycling of PVC was 0.25% in [6].

The re-use of waste plastics especially PVC and to get rid of them are a good manner and an alternative route for the benefit of the environment._PVC waste can be used as a partial substitute in the aggregates of cement in the civil engineering applications to make the concrete. The concrete is widely used in

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large quantities in various businesses such as producing cement mortar and the manufacturing of cement bricks. It can also be used in soil stabilization such_as road pavement, slope stability, tiles, sidewalks, stations, car parking, and footpaths. Several researches were conducted in this area to take the advantages of the PVC and to replace the rubble whether it is fine or coarse in the concrete mixture [7, 8].

The main objective of this study is to improve durability and strength of concrete by reducing the permeability via incorporating PVC dust in self-compacting concrete (SCC). To be more specific, the effect of the PVC has different percentages as the below:

i. Gas permeability test.
ii. Water permeability test.
iii. Sorptivity test.
iv. Dry shrinkage and weight loss test.
v. Restrained shrinkage test.
vi. Compressive strength test

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1.2 Thesis Outlines

Chapter 1: Introduction:

- Overview of the thesis.
- The study objectives.

Chapter 2: Literature review:

- Plastic waste
- Self-compacting concrete
- Tests of Permeability Properties.
- Types of Materials Replacement With Cement
- Use and Advantage of Plastic Waste

Chapter 3: Experimental studies:

- Material properties
- Mix designs of concrete
- Test procedures.

Chapter 4 : Results and discussions.

Chapter 5: Conclusion

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CHAPTER 2

LITERATURE REVIEW

2.1 General

Concrete is defined as a mix of water, cement, and aggregates where the cement and water combine to work as a binder. The binder is used to hold the aggregate particles together into a plastic mixture. The result of mixing water and cement is an exothermic reaction called hydration. Then, in a process is called curing, concrete changes from plastic to a solid state. It has been recorded that concrete continues to gain strength as it cures.

2.2 Plastic Waste

In many countries, the amount of plastic waste is increasing, occupying a large part of solid waste. Because plastic is non-biodegradable as a result, the accumulation of it is causing serious environmental problems. Recycling this type of waste can be used as a means to manufacture new materials such as concrete or mortar; it seems to be one of the best solutions due to its ecological and economic advantages. Using plastic waste has been proven possible in previous studies.

2.2.1 Types of Plastic Waste

Plastic has been put into six different groups by the plastic industry. These six types of plastic are:

1. High Density Polyethylene (HDPE): HDPE is used mostly in milk and detergent bottles.

2. Polyethylene Terephthalate (PETE): PETE is one the largest quantities of recycled plastic. It used to make various bottles such as soda, cooking oil, etc.

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3. Polyvinyl Chloride (PVC): PVC is most common in plastic pipes, liquid detergent jars, water bottles, and furniture, among other things.

4. Polypropylene (PP): PP is usually found in drinking straws and bottle caps.

5. Low Density Polyethylene (LDPE): LDPE finds its usage in dry cleaning bags, food storage containers, and other similar materials.

6. Polystyrene (PS): PS is found most easily in cups, plastic tableware, etc.

2.2.2 Properties of Plastic.

Plastic is a type of non-biodegradable material. Researchers have discovered that it can stay for 4500 years without degrading or breaking down. Many characteristics of plastic help to making it a good material to incorporate into concrete and other building activities. These properties are:

- Not easily biodegradable/ durable - This property means that plastic can be used as a substitute for inert matter in the cement matrix.
- Versatile - Plastic has various uses in many areas in the industry; it can be used in many different situations. This makes it economically an attractive choice.
- Light - Plastic is very light in terms of weight.
- Hard – The chemical makeup of plastic is strongly bond together particles that make it resistant to breakage.
- Relatively low linear dilation coefficient.
- Good, useful, and chemical resistance.
- High heat resistance.

2.2.3 Recycling Plastic

Recycling is defined as the process for getting used materials and incorporating them into manufacturing processes.

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Recycling is a vital issue in the precarious environmental times.

The aims of recycling are:

- Preserve natural resources.
- Reduce the risk of harmful substances for the environment through the introduction of environmentally friendly materials.
- Minimize the need for transportation and the costs associated with it.
- Reduce the environmental pressure caused by waste material, especially land requirement. Considering that plastic products do not decompose in landfills are difficult to reduce in size. The urgency to recycle plastic is clear. Even with the fact that the whole process of recycling is faced with technological and economic constraints. Limiting its efficiency to convert plastic waste into useful products, the need to increase recycling is obvious.

2.2.4 The Advantages of Using Plastics

Plastic has several valuable properties including:

- Maximal versatility and the ability for modification to meet specific technical standards.
- Relatively lighter weight when compared to other materials.
- Durability and does not fail easily.
- High resistance to water, chemicals, impact, and other external factors.

2.2.5 Polyvinyl Chloride (PVC)

Polyvinyl chloride (abbreviated as PVC) is a thermoplastic material that is used almost daily by humans in shopping, luxury, in bags, electronics, healthcare, etc. Many reviews of the physical/mechanical properties of polyvinyl chloride focus mainly on the possibilities of using it as construction material. Notably, in the areas of concrete technology that have been carried out.

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2.2.6 Consequences of Plastic Waste (PVC) on The Mechanical Properties of SCC

The application of plastic waste particles in concrete production has recently caught the attention of most researchers. In all their studies, it was noted that the size of the plastic waste particles and the volume surface texture have a significant effect on the mechanical properties of the modified concrete. They stated that the samples have a large load bearing capability after bursting and offered significant displacements without the need for fully separating. These deformations and displacements were reversible after releasing the load. The modulus of elasticity and strength properties of concrete including various types of plastic wastes are consistently lower than reference concrete having natural aggregate of a standard density. They further have reduced with increasing plastic waste content in concrete ratios [9]. However, it has been suggested that incorporating waste plastic-aggregate up to a specific level has no effect on the flexural and compressive strengths of cement mortar [10]. When coarse, recycled, aggregate of reliable quality is used, the total substitution of the natural course aggregated by recycled aggregate. The leveling of concrete structures has a minimal impact on the compressive and tensile strength reduction. The authors, at 28 days, found a reduction of 9% and 13% compressive strength and tensile strength, respectively.

2.2.7 Self-Compacting Concrete Containing Plastic Waste

Physical property Shows that the porosity and absorption of water reduces up to 30 % sand replacement by plastic waste after that slight increase was observed in both properties. Density also reduced and reduction in density was observed 37.5% at 50 % sand replacement. Mechanical property such as sound velocity, compressive strength, and flexural strength were also found to decrease when sand is replacement by plastic waste. Sound velocity becomes at 30% replacement. Reduction in the total compressive strength was observed at 15%, 33 %, 30 %, 50 % sand replacement respectively. A slight increase in flexural strength was noted after age of 28 days [1].

2.3 Concrete

Concrete is one of the most critical elements in any kind of construction work. It is composed mainly of cement, water, aggregate, and chemical admixtures. Most

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commonly, concrete is compacted by a steel bar or a vibrator after being placed inside the formwork. This process is to remove the entrapped gases afterwards, it became a uniform and dense material, namely, perfecting for building. Compaction is crucial for creating a homogenous concrete mixture with the desired durability and strength.

2.3.1 Self-Compacting Concrete (SCC)

As a great modernization in concrete-applied technology, self-compacting concrete is the casting process without the need of extra vibrating forces. Compared with regular concrete, SCC has distinct advantages. It is a significant step in the right direction of sustainable developed concrete, in reducing the cost of construction and improving the general environment of construction. The initial idea of SCC was firstly developed in University of Tokyo by a scholar was named Okamura in 1986. He noticed that reducing the number of skilled Japanese workers had a negative impact on the durability of the concrete. He then proposed developing self-compacting concrete to avoid the impact of construction quality. Self-compacting concrete is characterized by high-workability. Closely, after Ozawa, another scholar from the University carried on the study on self-compacting concrete and successfully created self- compacting concrete in 1988 [12, 13].

2.3.1.1 Improvement of Self Compacting Concrete

The advancements, which made in concrete studies have directed in achieving high-performing concretes among self-compacting concrete (SCC). During the late 1980’s, Japanese researchers were agitated about the durability of concretes. Notably, the concrete is cast in fortified and congested structures. The faced challenges while casting concretes in these kinds of construction works began the search for improved types of concretes hence , the Japanese’ efforts yielded the SCC [14].

These challenges entailed the quality control of the concretes cast, specifically segregation and/or honeycombing of the concrete. Another challenge is finding a skillful enough workforce to guarantee acceptable compaction for the concretes [15] Adopting self-compacting concrete is best for construction works in unusually seismic areas such as Turkey and Japan among others where construction requires a

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very large number of reinforcement structures for a particular civil engineering work. SCC is a concrete of low viscosity. Its compaction is achieved due to its weight and as a result, the efficiency of the work is improved [16]. The notion of a concrete mix can be packed into every small space of a formwork, by its own weight, without the use need for vibrating it. It was first contemplated in Japan, in 1983. During that time, concrete constructability, durability, and productivity became large topics of concern in Japan. During this time, a shortage of skilled workers in Japan was there, which directly influenced the concrete quality [17].

2.3.1.2 Benefits of Self Compacting Concrete

There are many benefits to using SCC, namely, the most notable manner is to improve quality of the concrete. A homogenous mix of concrete can be created even when the construction work is limited by jammed reinforcements structures and access difficulties specifically, in areas with frequent seismic activities. Another benefit is the fact that the concrete fills all areas of the framework and goes around reinforcements. SCC is vital to works of construction that require high compaction such as tunnel linings castings and closed space areas etc. In addition, many skyscrapers and high-rise towers need to employ a specific concrete type and concrete tubing, which uses SCC. Another advantage of SCC is that its properties vary minimally on site. Moreover, the shape of the concrete is not affected by the reinforcement structure already present.

Self-compacting concrete is also environmentally and human friendly. The production of self-compacting concrete is a low-noise process; it has a lesser impact on the neighbor hoods and surrounding areas. It also prevents 'white fingers', which is when blood circulation is cut off .It usually correlated to working with concrete production machines thus , the concrete is dubbed 'healthy concrete'. Yet another benefit of SCC is that it has a decreased manufacturing process, which increases productivity, efficiency, and speed, especially in pre-casting. The use of SCC also means less accidents due to less equipment being used creating less issues and complications. This in turn means less insurance problems and compensations.
This type of concrete is also economically friendly. The placement is easily achieved thus, increasing productivity, lowering the amount of labor and machines and decreasing the overall cost. The concrete of wear and tear is reduced drastically and

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increasing the total lifespan of the equipment and machines used. In addition, the amount of manual labor needed for the same job is reduced by an average of 70%. The increased fluidity of the concrete ensures that there is no need for vibrations to smooth and even out the concrete thus, being more productive and lowering the cost of production. Expenses and manpower are generally decreased when using SCC.

2.3.1.3 Uses of Self Compacting Concrete

SCC was used to help correcting a chloride-induced deteriorated bridge built in the 1960's in the Swiss Alps. The concrete structure had lost a large amount of steel and concrete reinforcement on the underside. Placements and formwork of the concrete followed the replacement of the steel reinforcement under the deck. The only poured concrete ready to sustain the job at hand was SCC where it was then pumped into the formwork via the underside. Holes for air were made at the top of the deck to allow the release of pressure that would be generated when concrete is pumped in. Self-compacting concrete allowed the project to be finished on time while at the same time, keeping the mandated concrete quality throughout the entire project [18].

The application of self-compacting concrete in the construction of the anchorages of the Akashi-Kaikyo Bridge in Japan has provided one of the most critical uses of SCC in the construction of the longest suspension bridge in the world – approximately 1991 meters .The two anchorages had used up about $2.9x10^5$ m^3 by volume. A newer system of construction that took full advantage of the performance capabilities of SCC was introduced to reduce it. The concrete was manufactured at the batching plant and then was pushed out of it via pipes. It was carried 200 meters through large pipes to the site of casting, where the pipes are arranged in rows about 3 to 5 meters apart. The concrete casting was done from gate valves positioned at 5-meter intervals, along the pipes. The time took for construction was reduced by 20% because of the use of SCC. [19, 10]. Discussed the use of SCC in Japan and the advantage was gained by the firms when producing their own. As an example, the Kiba-Park Large Bridge, a 151-m concrete bridge, called for only two manual laborers to pour 650 m^3 of SCC within nine months. The difficulty and arduous task cost of placing normal concrete in heavily fortified concrete structures pushes the needs for applying SCC. The second was a 70-story structure and the tallest high-rise

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in Japan that used 885 m^3 of SCC forced up into steel tubular columns. The concrete was pumped in from the bottom at a peak filling height of 40 m.

Figure.2.1 Akashi-Kaikyo Bridge in Japan (Google, 1998)

Figure 2.2 Kiba-Park Large Bridge (Google)

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2.4 Tests for Permeability Properties

2.4.1 Water Permeability Test

The normal permeability coefficient of RPC (reactive powder concrete) close to the 98-day mark is approximately 0.0005 as investigated by [27]. The low water penetration of RPC was also looked into and it was concluded that the low penetration of RPC with low water-concrete ratio could be traced back to the small-disconnected pores that occur in the dense and uniform parts of the RPC.

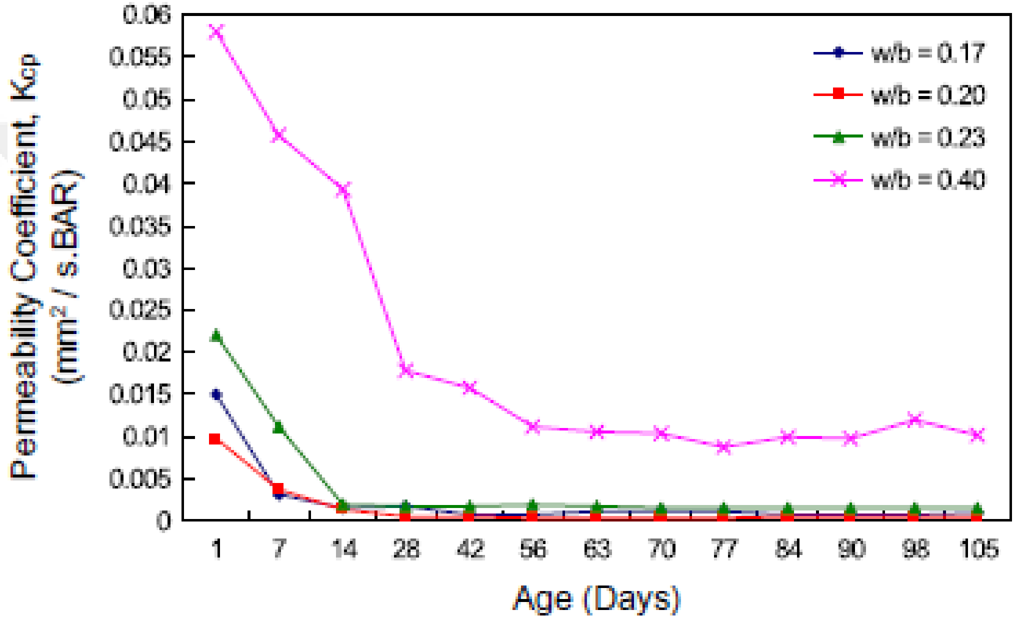

Figure 2.3 Water permeability with different water-to-binder ratios at various ages [27].

Rice husk bark ash (RHBA) mixed with fly ash (FA) were used to create inorganic polymer concretes (IPC) used as a cementitious material by [28]. Compressive strengths of all the IPC decreased from around 28 days to 90 days, which is the inverse of what happened to the permeability. At constant compressive strengths of the IPCs, the permeability is much higher than that of normal concrete. Additionally, the higher compressive strength, the less significant the measured differences between the water permeability.

