USE OF SELF-CLEANING PERVIOUS CONCRETE FOR SUSTAINABLE ENVIRONMENT

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USE OF SELF-CLEANING PERVIOUS CONCRETE FOR SUSTAINABLE ENVIRONMENT

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ABSTRACT

USE OF SELF-CLEANING PERVIOUS CONCRETE FOR SUSTAINABLE ENVIRONMENT

The water cycle, which is an important part of the ecological cycle, negatively affects the urban life due to the imporous structure of traditional concrete used in roads, pedestrian ways, pavements and similar transportation structures. Traditional concrete does not have voids, and it is not capable of transmitting the water puddle that occurs as a result of excessive rain to the soil. Adverse situations caused by puddles on roads, pedestrian paths and sidewalks as a result of excessive rain affects the urban life in a negative way. Additionally, this disadvantage of conventional concrete leads to negative chemical results such as bacteria formation, wear and corrosion due to air pollution that occurs in transportation structures. Air pollution is increasing in urban areas and it affects human health and also it causes damage to buildings. In this thesis, a pervious concrete mix is produced by using three different aggregate sizes. These aggregates have a tumbled and smooth geometry, which is different from the traditional type of aggregates used in pervious concrete designs. The intent of this research is to examine the effect of aggregate size and aggregate surface condition on the various properties of pervious concrete. The surface condition of the aggregates is chosen as tumbled so that the aggregates touch each other at minimum surface. It is believed that this type of aggregate will increase the number of interconnected voids which in turn increases the permeability.Various tests performed on the pervious concrete specimens showed that use of tumbled aggregates results in sufficient strength and permeability properties. Additionally, these pervious concrete samples are treated with titanium dioxide to achieve a self-cleaning concrete surface. It is concluded that titanium dioxide is also effective on pervious concrete and can be used on structures cast with pervious concrete to create self-cleaning concrete surfaces. It is concluded that use of titanium dioxide treated pervious concrete with tumbled aggregates is both strong enough and sustainable.

Keywords: pervious concrete, self-cleaning, sustainability, rain harvesting, heat island effect.

ÖZET

SÜRDÜRÜLEBİLİR ÇEVRE İÇİN KENDİ KENDİNİ TEMİZLEYEN GEÇİRİMLİ BETON KULLANIMI

Ekolojik döngünün önemli bir parçası olan su döngüsü, yollarda, yaya yollarında, kaldırımlarda ve benzeri ulaşım yapılarında kullanılan geleneksel betonun yetersiz yapısı nedeniyle kentsel yaşamı olumsuz etkilemektedir. Geleneksel betonun boşlukları yoktur ve aşırı yağış sonucu oluşan su birikintisini toprağa iletemez. Aşırı yağışlar sonucunda yollarda, yaya yollarında ve kaldırımlarda oluşan su birikintilerinin oluşturduğu olumsuz durumlar şehir hayatını olumsuz yönde etkilemektedir. Ayrıca geleneksel betonun bu dezavantajı, ulaşım yapılarında oluşan hava kirliliği nedeniyle bakteri oluşumu, aşınma ve korozyon gibi olumsuz kimyasal sonuçlara yol açmaktadır. Kentsel alanlarda hava kirliliği artmakta ve insan sağlığını etkilemekle birlikte binalara da zarar vermektedir. Bu tezde, üç farklı agrega boyutu kullanılarak geçirimli bir beton karışımı üretilmiştir. Bu agregalar, geçirimli beton tasarımlarında kullanılan geleneksel tip agregalardan farklı olarak tamburlanmış ve düzgün bir geometriye sahiptir. Bu araştırmanın amacı, agrega boyutunun ve agrega yüzey durumunun geçirimli betonun çeşitli özellikleri üzerindeki etkisini incelemektir. Agregaların yüzey durumu, agregaların minimum yüzeyde birbirine değmesi için tamburlu olarak seçilmiştir. Bu tip agreganın birbirine bağlı boşlukların sayısını artıracağı ve bunun da geçirgenliği arttıracağı düşünülmektedir. Geçirgen beton numuneleri üzerinde yapılan çeşitli testler, tamburlu agrega kullanımının yeterli dayanım ve geçirgenlik özellikleri sağladığını göstermiştir. Ek olarak, bu geçirgen beton numuneler, kendi kendini temizleyen bir beton yüzey elde etmek için titanyum dioksit ile işlenir. Titanyum dioksitin geçirimli beton üzerinde de etkili olduğu ve geçirimli beton ile dökülen yapılarda kendi kendini temizleyen beton yüzeyler oluşturmak için kullanılabileceği sonucuna varılmıştır. Titanyum dioksit uygulanmış geçirimli betonun tamburlu agrega ile kullanımının hem yeterince güçlü hem de sürdürülebilir olduğu sonucuna varılmıştır.