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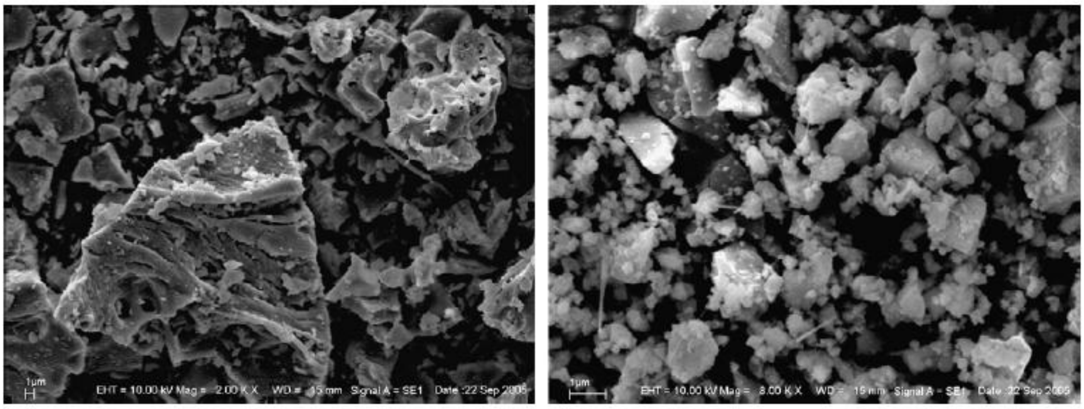

Figure 2.4 Particle images of original and ground RHBA [28].

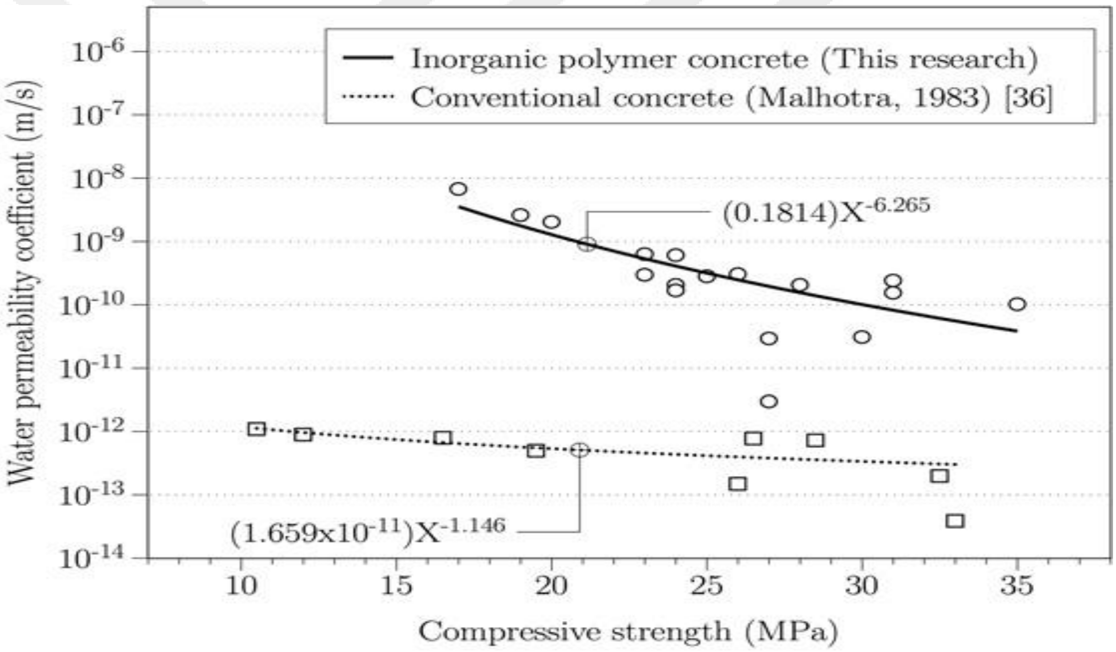

Figure 2.5 Relationship between water permeability coefficients, compressive strength of conventional concrete and IPCs [28].

A study was done by [29] on fully hardened concrete to test the crack effect on permeation with experimental methods. The specified technique was based on early concrete age models. The increasing of permeability due to cracking was contemplated in this technique. For crack widths more than 0.2 mm, the water permeability significantly increases. The increase in permeability ratios in cracked concrete in comparison with sound concrete are as follows: 1.5-2.9 (crack width of

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0.1 mm), 13.6-20.0 (crack width of 0.2 mm), 37.2-52.2 (crack width of 0.3 mm), and 747.5-1004.7 (crack width of 0.4 mm) respectively.

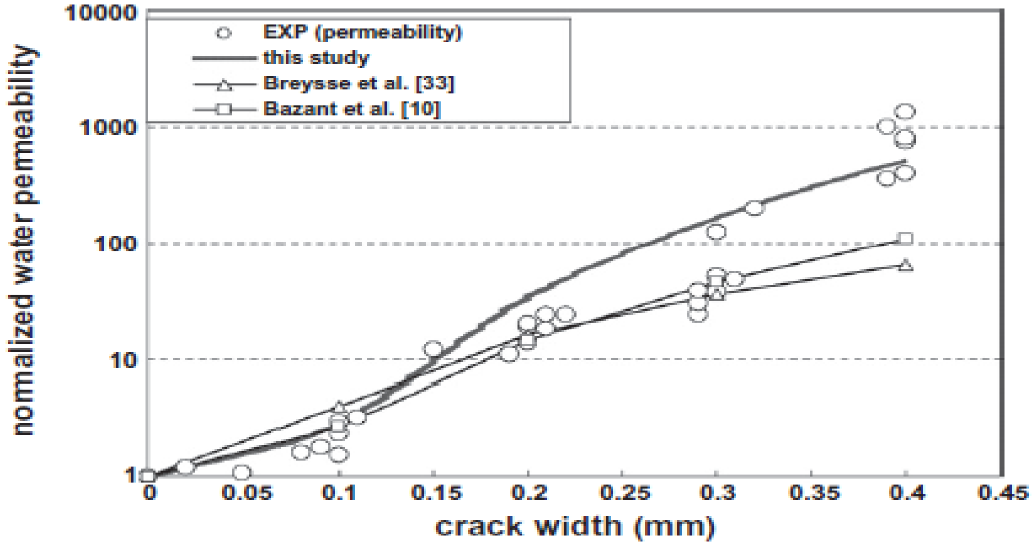

Figure 2.6 Normalized water permeability, with crack width with an inclusion of previous models [29].

An investigation by [30] was done about the use of 10-30% coarse and fine as substitutes for ordinary Portland cement and good water permeability results were reported; the results were dependent on the percentages of replacement, and the age of the concrete. Ground palm oil fuel ash (POFA) concrete had an increase in compressive strength as the water permeability of the concrete decreased. Moreover, the relation between the water permeability and compressive strength of POFA is distinct and positive.

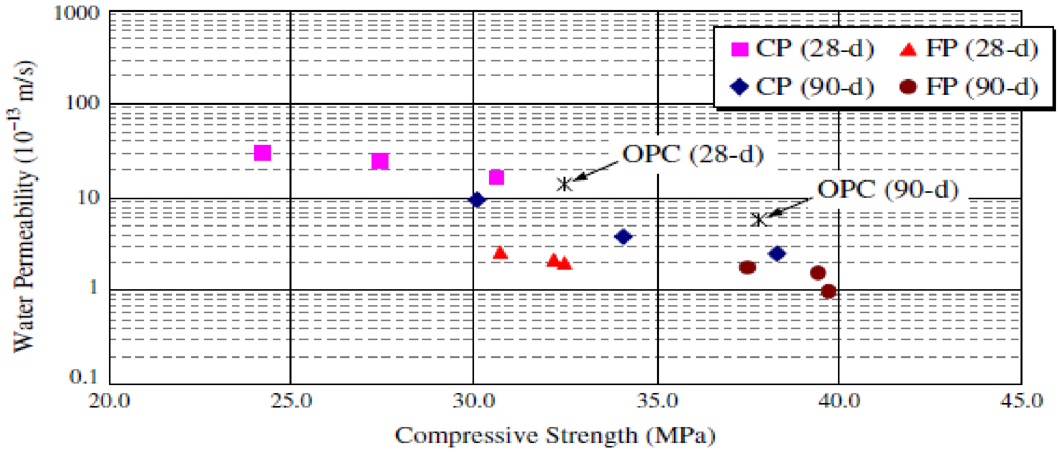

Figure 2.7 Relationship between compressive strength and water permeability of concrete [30].

In a study, done by [31], mixtures were advanced by adding 50-260 kg/m^3 cement content along with large amounts of fly ash, ranging from about 40% to 85% of the total material. The investigation was done for testing water permeability factor of the concrete. The concretes' permeability, as assessed by calculating the volume of water that permeated with time. The mean coefficient was calculated from two identical figures. It was noticed that concretes made of high fly ash content and low cement contents presented a higher permeability (RCC1 and RCC2). In addition, permeability of high cement and low fly ash concretes (RCC5 and RCC6) was somewhat higher than moderate cement and moderate fly ash concretes (RCC3 and RCC4).

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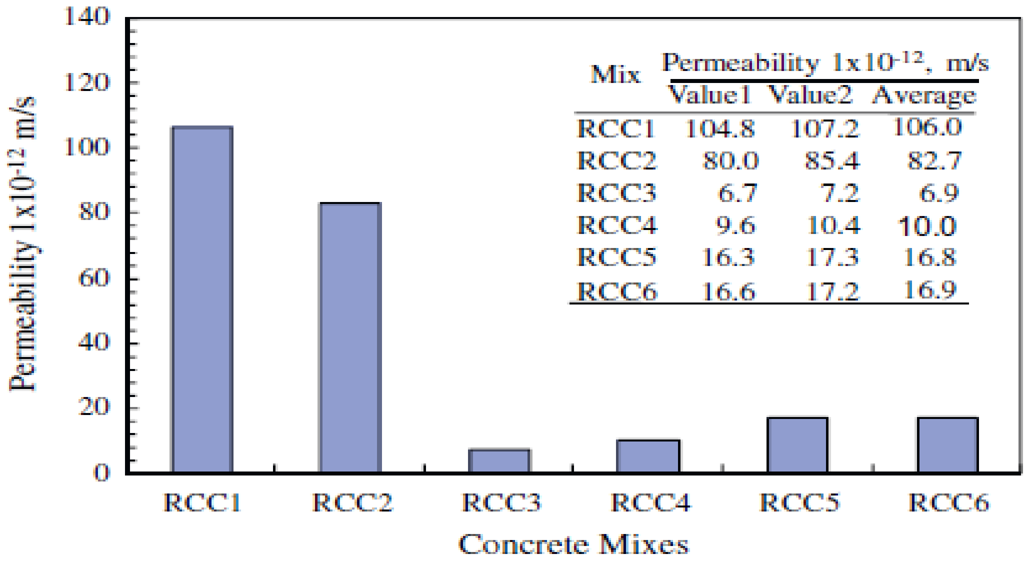

Figure 2.8 Water permeability for the concretes [31].

Test results from an experiment conducted by [32] revealed that HSCC (high strength self-compacting concrete) and MSCC (medium strength self-compacting concrete) mixtures with PFA (pulverized fly ash) experienced the lowest water permeability values than any other concrete type such as normal concrete. Vibrated concretes (this may be traced to their less porous interfacial area), as well as the paste matrix of SCC because of the refined pore structure. SCC viscosity modifying admixtures (VMA), however, indicated the highest relative capillary absorption, and that can be brought back to the fact that it lacks a pore filling effect, and has a higher water-binder ratio.

According to studies [33] using recycled aggregates increases the water permeability factor of self-compacting concrete, irrespective of the size of the addition; this effect was more notable in concretes with higher w/b ratios. The lowest water penetration result was 4 mm, with specifications of 0.3 w/b ratio, 0% RCA(Recycled Course Aggregate), 0% RFA(Recycled Fine Aggregate), and 10% SF(Fly Ash). On the other hand, the highest penetration value was with 0.43 w/b ratio, RCA 100%, 100% RFA, and 0% SF, RA concrete behavior is due to the aggregate's porous structure, allowing water to easily penetrate into the aggregate, as well as through it, under pressure. Because of this, water penetrates deeper into RA-mixed self-compacting concrete than NA-mixed self-compacting concrete. This increase in porosity can cause the

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concretes connectivity and adhesion to decrease. This in turn allows easier water penetration into this weaker concrete. During this study, it was understood that with the addition and incorporation of fine and coarse aggregates, water penetration increased notably, by 4.5-7.6 times, relative to the control mixtures where NA was used instead. It was supervised that with an increase in w/b ratios, an increase in water permeability was also recorded. For the control group mixes, an increase in the water-binder ratio leads to 2 times the penetration. When SF was used, a significant increase in penetration of the water was observed. This is due to SF being a substance that improves concrete's water impermeability. SF can take part in the hydration processes of cement, producing more hydrates, decreasing the porosity of the concrete. For example, a 20% reduction was observed in water permeability. Pore structure, pore continuity, and concrete durability may be determined from water permeability tests.

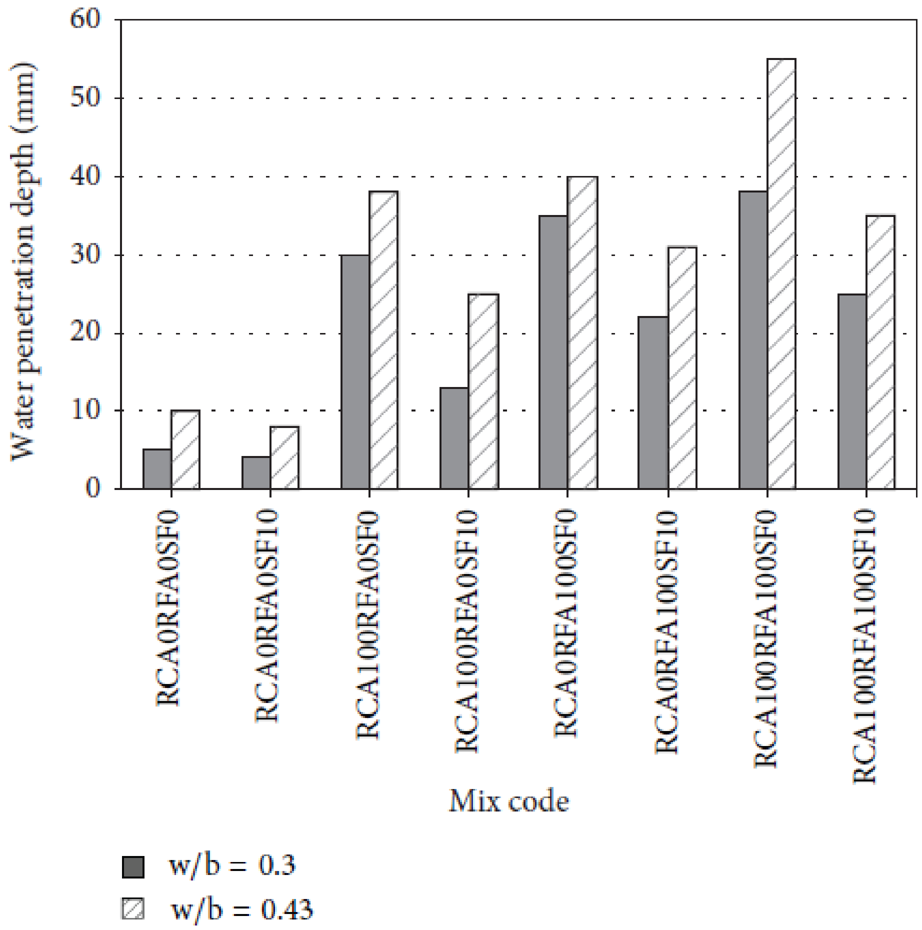

Figure 2.9 Water penetration depths of SCCs [33]

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At silica fume levels of 10% and 0% rubber, the water permeability was at its lowest, 25 mm. The maximum water permeability, 50 mm, was achieved at silica fume 0% and 10% and rubber 0%. Concretes with lower rubber content as well as regular concrete both experienced significant improvements with the addition of SF, even though the effects of SF at 25% rubber volume could not be seen [34]. As an example, plain concrete, that is, concrete without any SF additions had a water permeability level of 47 mm, but after the addition of SF, the number was reduced to 25 mm. A similar improvement occurred with 5% and 15% SF content. Moreover, plain concrete with SF is the most convenient to use in structures when it comes to harsh chemical effects. Water permeability of concretes with no SF, but containing rubber, however, was around 40-150 mm. At this level, 0.60 w/b ratio, using rubber notably increases the water permeability, which in turn makes the concrete weaker against chemical elements. Due to the chemical properties of rubber, the adhesion between the particles and the matrix is low. This means that there are numerous porosities in the concrete, which results in high permeability. As a general rule, the more porosities, the higher the permeability [34]. Tire chips have also been used in concretes with widths of 4 mm or more to decrease the number of pores; ultra-fine material has also been used to decrease the number of large pores by increasing homogeneity [35].