Anahtar sözcükler: geçirimli beton, kendi kendini temizleme, sürdürülebilirlik, yağmur suyu hasadı, ısı adası etkisi.

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LIST OF SYMBOLS/ABBREVIATIONS

A	Absorption
agg/c	Aggregate to cement ratio
ASTM	American society for testing and materials
BS	British standards
CO_2	Carbon dioxide
EN	European norm
pH	Potential of hydrogen
TiO_2	Titanium dioxide
UV	Ultraviolet
UV-VIS	Ultraviolet visible spectrophotometry
w/c	Water to cement ratio
λ	Wavelength
f_{c1-10}	Compressive strength of the cylinder specimen 1 with 10 mm aggregate
f_{c1-15}	Compressive strength of the cylinder specimen 1 with 15 mm aggregate
f_{c1-25}	Compressive strength of the cylinder specimen 1 with 25 mm aggregate
f_{c2-10}	Compressive strength of the cylinder specimen 2 with 10 mm aggregate
f_{c2-15}	Compressive strength of the cylinder specimen 2 with 15 mm aggregate
f_{c2-25}	Compressive strength of the cylinder specimen 2 with 25 mm aggregate
f_{c3-10}	Compressive strength of the cylinder specimen 3 with 10 mm aggregate
f_{c3-15}	Compressive strength of the cylinder specimen 3 with 15 mm aggregate
f_{c4-25}	Compressive strength of the cylinder specimen 4 with 25 mm aggregate
V_{1-10}	Applied axial force on the cylinder specimen 1 with 10 mm aggregate
V_{2-10}	Applied axial force on the cylinder specimen 2 with 10 mm aggregate
V_{3-10}	Applied axial force on the cylinder specimen 3 with 10 mm aggregate
V_{1-15}	Applied axial force on the cylinder specimen 1 with 15 mm aggregate
V_{2-15}	Applied axial force on the cylinder specimen 2 with 15 mm aggregate
V_{3-15}	Applied axial force on the cylinder specimen 3 with 15 mm aggregate
V_{1-25}	Applied axial force on the cylinder specimen 1 with 25 mm aggregate
V_{3-25}	Applied axial force on the cylinder specimen 3 with 25 mm aggregate
V_{4-25}	Applied axial force on the cylinder specimen 4 with 25 mm aggregate
f_{c-ave}	Average compressive strength of the cylinder specimens

KPC 10-1	Cylinder specimen 1 with 10 mm aggregate used in compression test
KPC 10-2	Cylinder specimen 2 with 10 mm aggregate used in compression test
KPC 10-3	Cylinder specimen 3 with 10 mm aggregate used in compression test
KPC 15-1	Cylinder specimen 1 with 15 mm aggregate used in compression test
KPC 15-2	Cylinder specimen 2 with 15 mm aggregate used in compression test
KPC 15-3	Cylinder specimen 3 with 15 mm aggregate used in compression test
KPC 25-1	Cylinder specimen 1 with 25 mm aggregate used in compression test
KPC 25-3	Cylinder specimen 3 with 25 mm aggregate used in compression test
KPC 25-4	Cylinder specimen 4 with 25 mm aggregate used in compression test

1. INTRODUCTION

1.1. HEAT ISLAND

Heat islands are urban areas with significantly higher temperatures when compared with their surroundings. The main reasons of heat islands are the usage of man-made materials and increased anthropogenic heat production. The heat island effect has serious consequences on health and well-being of the people who are living in cities [1].

The main reasons behind the heat islands are the man-made surfaces such as roofs, buildings, pavements and roads. These surfaces, that are exposed to solar heat, absorb and emit the sun's heat more than natural surfaces. This causes temperature increase in cities [1].The heat island also causes increased energy consumption which leads to an increase in the temperatures of the cities.

Figure 1.1 shows the reasons behind the formation of heat islands.