2.4.2 Gas Permeability Test

Care and Derkx [36] .have characterized the cementitious material's microstructure and its effects on the gas permeability of the material. Pastes of cement with varied cement-water ratios and mortars with two aggregate volumes were set. The microstructure of the materials was specified by mercury intrusion porosimetry; gas permeability tests were performed by using a low-pressure machine, after preconditioning them at a specific relative humidity. The specific gas permeability depends on the mixture (cement-water ratios, aggregate size, and aggregate volume content). Gas permeability was in correlation with the relative mass loss, or the porosity for the cements; no correlating factor was found between gas permeability and mortar because of the fact that aggregate size and volume content adjusted the transport properties for the cement paste matrix.

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Three types of concrete were experimented on by [37] for the effect of compressive axial loading on their gas permeability. The three types were ordinary concrete, high performance concrete, and steel reinforced high performance concrete, abbreviated OC, HPC, and HPFC, respectively. Cyclic and monotonic loads were applied to the concretes, 220x100-mm diameter cylinders. The stress levels of the concretes changed from between 60% to 90% of their ultimate strengths. During the finale of the loading stage, a disc is taken from the middles of the specimens where it is then dried in a ventilated oven. During the proves to dry them, four different gas permeability tests were carried out. At every drying stage, the discs' permeability increased with the load-generated strain. In general, the gas permeability of the HPFC was lower than the analogous HPCs, and it was consistently lower than that of the OC.

Sugiyama et al. [38] looked into the effects of stress on the gas permeability of concretes. This was done by using nitrogen gas as the test flowing material. Cylindrical hollow concrete specimen was assigned uniaxial compressive loads. The loads' weights were added steadily until the concrete failed; meanwhile, the gas flow was measured to calculate gas permeability of the concrete at each increasing stress level. At similar stress levels and with identical cement-water ratios, structural lightweight concrete with ratios of 0.4 and 0.6 were compared with normal weight concrete. Concrete exposed to the oven drying process, for seven days, was constant or with a minimal decrease with 45-55% of the ultimate strength. When stress levels were increased even more, gas permeability was boosted slightly. At approximately 76-79% of the maximum strength load level, the effect of the compressive stress on the permeability of the gas became more notable; the structural lightweight concrete had approximate stress levels of 82-89% of max strength. Moreover, gas permeability was greatly affected by the level of saturation in the concrete. The higher saturation degree, mean the lower level of permeability. In addition, the compressive stress was discovered to have a smaller impact on the permeability of the concrete as the saturation degree increased even at relatively higher stress levels (90% of ultimate strength).

The relationship between HPC (high performance concrete) with GGBFS (ground granulated blast furnace slag) or FA (fly ash) was discussed in a study by [39]. Compressive strength and nitrogen gas and the relationship between them are

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discussed. From the correlation coefficients and trends, it has shown that the relationship between gas permeability and compressive strength is largely affected by water-binder ratios, and is very reactive to the combined cementious systems. For HCP with FA, correlation coefficient values R2 are 0.73 at w/cm of 0.30 and 0.60 at w/cm of 0.35. For HCP with FA/GGBFS, it was noted that the correlation trends are significantly different. The compressive strength of high performance concrete with fly ash was exponentially related to the gas permeability coefficient, and it was linearly related for HCP with GGBFS.

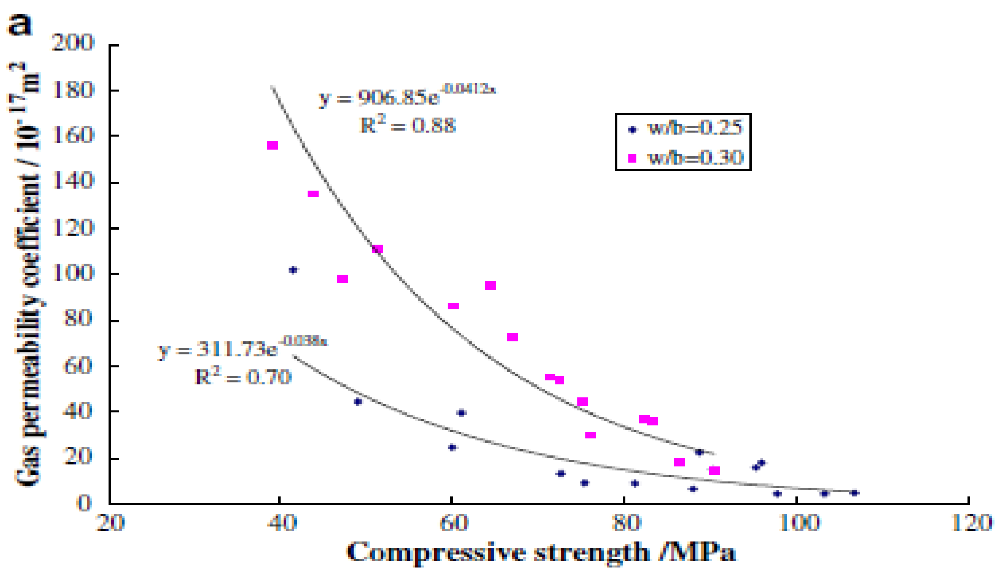

Figure 2.10 Relationship between compressive strength and gas permeability (a) [39].

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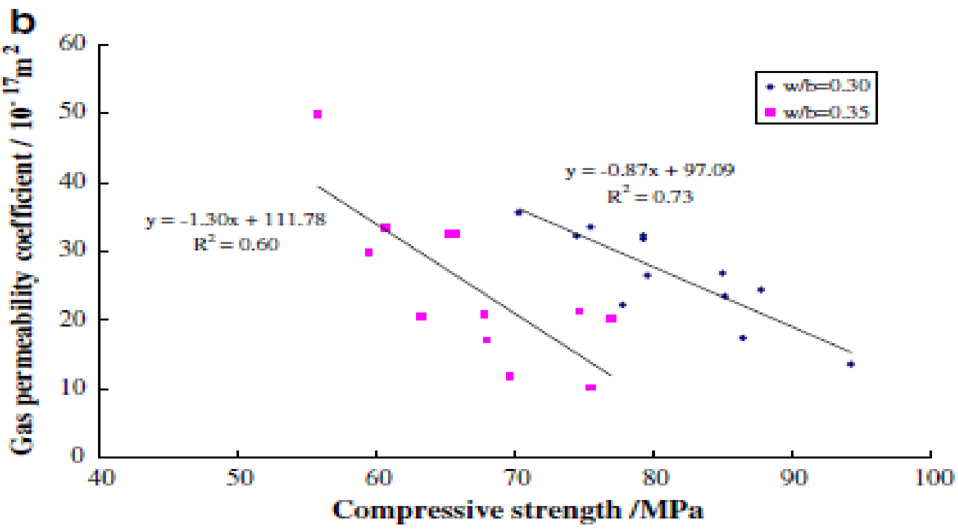

Figure 2.11 Relationship between compressive strength and gas permeability (b) [39].

The gas permeability of the limestone cement concrete was significantly influenced by the clinker quality, as looked into, by [40]. It was recorded that cement fineness and clinker quality, limestone cement concrete with optimal content of limestone gave lower gas permeability in relation to pure cement concrete. The permeability properties of the cement were increased with the addition of limestone especially, if that cement has high contents of C3A. The size of the pores' distribution, particularly the average pore size, influenced the concrete's gas permeability factor. However, in concretes (cement with clinkers of high C_3A value included), the hydration products form precipitates on the surface of the aggregate; it does not affect the concrete's gas permeability, though.

High volume fly ash (HVFA) mixed with a binder content of 400 kg/m^3 and with a water-binder ratio of 0.4 can was significantly less accessible to water and various gasses (carbon dioxide (CO_2) and oxygen (O_2)) than OPC (ordinary Portland cement) concrete. The HVFA mix was defined by 78.9% and 78.0% lesser apparent gas permeability (known as k), at 28 and 91 days, accordingly. For both, fly ash concrete and OPC, a clear linear relationship existed between the gas permeability the total permeable porosity and the permeability measured at 2-bar pressure. The square root of k was plotted, as a function relating to the dryness of the concrete, the correlation was defined and it can be used practically to calculate the gas permeability and

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corresponding with degree of saturation in the concrete balanced with the environment [41].

The basis of the Hagen-Poiseuille, which states the relationship for laminar flow of a compressible fluid through capillaries of a porous fluid, under constant conditions was used to calculate apparent gas permeability. At 56 days, the lowest gas permeability coefficient was the 0.3 w/b ratio, 0% RCA, 0% RFA, and 10% SF mix, at $1.04x10^{-16}$ m^2. The highest coefficient, at the end of the curing period, was found to be $8.82x10^{-16}$ m^2 (0.43RCA100RFA100SF0) [33]. Because concrete's transport properties are heavily attributed to pore structure, an increase in gas permeability is caused by increased pore structure in the concrete, due to RAs. As anticipated, low w/b ratios in self-compacting concrete displayed better performances than high w/b ratios. For example, in control mixtures, a reduction in the w/b ratios increased the gas permeability value by 24-26%. Voids in the concrete and a result of evaporated water are the reason for concrete degradation related to gas diffusion. It was pointed out that SF-incorporated concrete is better in terms of gas permeability than non-SF-incorporated concrete. This is due to the pore structure improving with the addition of silica fumes. Generally, concrete permeability decreases with SF additions. Here, specifically, it reduces the water absorption factor. Evidently, a large quantity of SF alters the microstructure of the concrete. Moreover, SF, due to its fineness, assists in physically improving the concrete's pore structure.

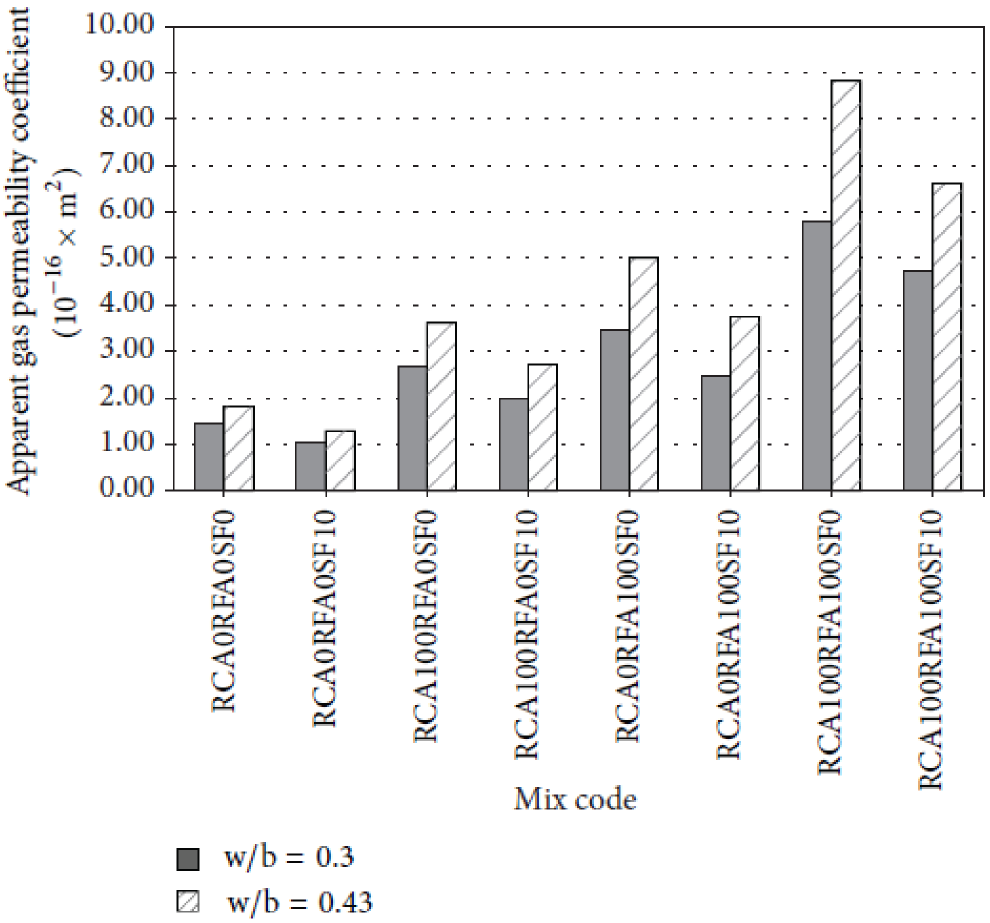

Figure 2.12 Gas Permeability coefficient of SCCs [33]

In the experiment, the gas permeability coefficients for rubberized concrete with and without the incorporation of silica fumes [34]. The gas permeability test failed because of the high porosity at 15% and 25% replacement levels. The gas permeability coefficients were from about $0.83x^{10-15}$ to $2.35x^{10-5}$ m^2The concrete with 0% silica fume and 5% rubber had the highest gas permeability coefficient while silica fume 10% and rubber 0% ratios had the lowest gas permeability coefficient. Adding silica fume can strengthen the concrete's resistance gas permeability and water absorption. As an example, concrete with no silica fume had a gas permeability of $1.35x10^{-5}$ while silica fume-incorporated concrete was $0.83x10^{-15}$. This may be a result of improved pore structure of the concrete because of micro-filing [42].