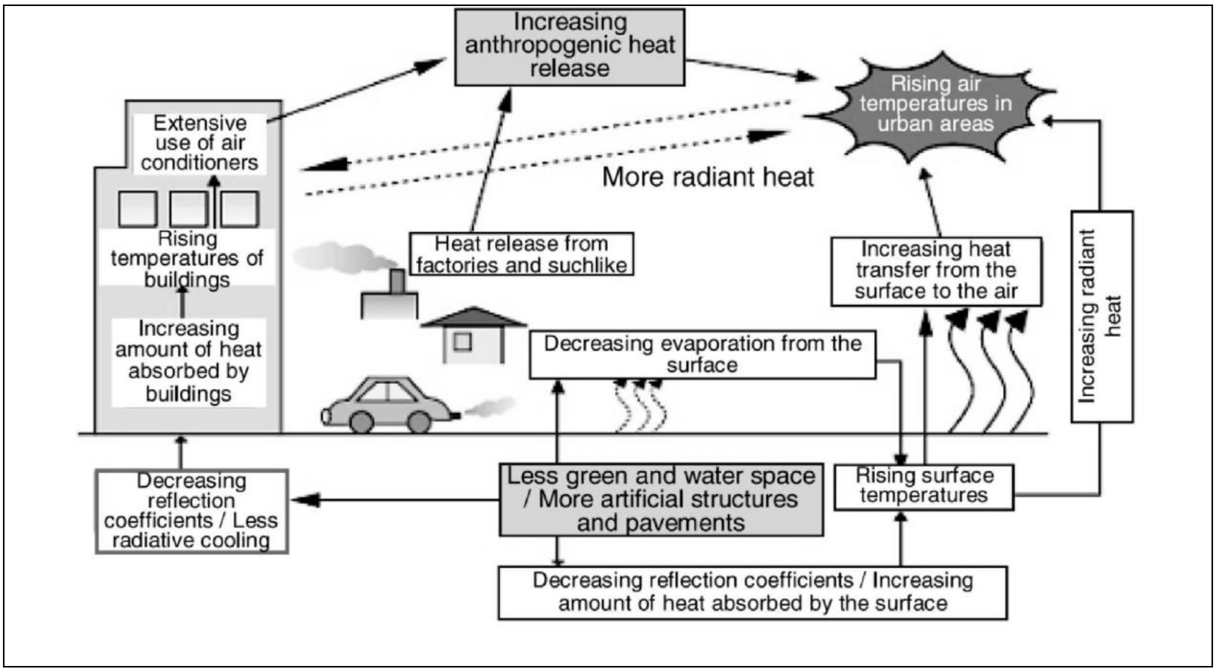

Figure 1.1. Formation of heat islands (adapted from [1])

According to the recent studies, concrete has significant effects on heat islands [1]. Most of the studies are concentrated on density,water retention,albedo and permeability properties of the concrete [1].These properties of the concrete have strong effect on surface temperature. It is important to consider these properties in order to assess strategies to overcome heat island effect [1]. In various studies mesoscale imagery from satellites of infrared and thermal activity had used and it proved that pavements are strong sources of heat radiation. Use of pervious concrete when casting pavements is regarded as one of the strategies to overcome heat island effect. Therefore, it is important to produce pervious concrete with sufficient compressive strength in order to improve thermal characteristics of the cities [1].

1.2. RAIN HARVESTING

Rain harvesting is considered as a potential water supply. Rain water reaches the ground and it returns to the air by evaporation. However, it can be collected and used. Besides rain harvesting method prevents floods. There are some techniques used in order to achieve rain harvesting [2,3]. These are given in the following Table 1.1 [2].

Table 1.1. Rain harvesting techniques (adapted from [2])

Control Sites	**Facilities**
Above the ground	Green roofs, non-vegetated roof
On the ground	Trees, pervious pavements, water-retaining pavements, infiltration trenches, rain barrels, rainwater tanks, bioretentions
Below the ground	Soakaways and underground cisterns

As can be seen from Table 1.1 there are different techniques for rain harvesting and use of pervious concrete in the construction of pavements is one of them. Pavements constructed by pervious concrete will allow the rain water to seep into the ground and eventually join the underground water system. In this study, use of tumbled aggregates to increase permeability properties of concrete is studied.

1.3. SELF CLEANING PERVIOUS CONCRETE

Since the environmental pollution caused due to urbanization is a huge problem, self cleaning structures have become popular [4,5,6,7].

Self Cleaning Concrete Applications

Areas of use for self-cleaning concrete for horizontal and vertical construction are given as follows.

Horizontal construction

- Concrete pavements
- Interlocking paving stones
- Paving and road coverings
- Cement-based tiles
- Concrete roof tiles

Vertical construction

- Architectural pre-cast façade panels
- Plaster
- Exterior plaster
- Cladding elements
- Noise barriers

An example of self-cleaning concrete application is given in Figure 1.2.

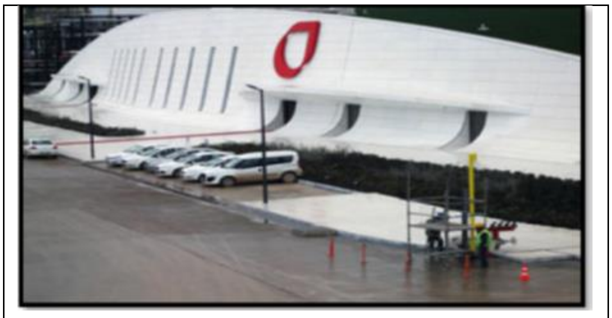

Figure 1.2. Tupras Rafinery (Kocaeli, Turkey)

The idea behind the self cleaning concrete is the use of photocatalytic materials. These materials are activated by ultraviolet radiation and decompose organic materials such as; soot; grime; oil ; mold; algae ; bacteria and allergens into oxygen, carbon-dioxide, water, sulfate, nitrate and other inorganic molecules.

Titanium di-oxide (TiO_2) is the most popular photocatalyist. It is used in pavement engineering in order to reduce vehicle emission pollutants. Besides, TiO_2 has lots of advantages as photocatalyist. These are low cost,fast reaction at room temperature and fast reaction at atmospheric pressure [8].

Titanium dioxide is activated by UV light below the wavelength of 387 nm and it converts wide types of organic contaminants into water and CO_2.

This process does not require chemical reactants and no side reactions occur. Photocatalytic effect of titanium dioxide is shown in the following Figure 1.3.

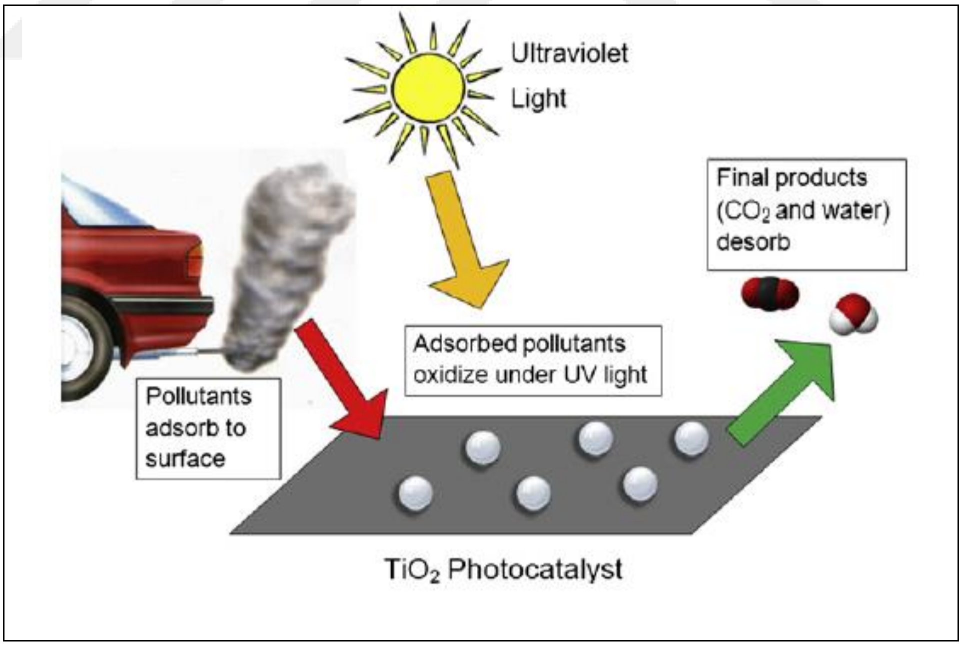

Figure 1.3. Photocatalytic effect of titanium dioxide on pavement (adapted from [8])