In regards to MK- and SF-incorporated concrete, the apparent gas permeability coefficient was varied with the inlet pressure from 150 to 500 kPa. The Hagen-Poiseuille principal, who was used for the apparent gas permeability, states the

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relationship for laminar flow of a compressible liquid through a porous body with small capillaries, under steady conditions. During the study, it was noted that the gas permeability coefficient usually diminished up to 350 kPa; it began to increase at 350-kPa inlet pressure. MK and SF concretes both had notably lower permeability coefficients than normal concrete, for both w/c ratios, disregarding the inlet pressure applied to them._The use of 150, 200, and 300 kPa of pressure are recommended by RILEM [43] for finding the mean permeability coefficients. For 0.35 and 0.25 w/c ratios, the permeability coefficient ranges are as follows: 1.32-3.45 ($x10^{-16}$) m^2 and 0.97-2.04 ($x10^{-16}$) m^2, respectively, independent of the amount and types of admixtures [44]. For both concretes, the highest value for gas permeability was in the control concrete groups. Adding SF and MK seem to have influenced the reduction of gas permeability in their respective concretes. Although the reduction rates for both are similar, there is a distinct difference in effectiveness with varying w/c ratios. For instance, at 0.35 w/c ratios, and at 15% levels of replacement, the SF and MK produced 61% and 56% reduction, respectively. On the other hand, at 0.25 w/c ratios and at the same percentage replacement levels, they experienced only 50% and 52% reduction, respectively [44]. This leads to the conclusion that the higher the w/c ratio, the lower the degree of change. In terms of gas permeability, the concretes with MK and SF incorporated in them, especially at 15% replacement levels, had much better results than normal concrete. Because pore structure largely affects the transport properties of concrete, a decrease in gas permeability is attributed to the refinement of the concrete's pore structure through additions of metakaolin (MK) and/or silica fume (SF). Metakaolin's influence mechanism is because of the secondary hydration that occurs converting portlandite (CH) to calcium-silicate-hydrate (C-S-H) to the one presented by Portland cement hydration. This reaction turns out to be significant within the interfacial transition zone (ITZ) between the cement paste and the aggregate. ITZ normally includes a large concentration of connected CH crystals, which may cause the region lower mechanical property and increased porosity. MK reacts with of the CH produced from cement hydration, helping to harden the cement paste.

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2.4.3 Sorptyvity Test

Sorptivity variations are caused by water-binder ratios, curing conditions, and concrete age for regular and MK-varied concrete was investigated by [45]. It is well known that with an increase in curing time that a consistent decrease in sorptivity is observed; the sorptivity gradient usually reduced when replacement levels of MK increase. The value of the sorptivity is distinctly reflected in the strength of the concrete at 18 days. For the water-cured and 0.55 water-binder ratio concrete, an increase in the MK amount resulted in a decrease in the sorptivities of both 28 and 90-day concretes. The values for the sorptivity of the concrete (including MK) ranged from 2% to 36%, and also from 8% to 60% less than plain concrete, at 28 and 90 days, analogously, dependent on water-binder ratios, the curing regimen, and the MK content.

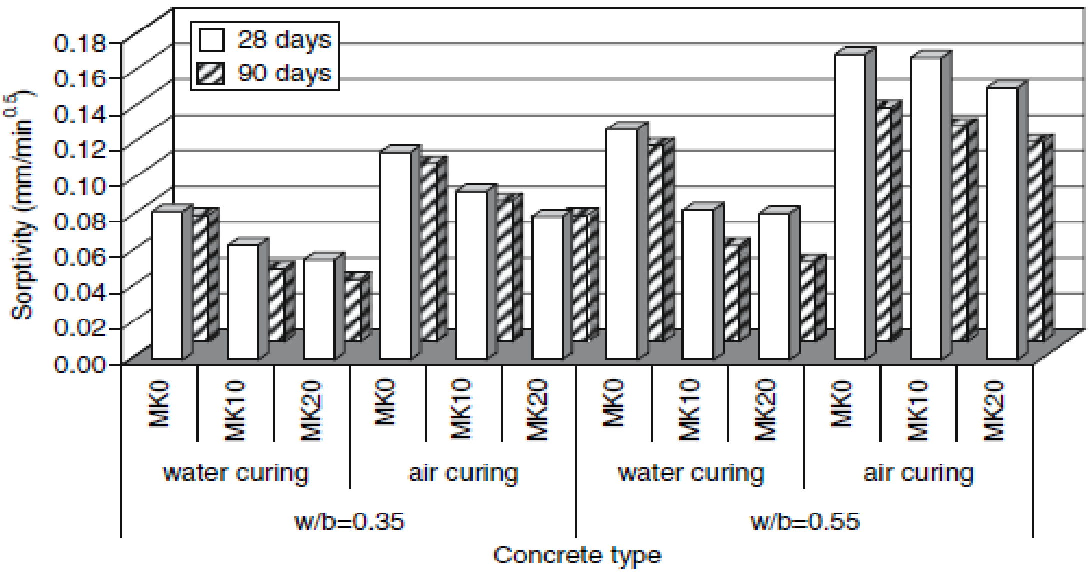

Figure 2.13 Variation in sorptivity of plain and MK-modified concretes to different curing regimes [45].

The normal water sorptivity of the concretes relative to control specimen are according to [46]. At 90 days, the repercussions of the sorpivity test on the self-compacting concretes were measured. The concrete with the highest total sorptivity ended up being the control group concrete. With the incorporation of the mineral admixtures, the self-compacting concrete's sorptivity decreased; in the end, the minimum sorptivity index was measured at approximately 15% MK and 45%

GGBFS for the ternary blends, and 15% MK for the binary blend concrete. Using MK effectively brought down the sorptivity of the concrete by reducing the volume of the concrete's pores. Another action that decreased sorptivity was the addition of fly ash and/or GGBFS with the MK.

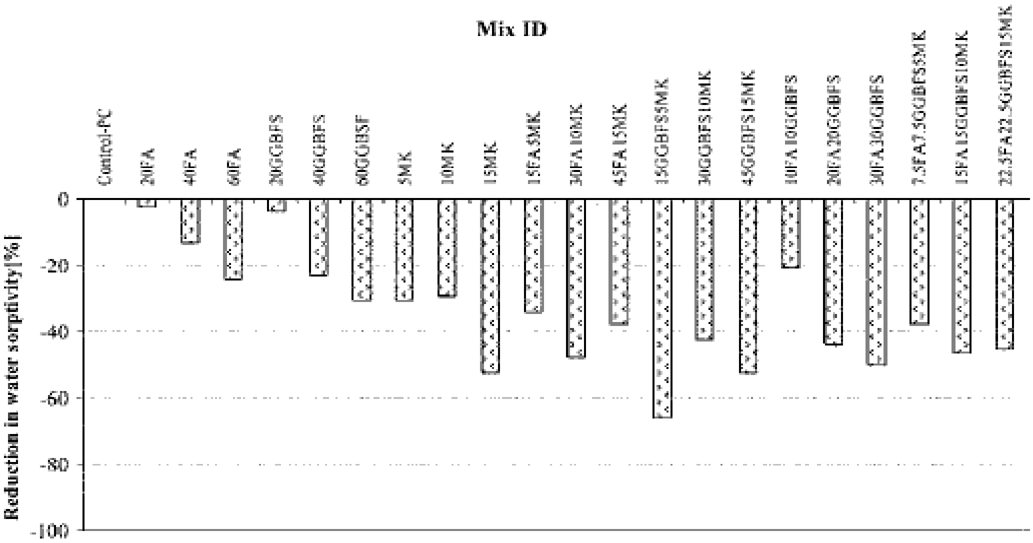

Figure 2.14 Normalized water sorptivity of concretes with respect to control specimen [46].

It is well known that sorptivity varies with the age of concretes such as water-cured metakaolin-pulverized fuel ash (MK-PFA) and with Portland cement-pulverized fuel ash metakaolin (PC-PFA-MK); the concretes have multiple replacement levels (10%, 20%, 30%, and 40%) and are curd up to 18 months. In each of these situations, there is a control concrete sorptivity value to compare with. Obviously, there is a systematic reduction in the sorptivity with the increase in the curing period of the concretes. In addition, the curves of the sorptivity versus age graphs are usually reduced with an increase of MK. Additionally, at 28 days, the significant sorptivity values are distinctly reflected in the strength prices. As such, the water cured concretes that have the highest sorptivities also have the lowest strengths (for example, PC-PFA blended); moreover, the highest strength concretes, not surprisingly, have the lowest sorptivities (for example, PC-PFA-MK blends that have the highest MK content [47].

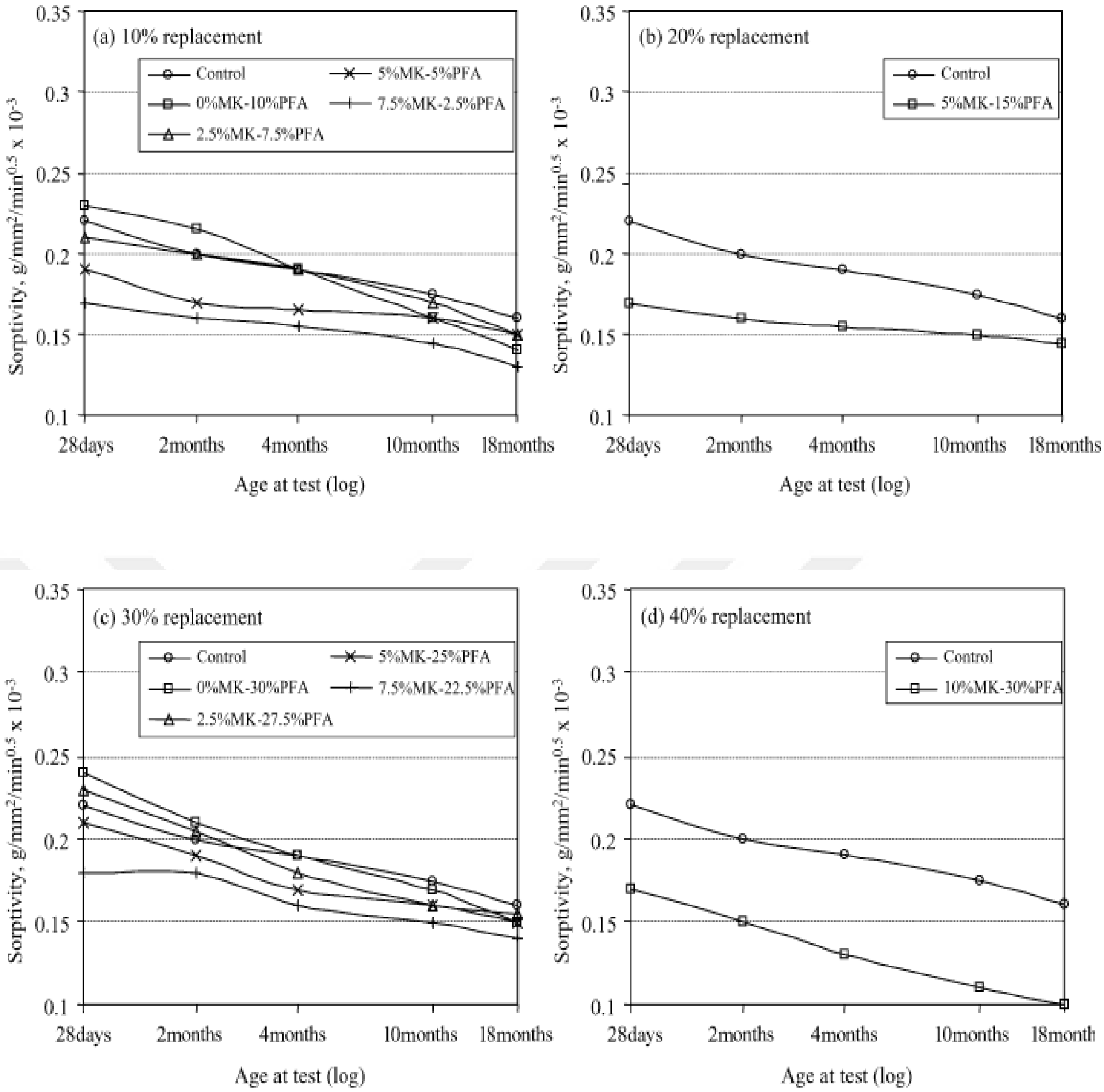

Figure 2.15 Sorptivity with age at 10%, 20%, 30%, and 40% cement replacements for water-cured concrete [47].

The sorptivity of high fly ash and low cement RCCs (RCC1 and RCC2) were significantly higher than any other concrete according to [48]. Additionally, it can also be noted that the sorptivity of high-cement, and low-fly RCCs (RCC5 and RCC6) was very close to that of average cement and average fly ash content (RCC3 and RCC4). In respect to permeability, an increase in cement content did not present any notable decrease in sorptivity RCCs (5 and 6). A comparison is given for permeability and sorptivity in the concretes, and the amount of cementitous material, fly ash percentage, cement content, and w/(c+f). Generally speaking, a distinct correlation is noted between the permeability and sorptivity values of the concretes.

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Because both sorptivity and permeability are functions of the pore system and porosity, permeability usually increases alongside sorptivity.

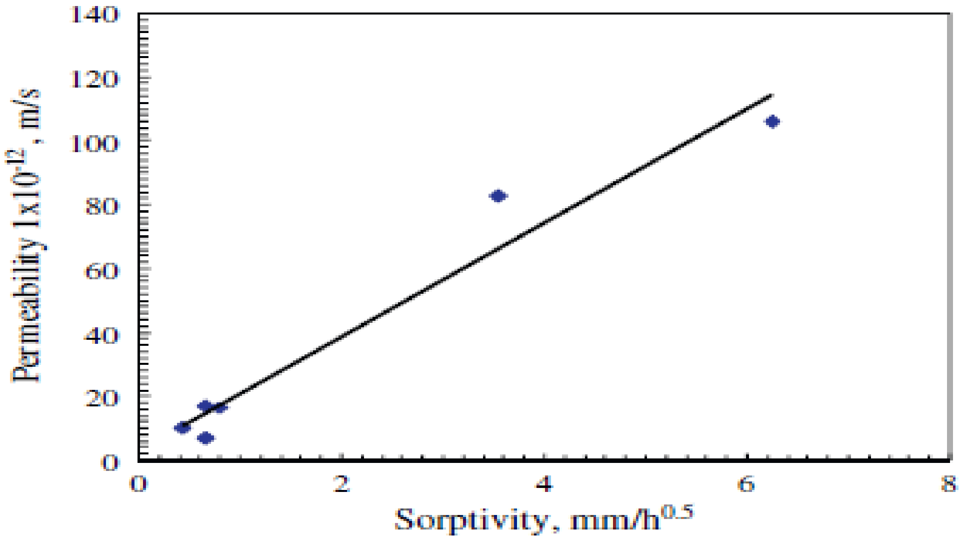

Figure 2.16 Relationship between permeability and sorptivity [48].

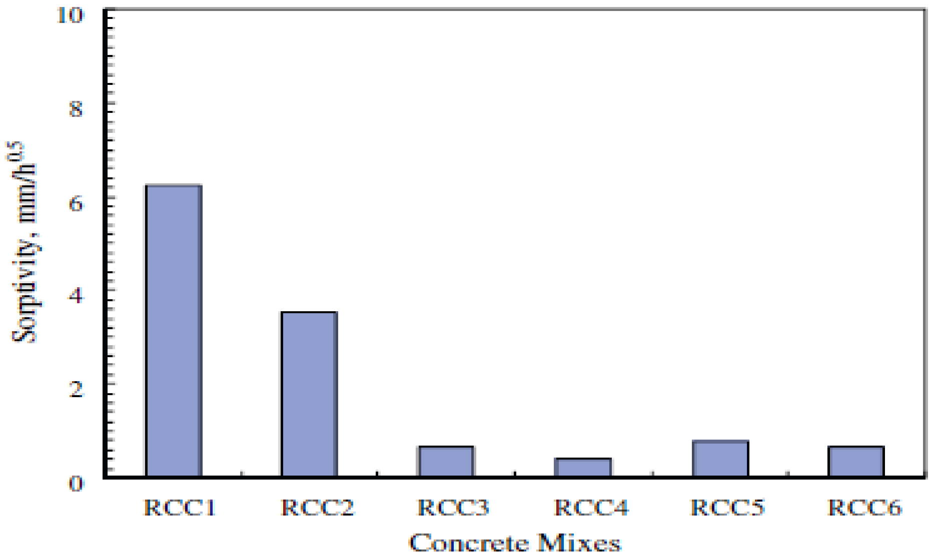

Figure 2.17 Sorption characteristics of the concretes [48].

In a study by [33], water sorptivity tests are used to measure the rate at which water seeps into the concrete specimen, under the influence of capillary forces. One way to determine it is to measure the amount of water gained, with time, when the specimen's lower surface is lowered into water [49]. It was demonstrated in the test results that when recycled aggregates (RA) are used, the sorptivity coefficients increased. Sorptivity, by definition, measures the rate of the water that enters the concrete's pores, and it is largely correlated to the aggregate's ability of absorption. RA has a gain over NA (natural aggregate) in terms of absorption capabilities, so logically; RA-incorporated concrete has a larger absorption factor than NA. As such, when RA is used, one would expect to have a relatively higher penetration through capillary suction than otherwise. When w/b ratios and SF (silica fume) are disregarded, RCA (recycled coarse aggregates) concretes had lower sorptivity coefficients than those of RFA (recycled fine aggregates). The reasoning behind this is attributed to the fact that there is more cement paste on smaller sized aggregates than on larger ones, leading to more porosity. Additionally, RFA concrete absorbs more than large aggregate concrete, causing an increase in the overall porosity of the concrete. This same trend was observed with other mixes as well. Using recycled aggregates significantly affected the absorption rates of the different specimens of SCC. A direct linear relationship was proposed by [50], between sorptivity and open porosity percentage. He observed that there was a strong correlation between open porosity and the sorptivity values of the concretes.

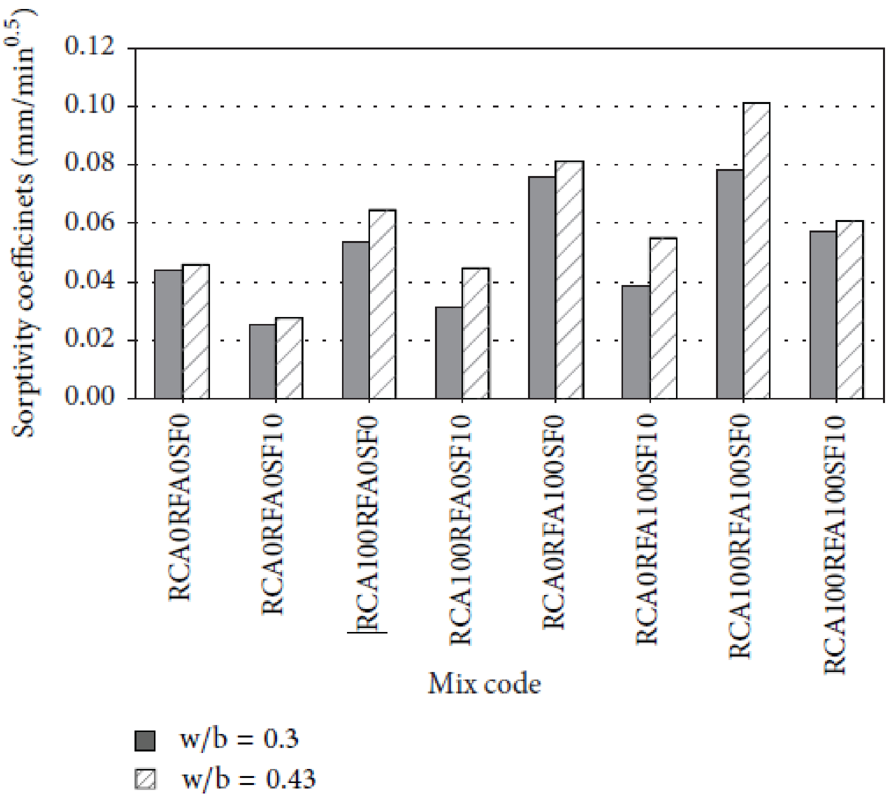

Figure 2.18 Water sorptivity test results of SCCs [33]

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The incorporation of SF (silica fumes) noticeably decreases the sorptivity of SCCs. In the control mixes, when SF was blended in, the water sorptivity decreased from (0.044 to 0.025) and from (0.046 to 0.027 mm/min$^{0.5}$) at the low and high water-binder ratios, respectively [33]. The observed benefits of SF are the reduction in the sorptivity values of the concrete, and an escalation in strength. In a study by [51], they attributed the decrease in sorptivity by SF to the refinement of the concrete's pore structure, and a blockage in capillary. Reducing sorptivity is an important factor, in order to keep sulfate- or chloride-containing water from seeping into the concrete, leading to significant damage.

In general, MK- and SF-incorporated concrete showed better results than plain concrete, in terms of water penetration through capillary suction. As per expectations, with the decrease of w/c binder ratios, a systematic decrease was noticed in sorptivity; also, the sorptivity gradient tended to decrease with increasing replacement levels. Moreover, there is an evident inverse relationship between sorptivity and mechanical properties. The lower the sorptivity value, the higher mechanical property the concrete had. The reason for this is the secondary mineral admixture hydration and pore improvement through filling. Better strength and higher lower capillarity happen because of pore refinement. As such, especially at 15% MK or SF replacement, the highest strength concretes were also ones with the lowest sorptivity, regardless of w/c ratios. A 29% reduction in sorptivity, at both w/c ratios, was witnessed with 15% MK; the same level of replacement for SF achieved 30% and 20% decreases in sorptivities for 0.25 and 0.35 w/c ratios, respectively [44]. Consequently, SF-incorporated concretes were more vulnerable to change, with w/c ratios. In a related study [47] used MK-blended Portland cement (PC) and PFA (pulverized fuel ash) for water- and air-cured concretes. From their findings, it was concluded that sorptivity values decreased when increasing MK content was added to water-cured PC-PFA-MK concrete, while the sorptivities of PC-PFA were more than control concretes' sorptivities. In a study by [51], it was noted that adding 20% of the concrete weight of SF significantly changed the sorptivities of the concretes for the better, especially for high replacement levels. This was attributed to the refinement of the concrete's pore structure and blockage of capillaries. Reducing sorptivity is vital to the concrete because it reduces the ingress of sulfate- and chloride-chloride

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containing water, which is harmful to concrete, and can cause serious damage if it is not treated or prevented.

2.5 Types of Materials Replacement With Cement

- In general, many researchers studied several areas such as the partial replacement of cement in concrete, the usage of waste materials such as cement kiln dust (CKD), ceramic waste, palm oil fuel ash (POFA) and finally, plastic. These materials are classified as a risk to the environment. They found that replacement 15% of (CKD) by cement has trivial effect on the strength of the cement. Results present that concrete with a partial cement replacement of ceramic dust has an increased durability, while the loss of strength was small. It is common that experiments, with many tests, have been attained in replacing 10%, 20%, 30%, 40%, and 50% of POFA by weight of Ordinary Portland Cement. The properties of concrete, like compressive strength, setting time, and expansion due to magnesium sulfate attack were looked into. The results reported that using POFA in concrete caused a delay together initial and final setting times, and depended on the fineness and acuteness of the replacement of POFA. They had spotted that the addition of 5% plastic, by weight, increased the strength by 200%, when compared to plain-cement concrete [52].
- Researchers, in many tests, investigated the impact of partially replacing cement in addition to the quarry dust and Metakaolin on the strength of concrete. They, at the beginning, investigated quarry dust partial replacement, and as a result, they found that 25% of partial replacement is the most helpful to concrete, while maintaining and saving the standard strength of cement. They also partially replaced cement with quarry dust by 25%, as a constant, and added 2.5%, 5.0%, 7.5%, 10.0%, and 12.5% of Metakaolin. They concluded that could be used quarry dust and Metakaolin as a partial replacement of cement [53].
- The use of poultry waste in concrete through developing concrete and incorporating eggshell powder (ESP) were found out and investigated by investigators. Different eggshell powder (ESP) percentages of concretes had developed by replacing 5-15% of cement with ESP. These results, clearly,

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referred to that, eggshell powder (ESP) can be successfully used as a partial replacement of cement in concrete production. The data presented transport properties and cover strength development. Being respected to the results, with 5% (ESP) replacement, the strength was higher than the control concrete, and indicated that 5% ESP is the optimal percentage for maximum strength. They studied the performance of ESP concretes with 10% addition; the result was comparable with the control concrete mix in terms of transport. They concluded that the addition of fly ash, along with eggshell powder, was beneficial for improved performances of concretes [54].

- By preparing for rice husk concrete, it can be clear that the cement was slightly replaced with various percentages, like 5%, 10%, 15%, and 20%. Control concrete was, in addition to, prepared for comparison. This percentage of resistance In front of alkaline attack of M30 grade RHA concrete varied, from 25 to 67. In addition to, the corresponding value for M60 grade was from 35 to 70 for replacement levels changing from 5% to 20%. Additions of 20% RHA observed, slightly, higher resistance against sulphates attacks, for both continuous soaking and cyclic conditions. Overall, the addition of RHA as CRM improved the strength and durability properties of concrete to a significant extent [55].
- It is clear that investigated the effect of a limestone micro-filler replacement upon the mechanical performance, in addition to cost effectiveness of low w/c ratio, for instance, super plasticized Portland cement mortars. They also demonstrated that a limestone micro-filler replacement did not significantly affect the strength of mortars at early stages, up to about 10% to 15% by volume. Higher levels of limestone micro filler brought about essential strength losses, which as a result, were more significant in the silica fume mixes. At last, limestone micro-filler replacement of cement 10 to 15% caused strength losses, which were more important [56].

2.6 Use and Advantage of Plastic Waste:

2.6.1 Fine Aggregate

Investigated the effect of ground plastic on the slump of concrete, concrete mixes, of up to 20% plastic particles, were measured to partial replace the fine aggregates. It

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was recorded that there was a decline in the slump with the increase of the plastic content added. In fact, at 20% replacement, the slump decreased by 25% of the original slump value, of the control mix. The decrease in slump value was associated with the shape of the plastic particles, which had sharper edges when compared with the fine aggregate. Along with that, plastic, glass, and crushed concrete were also used as partial aggregate replacement [57].

2.6.2 Course Aggregate

It widely has been investigated the effect of plastic as substitute coarse aggregate, on diverse fresh and hardened properties of concrete, in addition to (PET). After increasing the (PET) replacement ratios, w/c ratio, lower unit weights, and finally compressive strengths are slightly showed for PAC when it compared to NAC. Compressive strength at 20% PET accurately replaced PAC at 0.42 w/c ratio is 30.3 MP, which, as it is appearing, is just 9% or less than the NAC. Anyway, PAC, in other words, has a significantly higher workability than the 1.8 cm slump value that is clearly showed for 20%. PET replaced PAC at 0.42 w/c ratio. Thus, PET replaced concrete in addition to a low w/c ratio, and high workability, which can be utilized for structural concrete components [58].

2.6.3 Bituminous Concrete Mixtures for Road Construction

It is a common way that many effects of recycling PET plastic bottle wastes rejected in Nigeria and in some substance like bituminous asphalt concrete (BAC) utilized a lot in flexible pavement construction, moreover, estimated. The mix design is composed of the following percentages such as 60/70 penetration-grade asphaltic concrete (5%), 6% fine aggregate, 68% coarse aggregate, and 21% filler. The optimal bitumen content (OBC) for traditional BAC was taken as 4% by weight of high amount of aggregates and filler. Polymer-coated aggregate, (PCA)-converted BAC seems preferable because of the potential to utilize more plastic wastes with a higher optimum plastic content (OPC), of 16.7% by weight, of total aggregates and filler. It has been tested and compared that to of 9% by weight of (OBC) attained by PMB-BAC, and the choice is very clear. For both PMB- and PCA-modified BAC, an increase in mineral aggregate voids, in air voids [59].

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2.6.4 Cement

PVC dust can be utilized in concrete with cementitious materials. It can be shown that the adding a 10% of dust PVC usually leads to reduced strength of concrete. The tensile strength was reduced when PVC dust is used in the concrete when comparing with normal concrete [60].

Okoro [11] found when (PVC) and (PE) were ground into a fine powder of 2.5mm size and were combined with (PC) at various condensation of pure Portland cement. Physical-chemical properties of the cement-polymer composites produced were resolved and the results gained were compared with pure Portland cement, which served as the control group. The results have shown that abrasion resistance and hardness of the composites increased, except at specific concentrations; meanwhile, thermal electrical and electrical conductivities of the composites went down as the polymer concentrations increased. It has appeared and observed that 7.0% of concentration of both polymers directed and gave the best composites when hardness and abrasion resistance is needed. 7.0% PE concentration directed and gave the best PE composite for electrical conductivity and water absorption while 25.0% PVC concentration directed and gave the best PVC composite for water absorption and electrical conductivity.

2.7 Fly Ash

Fly ash is a byproduct of coal burnout that has an ability to react with $Ca(OH)_2$ (calcium hydroxide) at 23°C. The pozzolanic activity of fly ash depends on the presence of SiO_2 (silicon (IV) oxide) and $Al2O_3$ (aluminum oxide) in the amorphous condition [21-23]. Usage of fly ash in concrete technology goes all the way back to the 1930's [24]. It is approximated that about 450 million tons of fly ash are produced annually, on a global scale, but only 6% of the total available is used as pozzolan in blended cements or in concrete mixes [21]. In Turkey, there are twelve active coal-burning power plants with an annual fly ash production yield of about 15 million tons. "According to ASTM C 618" [25], fly ash can be classified into two classes, F and C. This classification is based mainly on if the fly ash in question carries only pozzolanic (Class F) or pozzolanic and cementitious (Class C) properties. The former is usually formed due to the combustion of anthracite or bituminous coal whereas the

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latter is manufactured by means of flaming the brown or sub-bituminous coal. From a physical 31 viewpoint, fly ash can also be very different from one another. They can appear in various shapes, e.g. spherical, rounded: irregular and angular.

2.8 Superplasticizer (SP)

Superplasticizer also well known as a high range waters reducer is a chemical admixture required where well-spread particle suspension is necessary. This polymer used as dispersants in order to refrain separation. Additionally, to enhance the flow property of fresh conditions of varied types of concrete, the amount of water (w/c) added to the concrete mixture is reduced by addition of SP and enables the production of self-compacting concretes [26].

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CHAPTER 3

EXPERIMENTAL STUDY

3.1 Materials:

3.1.1 Cement

Portland Cement (PC) (CEM I 42.5R), specific gravity of 3.15 g/cm^3 and a specific surface area 326 m^2/kg.

3.1.2 Fly ash (FA)

According to ASTM C 618, having a specific gravity of 2.25 g/cm^3 and a specific surface area of 379 m^2/kg.

3.1.3 PVC dust

A specific gravity of 1.35 g/cm^3 and a specific surface of 16 m^2/kg.

Table 3.1 Chemical compositions of PC, FA, and PVC dust

Analysis Report (%)	Cement	Fly Ash	PVC Dust
CaO	62.58	4.24	-
SiO_2	20.25	56.2	-
Al_2O_3	5.31	20.17	-
Fe_2O_3	4.04	6.69	-
MgO	2.82	1.92	-
SO_3	2.73	0.49	-
K_2O	0.92	1.89	-
Na_2O	0.22	0.58	-
Ignition loss	3.02	1.78	≤1.00
Specific surface area (m^2/kg)	326	379	16
Specific gravity	3.15	2.25	1.53

3.1.4. Aggregates

Mashed stone with a nominal size of 16 mm^2 was used in this work as course aggregate and natural river sand with a maximum size of 4 mm^2 as a fine

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aggregate. The sieve analysis and physical properties of the aggregates used are mentioned in Table 3.2.

Table 3.2 Sieve analysis and physical properties of the aggregates

Sieve Size (mm)	Crushed stone 16-8 (mm)	Crushed stone 8-4 (mm)	Natural River sand
0.250	0	0	3.79
0.50	0	0	14.27
1.00	0	0	30.85
2.00	0	0	49.35
4.00	0	2.05	83.06
8.00	1.28	66.66	100
16.00	78.16	100	100
specific gravity	2.66	2.65	2.58

3.1.5 Superplasticizer

Superplasticizer is a water-reducing admixture that is employed to significantly enhance the flowing ability of the proposed concrete while having a very low effect on the viscosity.

Table 3.3 The properties of superplasticizer

Properties	Superplasticizer
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity (kg/l)	1.07
Chemical description	Polycarboxylic-ether
Recommended dosage	%1-2 (binder content)

3.2 Mix Design of Concrete

The self-compacting concrete mixtures were designed with a total binder mass of 550 kg/m^3 and at a constant w/b ratio of 0.35. Six SCC mixtures were produced in this study, and in each SCC, mixture is carried out as follows: the PC was replaced with PVC dust at 0%, 5%, 10%, 15%, 20% and 25% replacement ratios by weight. In addition, the FA was added into the mixtures with a constant ratio

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to increase or improve workability of the concrete. Total of (6) SCC mixtures, including a reference mixture, were produced according to above variables. Slump flow off all concrete mixtures was designed according to 700 ± 50 mm diameter. The mix proportions of the study are shown in Table 3.4, with details.

Table 3.4 Mix proportions for self-compacting concrete (kg/m^3)

Mix ID	(w/b)	PC	FA	PVC	Water	SP	Coarse Agg.		Fine Agg.
							16-8 mm	8-4 mm	
PVC0S1	0.35	440	110	0	192.5	12	404.9	403.4	785.5
PVC0S2	0.35	418	110	22	192.5	11	400.0	398.5	776.0
PVC0S3	0.35	396	110	44	192.5	9.9	395.1	393.6	766.5
PVC0S4	0.35	374	110	66	192.5	9.1	390.2	388.7	757.0
PVC0S5	0.35	352	110	88	192.5	8.4	385.3	383.8	747.5
PVC0S6	0.35	330	110	110	192.5	7.3	380.4	378.9	738.0

3.3 Concrete Casting

Concrete mixing and mixing procedures are proposed "according to Khayat" [61] were adopted to ensure uniformity and consistency in all mixtures of SCC, considering the mixing sequence and duration of the task in the production of self-compacting concrete. The following procedure was used during mixing: first, fine, and coarse aggregates, followed by cement, fly ash, PVC, and Superplasticizer were mixed in a revolving pan mixer. They were mixed evenly for 30 seconds. Next, half of the water was added in the blender, and mixing continued for 60 seconds. The aggregates were left to soak up water in a blender for 60 seconds. Then, the blender began again for another 60 seconds.

Finally, the mixture was poured in a blender along with superplasticizer and outstanding water. The concrete was mixed for 180 seconds and left to rest for another 120 seconds. Moreover, the concrete was mixed for 2 minutes and additional tests were performed to determine the viability and conducted passing ability of the SCC, and the results were recorded. This was followed by casting the concrete, which was protected by plastic sheeting and was left in the casting room for 24 hours at 20 ± 2 ° C.

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3.4 Test Procedure

3.4.1 Water Sorptivity Test

A sorptivity test is a method to measures the rate at which water is pulled into the pores of concrete. For this, two test specimens, with dimensions of (Ø100 x 50 mm height) were used. To prepare for the test, the specimens were dried in an oven at approximately 100±5°C, until a constant mass was obtained; afterwards, they were allowed to cool to room temperature in a sealed container.

Next, the sides of the specimen were coated with paraffin wax. The sorptivity test was carried out by placing the specimen on glass rods, lengthwise, in a tray. They were then lowered until the bottoms of the specimens were submerged in 3 mm of water, as seen in (Figures 3.2. and 3. 3). This procedure was used to allow free water flow through the surfaces in contact with the water.

The specimens were then removed from the tray and weighed at different time intervals for up to 1 hour, to evaluate net mass gain. The test was carried out at 90 days.

Sorptivity was evaluated from equation (1), below:

$$I=S\sqrt{t}, \qquad (3.1)$$

Where: I is the cumulative infiltration,

S is the sorptivity,

t is the time interval.

The unit for sorptivity is $mm\cdot min^{-0.5}$.

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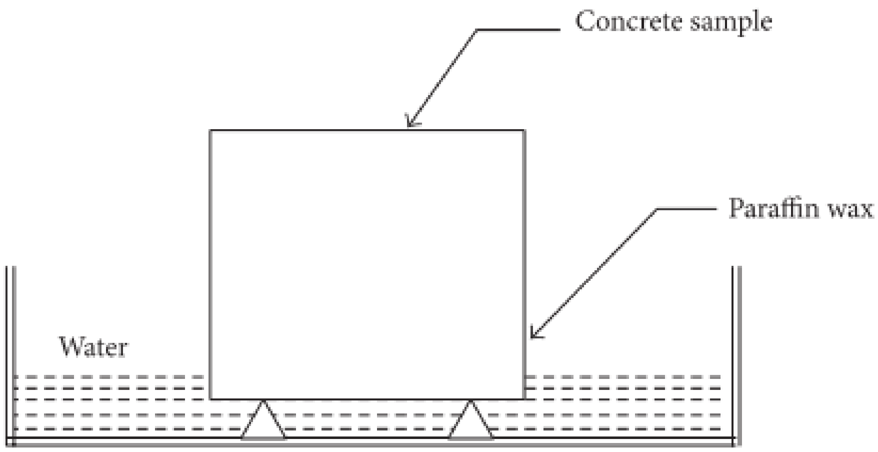

Figure 3.1 Details of water sorptivity measurement

Figure 3.2 Photos of water sorptivity measurement

3.4.2 Gas Permeability Test

The CEMBUREAU Method, "Recommended by RILEM TC "[43] was used for investigating the gas permeability coefficients of SCC mixtures. Photos of the test apparatus, the schematic layout, and the details of the testing cell are shown in Figures 3.4**.** The gas permeability of the samples were measured on concrete discs, with dimensions of 50mm height and 150mm diameter, cut from the midsection of a cylinder with a diameter of 150 mm and height of 300 mm. Oxygen gas was used as the penetrating middle. Pressures was different like 150 up to 500 kilo PA as a result, these specimens were used in pressure cells. These cells were closed by tightly fitting rubber under high pressure against the curved surface. However, it is prior to the gas permeability test and it has dried by oven.

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After the curing period of 90 days in the oven, the specimens dried at 105±5°C to make sure that each specimen's weight change was less than 1%. Then, they were protected in a sealed box until the test began. Each two specimens for each concrete mixture were tested at the age of 90 days, and the average of this test was reported as a test result. For every differential pressure, namely, the Hagen-Poiseuille equation was used. It is clear that that equation is because of measuring laminar flow of a compressible fluid inside a porous medium in addition to small capillaries under steady-state conditions. It was done to determine the apparent gas permeability coefficient, which can be calculated using the modified Darcy's` equation:

$$K_A = \frac{2P_2QL\mu}{A(P_1^2 - P_2^2)} \tag{3.2}$$

Where K_A is the gas permeability coefficient (m^2), P_1 is the inlet gas pressure (N/m^2), P_2 is the outlet gas pressure (N/m^2) A is the cross-sectional area of the sample (m^2), L is the height of sample (m), μ is the viscosity of oxygen 2.02×10^{-5} Ns/m^2, and Q is the volume flow rate (m^3/s).

(a)

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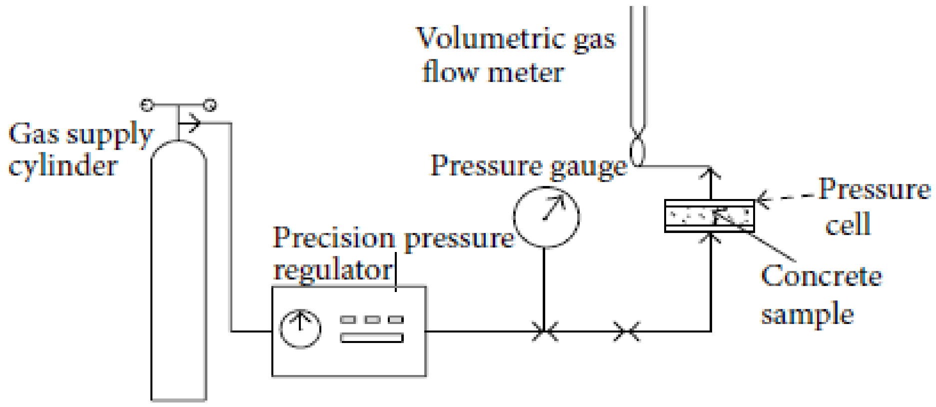
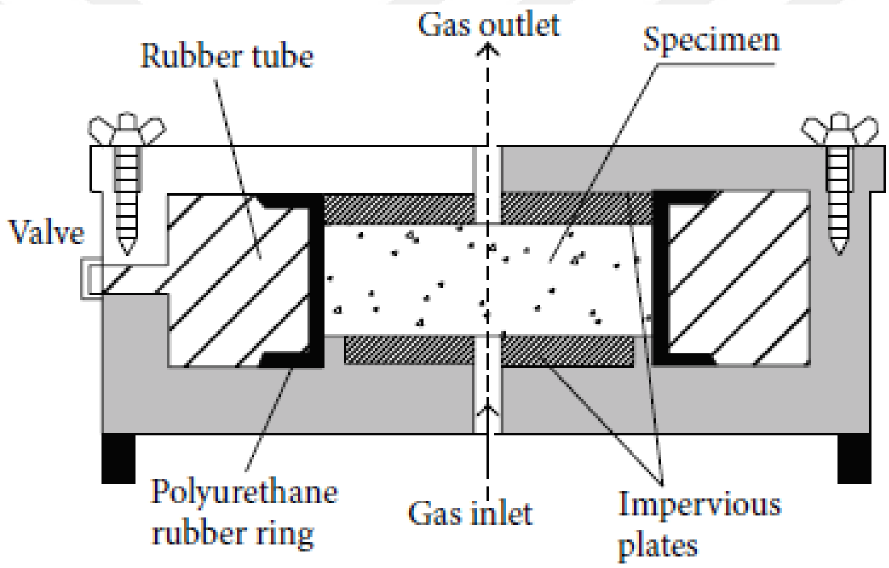


(b)



(c)

Figure 3.3Gas permeability setup: (a) photographic view of the gas permeability test setup, (b) schematic presentation of the gas permeability test setup, and (c) schematic presentation of the pressure cell and test specimen

3.4.3 Drying, Shrinkage, and Weight Loss

In order to observe the drying, shrinkage, and weight loss of the SCC, three 70×70×280mm rectangular prisms, "according to ASTMC157" [62], were used as shown in Figure 3.5 . As soon as the prisms were demoded, the gage length was fixed on each specimen by means of the glued pins on the faces of the prisms. The length change was measured with a dial gage extensometer with 200 mm gage length, and 0.002 strain for measuring. Measurements were implemented for the first 3 weeks, once every 24 h, and then 3 times a week. Meanwhile, measurements of weight loss were accounted for on the identical prism, as well. After the gage length was fixed on each specimen, its initial weight was recorded to monitor the weight loss during drying period. Then, the specimens were subject to drying at 23± 2°C and50± 5% relative humidity for about 56 days. The test results for each property were evaluated by averaging the measurement of tow prism specimens.

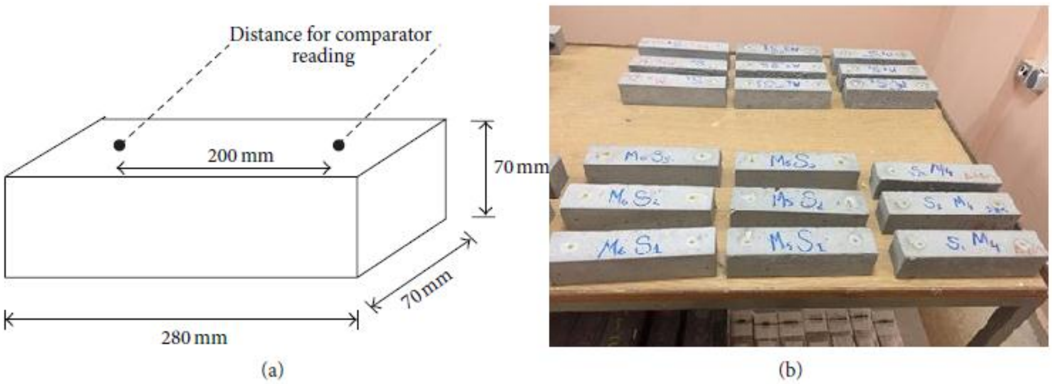
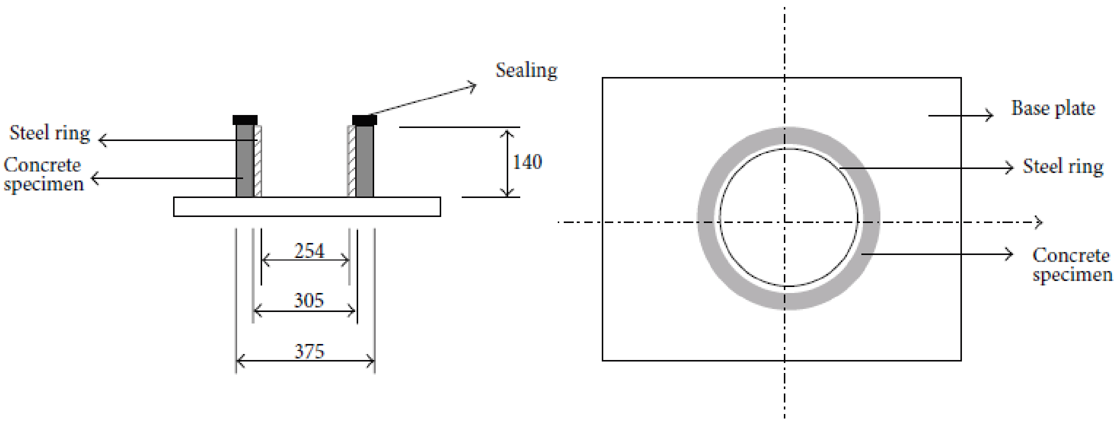


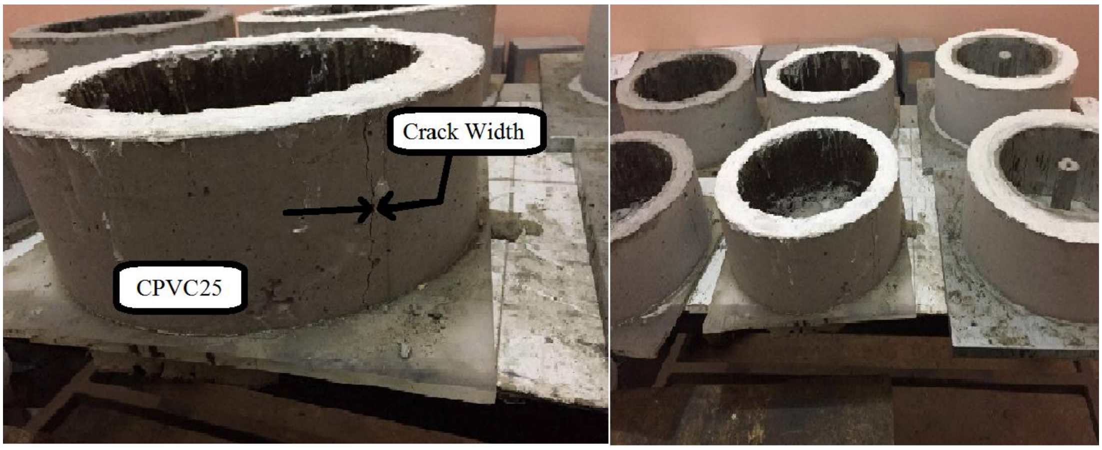
Figure 3.4 Free shrinkage test: (a) free shrinkage test setup and (b) test specimens

3.4.4 Restrained Shrinkage Cracking

In this study, the ring-shaped specimens were utilized in order to determine the shrinkage-stimulated cracking of SCC. Concerning drying and restrained shrinkage test immediately after casting, specimens were cured for 24 hr. in a cabinet having 100% relative humidity and a temperature of 20∘C. Immediately following this curing period. After the mold has been removed, the top surface of the concrete ring was covered with a silicone rubber so that drying would be permitted only by the outer circumferential surface Figures 3.6. Measurements were taken in the casting room at 23±2∘C and 50±5% relative humidity. We can say that to measure accurately the widths of crack upon specimens ring, a specific microscope setup was carried out [64, 65]. The crack widths reported in these experiments were the average of three measurements: the first one is at the ring center and the second one is at the centers of the top, bottom of the ring. The specimens surface, in these tests, were accurately examined because of the new cracks, and the measurement of the existing widths cracks was ,in the same manner, performed every 24 hr. throughout the onset of seven days after cracking and in addition every 48 hr.



(a)



(b)

Figure 3.5 Restrained shrinkage cracking test: (a) dimensions of a restrained shrinkage ring specimen in (mm) and (b) a photographic view of a cracked ring specimen

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3.4.5 Water Permeability Test

Water permeability of SCC mixtures was conducted according to TS EN12390-8 [65]. For this, a 500± 50-kPa downward pressure was applied on the bottom side of the specimens 150 mm cube for 72 hr. After that, the test specimens were split in the middle and the greatest penetration depth of water was evaluated in mm. In order to characterize the concrete resistance to the chemical attack, water should not penetrate to a depth of more than 50mm in concrete likely to come in contact with slightly aggressive media and not more than 30mm if concrete is likely to come in contact with aggressive media [33]. Photo of water permeability test equipment is given in Figure 3.7,8. The results presented herein are the average of two concrete specimens. Test was conducted at the age of 56 days

Figure 3.6 Water permeability test set up

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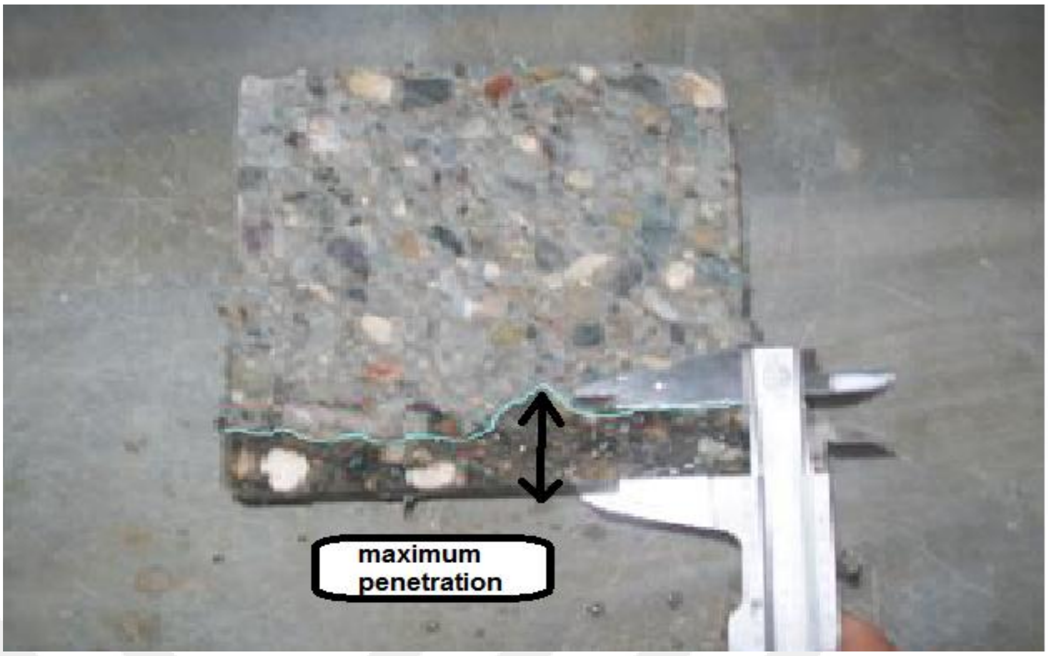

Figure 3.7 Measurement of penetration depth

3.4.6 Compressive Strength Test

The compressive strength test was carried out on the cube specimens with dimensions of 150 x 150 x 150 mm, according to ASTM C39 [66]. They were used as shown in Figure 3.9, by using a 3000 KN capacity-testing machine. The test was conducted on three specimens from each mixture, and they were checked at each testing age. The compressive strength was measured by averaging the results from the three tested specimens at each age of testing.

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Figure 3.8 Compressive strength test

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CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Sorptivity Test

Water sorptivity testing is operating to measure the rate of water flow into the concrete samples under the action of capillary forces. It can be determined from weight gain of the sample with time of disclosure of the lower surface to water [67]. The 90-day sorptivity coefficients of SCC for different percentages of PVC (5%, 10%, 15%, 20%, and 25%) are shown in Figure 4.1. The test results demonstrated that when the percentage of PVC increased, the sorptivity coefficients decreased. For example, the sorptivity coefficient of mix 6 (CPVC25) was 0.0343 when compared with 0.0611mm/min$^{0.5}$ for the mix 1 (CTR) mixture. Generally, the rate of the sorptivity test proportion in water has drowned into the pores of concrete. From these results, it is clear that the relationship between the addition of PVC and sorptivity coefficients is inversely proportional. Consequentially, decrease sorptivity is important to reduce the absorption of chloride- or sulfate-containing water into concrete that causes severe damage to the structural integrity of the concrete [68].

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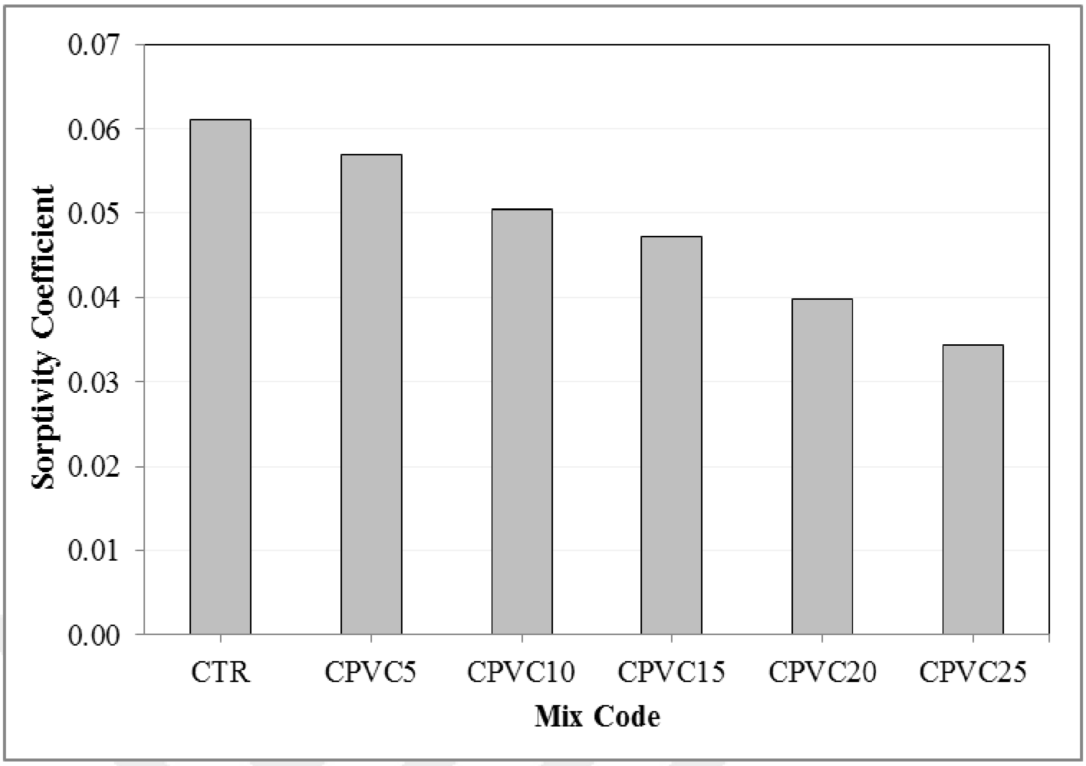

Figure 4.1 Relationship between sorptivity and percentage of PVC dust

4.2 Gas Permeability Test

The calculation of the effect of gas permeability was done on the principle of the Hagen-Poiseuille relationship for laminar flow of a compressible fluid through a porous body with small capillaries under steady-state conditions [44]. 150, 200, and 500 kPa inlet pressures were used to evaluate the average gas permeability coefficient as recommended by RILEM [43]. Thus, the gas permeability coefficients of SCC measured at 90 days are presented in Figure 4.2. The lowest gas permeability coefficient at 90 days was quantified at mix 6 (CPVC25) 1.32×10^{-16} m^2. The permeability coefficients ranges were found $1.617–1.32 \times 10^{-16}$ m^2. Since Pore, structure is important in determining the transport properties of the concrete. The rise in gas permeability of concrete can be attributed to the decreased pore structure in concrete due to the increase of PVC incorporated into it. From Figure 4.2, we can see that mix 1 (CTR) has the highest gas permeability; gas permeability of the mixtures decreased with the increase of PVC.

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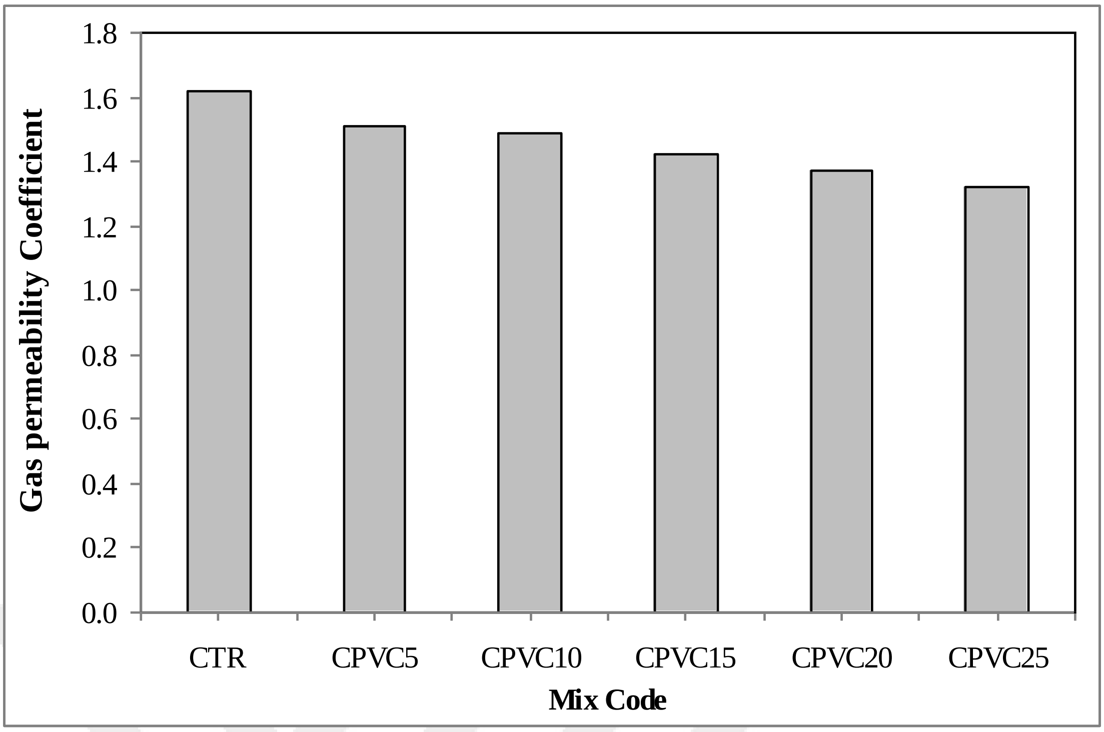

Figure 4.2 The relationship between gas permeability and the percentage of PVC dust

4.3 Drying Shrinkage, and Weight Loss Test

4.3.1 Dry Shrinkage

Drying shrinkage is known as the change in volume because of the drying of the concrete. The loss of water comes first; however, this usually causes minimal shrinkage with the continuation, the absorbed water was lost; it gets held in hydrostatic tension, located in small capillaries, usually >50 nm in width. The loss of water produced tensile stresses, which caused the shrinkage of the concrete. The shrinkage that occurred due to this water loss was significantly larger than the loss of free water [69]. The difference between the measures of the drying shrinkage of PVC dust-inserted concrete was small especially during the first week. However, after 2 weeks, the difference became more significant and the concrete shrinkage with PVC dust had a reduction with an increase of replacement levels of PVC dust. It can be said that the rate of drying shrinkage experienced a decreases with an increase in percentage of PVC. However, Figure 4.3 showed that the percentage of PVC dust led to a decrease in shrinkage according to the curves.

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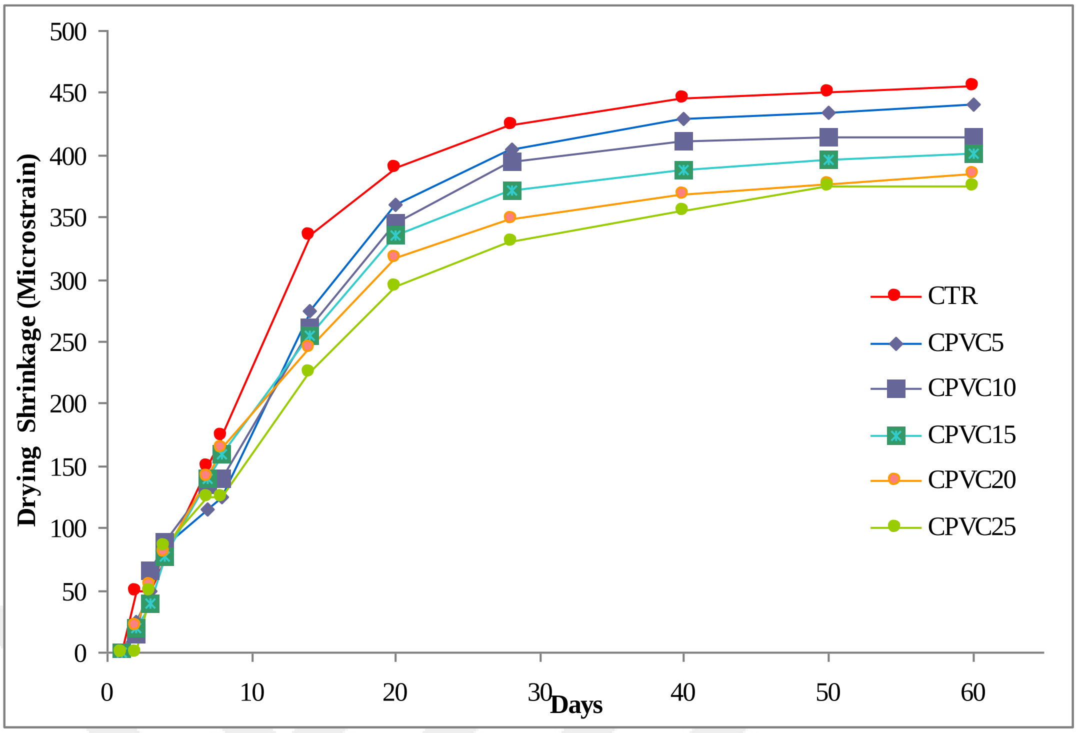

Figure 4.3 The relationship between dry shrinkage and percentages of PVC dust

4.3.2 Weight loss

The weight loss results with time, due to the SCC drying, are shown in Figure 4.4, gives the maximum weight loss values of SCC similar to drying shrinkage test results, SCC incorporated with PVC dust lower weight loss in comparison with the control mixture. During 56 days of drying duration, the difference of weight loss between SCC mixtures became more distinguishable after two weeks.

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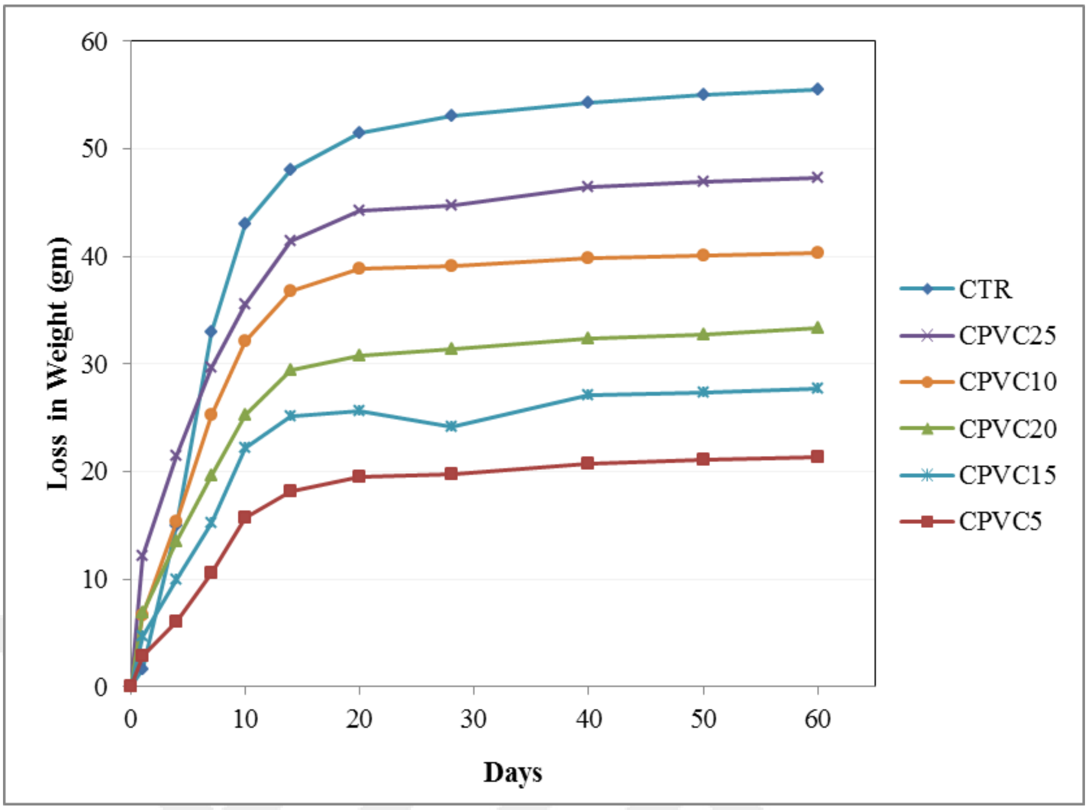

Figure 4.4 The relationship between weight loss and percentages of PVC dust

4.4 Restrained Shrinkage Cracking Test

Figure 4.5 shows the concrete of crack developments with time. It also shows different cracking width due to different additions of PVC. The concrete cracked very fast during the first few days and the speed decreased at later days i.e., about half of the cracks width happened within the first ten days. It is shown in Figure 4.5 that first cracking of the sample was spotted at the 6th days for mix2 (PVC 5%); however, the crack of the control mix concrete was observed happen on the 7 days. The more the percentage level of PVC dust used, the more decreased the restrained shrinkage crack widths that were observed. The PVC additions reduced the cracks width relative to with the control treatment (no PVC addition). At the same time, increasing the PVC ratio reduced the cracks width and the addition of 25% PVC resulted in the smallest crack overall for the measuring intervals. The minimum crack width at the end of 56 days was found to be 0.625mm for mix 6 (PVC 25%). From Figure 4.5, it seems that the cracks reached almost a maximum width at 50 to 56 days.

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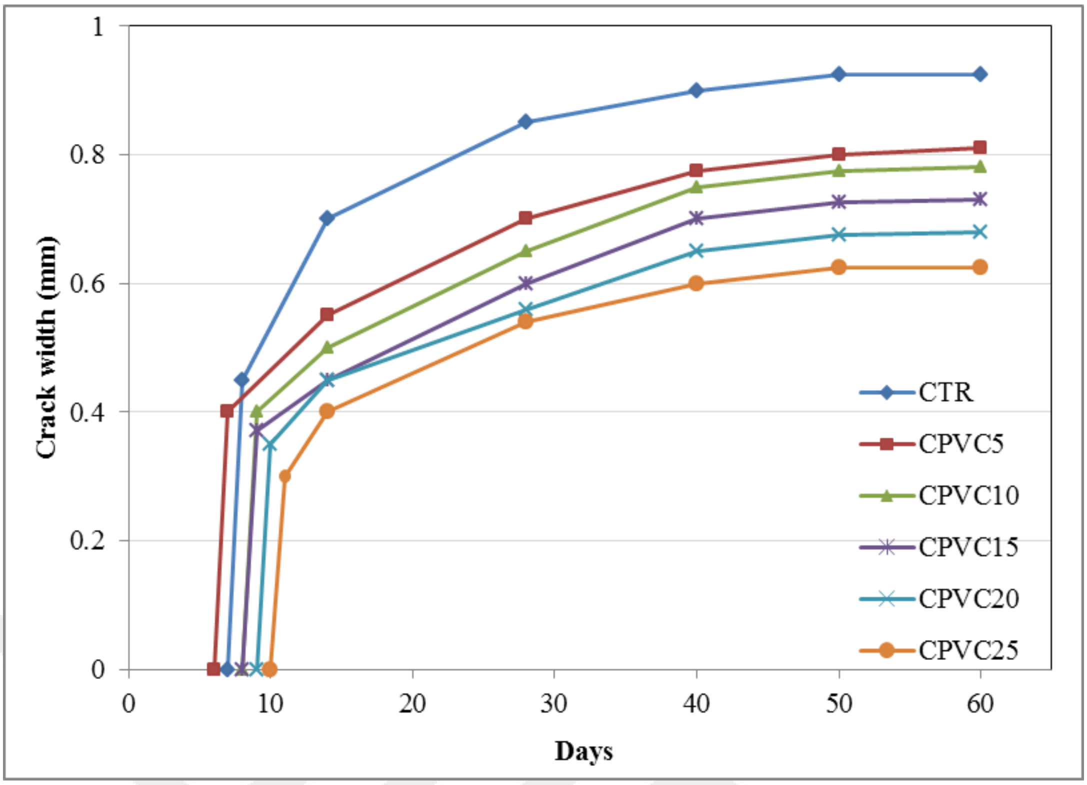

Figure 4.5 The relationship between Restrained Shrinkage Cracking and percentages of PVC dust

4.5 Water Permeability Test

Figure 4.5 shows the water permeability of self-compacting concrete. It was noted that water permeability for all the various concrete was lower than 6.5 mm. The highest penetration depth for mix 1 (CTR) was 6.5 mm whereas the lowest penetration depth for mix 6 (PVC25) was only 2.75 mm. Therefore, the use of PVC dust reduces the water permeability of SCC relative to the reference (control) concrete. The water permeability test also provides some information about the continuity of the pores, the pore structure of the concrete, and the potential of concrete durability against intrusive media. Generally, concretes exposed to aggressive media are resistant to chemical attacks more when their respective permeability values are below 30mm [71].

The permeability is adversely affected by the age of the concrete as the hydration process completes, and leads to the increase in volume of gel and other hydration products and reduces the voids [70].

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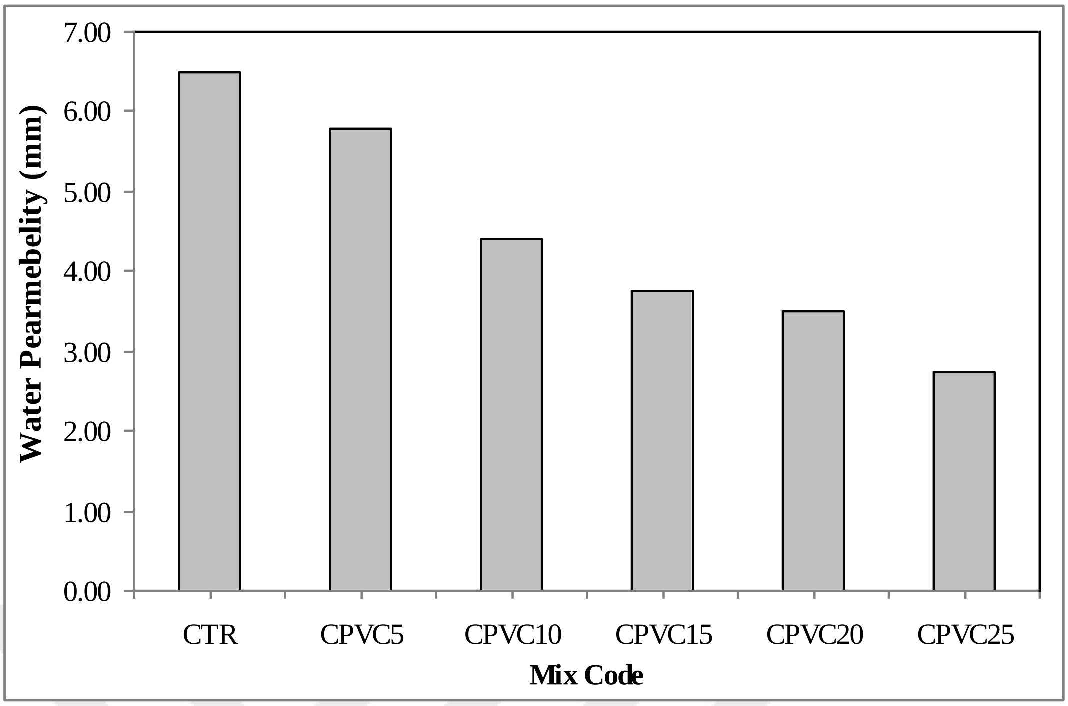

Figure 4.6 The relationship between water permeability and different percentages of PVC dust

4.6 Compressive Strength Test

The compressive strengths of different concrete mixes are given in Figure 4.6 .The compressive strength of self-compacting concrete was within the range of 45.54–60.40 MPa. The use of PVC decreased the compressive strength of SCC when an increase in replacement levels of PVC was made. Replacing Portland cement with 25% PVC had the effect of a reduction in the compressive strength, about 25%. Interestingly, the concrete containing the highest replacement level achieved the lowest compressive strength of all 5 of the mixtures. It is clear that PVC causes a decrease in compressive strength when the amount of PVC dust increases. As indicated in Figure. 4.6 the addition of PVC dust with the amount of 5%, 10%, 15%, 20%, and 25% causes a reduction in 56 day compressive strength values about 5%, 8%, 12%, 23%, and 25%, respectively. The test results proposed that it was PVC among the mix concrete used that controlled the compressive strength reduction in the SCC. The concretes incorporated with PVC had generally comparable strength values, in comparison to the control concrete [71].

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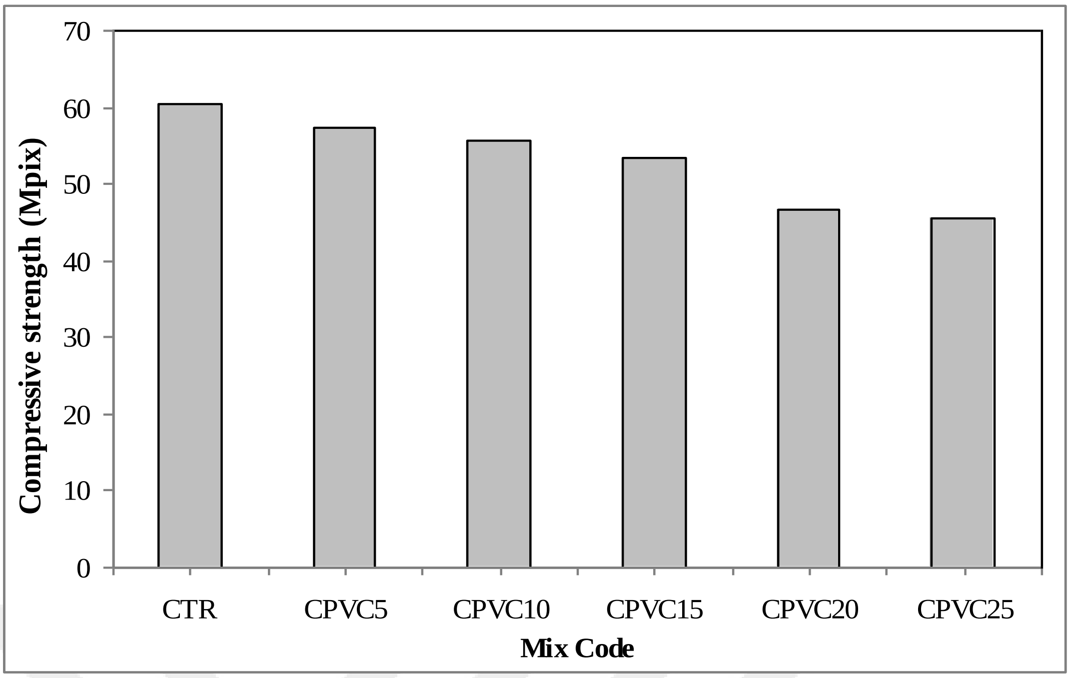

Figure 4.7 The relation between the PVC and compressive strength

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CHAPTER 5

CONCLUSION

From the gained results, the subsequent conclusions can be made:

- Sorptivity of the concrete is reduced by the addition of the PVC as compared with the control of zero PVC. Increasing the PVC percentage from 5 to 25% lead to decrease the sorptivity of all mixtures. The addition of 25% of PVC reduced sorption ratio by 43%, which means that the total porosity has decreased.

- The gas permeability has the same direction as the sorption test. With the increased content of powder, the gas permeability of the concrete reduces. These decreases can be referred to the low pore structure in the concrete because of addition. The lowest recorded values of gas permeability of self-compacting concrete is CPVC25 mix as $0.0343 \times 10^{-16} m^2$

- The use of PVC dust in SCC decreases dry shrinkage at each additional percentage level of PVC dust. SCC incorporated with PVC exhibited lower weight loss in compared with the control mixture.

- For all SCC mixes tested in this study, restrained shrinkage rate reduced with the additional percentages of PVC.

- For all SCC mixtures, incorporating PVC decreases the pores and resulted in a better realization related to drying shrinkage, weight loss, and restrained shrinkage cracking width.

- Water permeability decreases with the inclusion of higher percentage levels of PVC dust content. The highest water penetration depth was measured

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For CTR as 6, 5 mm whereas the lowest penetration depth was measured for CPVC25 as 2, 7 mm at 56 days.

- At 5, 10, 15, 20, and 25% replacement levels of PVC, there was a significant reduction in the compressive strength with the increasing levels of PVC .Relative to the control mix, which had 0% PVC dust content. When adding 25% of PVC dust, the compressive strength is reduce by a percentage of 25%

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