As can be seen from Figure 1.3 pavements are exposed to the pollutants exhausted from the vehicle. The titanium dioxide coat on the pavement surface is activated due to exposure of ultraviolet sunlight. It decomposes the pollutants. Lastly, the final products of the process are then desorbed [8]. The performance of the self cleaning concrete is affected from environmental factors due to their effect on photocatalysis. These environmental factors are light wavelength,wind,humidity and temperature [8]. The best results are obtained under high temperature and light conditions. Other factors are porosity,aggregate size,application method and applied wear [8]. According to studies conducted, better retention of titanium dioxide particles on the sample surface and higher toluene removal efficiency is obtained when samples have higher porosity [8]. In this thesis, titanium dioxide is applied on the surface of pervious concrete samples to observe the retention of titanium dioxide particles on a surface.

Self-cleaning concretes have various advantages and disadvantages. These are given as follows [4].

Advantages of self-cleaning concretes

- Solar reflective index is higher when compared to other conventional concretes.
- Sunlight emmission rate is low when compared to other conventional concretes.
- Sunlight reflection rate is higher when compared to other conventional concretes.
- It reduces organic and inorganic substances that cause air pollution thanks to its TiO_2 content.
- Durability is higher when compared to other conventional concretes. Self cleaning concretes contain TiO_2. It is capable to preserve its durability for a longer period.

Disadvantages of self-cleaning concretes

- White spots can be formed on the surface of self-cleaning concrete because of its titanium di-oxide content.
- Light is required in order to activate chemical reaction. Therefore, it cannot be used in indoor applications.
- The cost of self-cleaning concrete is higher than other conventional concretes. Besides there is no published standard in Turkey for self-cleaning concretes.

1.4. STATEMENT OF THE PROBLEM

The continuity of the water cycle is very important for the continuation of the ecological cycle. The increase in the use of conventional concrete, especially in megacities, constitutes an obstacle to the continuity of the water cycle because the non-porous structure of conventional concrete makes it difficult to transmit water to the soil. Use of conventional concrete also causes temperature increase in mega cities. In addition, this situation causes puddles and water overflows on the roads, especially in rainy weather conditions. At the same time, it is inevitable that chemical contaminations such as bacteria formation and abrasion will occur, especially in transportation structures such as pedestrian roads and pavements. In this thesis a pervious concrete mix is designed using tumbled aggregates. It is believed that this type of aggregate will increase the number of interconnected voids which in turn increases the permeability. The effects of aggregate surface and aggregate size on the various properties of pervious concrete are then studied.

1.5. THESIS OUTLINE

In this thesis, pervious concrete was produced by using tumbled aggregates of three different sizes. These aggregates are different from the traditional aggregates because they have a tumbled and smooth geometry.

Compressive strength tests are performed on the cylindirical pervious concrete specimens according to the relevant procedures.

The void percentage was determined by the Archimedes' principle using cube specimens. Additionally, permeability tests are carried out to understand the effect of aggregate size and surface geometry on the permeability of concrete. The relationship between the water permeability of the cube specimens and the aggregate diameter was examined.Later, titanium dioxide is applied to specimen to understand the effectiveness of this self cleaning concrete application.In addition to this,the purpose of applying the titanium dioxide solution to the specimen is to observe the reduction of the pollution that will occur on the surface of the concrete with the photocatalytic effect it creates on the surface.Finally, suggestions are given for future studies on pervious concrete and its sustainability based on the findings obtained.

2. STUDIES ON PORTLAND CEMENT PERVIOUS CONCRETE

2.1. PERVIOUS CONCRETE MIX DESIGN

The design of pervious concrete mixture mainly depends on proper selection of narrow graded coarse aggregate and variations of paste volume until the aimed features are achieved [10]. The optimum water amount that will be used in pervious concrete mix design is based on gradation and cementititous materials type and content and also other physical characteristics of the aggregate [10]. Typical w/c ratio for pervious concrete mixture varies between 0.27 and 0.43. Pervious concrete is a mixture that includes cement, aggregate and water. It is different from conventional concrete as it includes less amount of fine aggregate. Typically there is a single size aggregate used in pervious concrete as This results in larger air void when compared to conventional concrete [9].

A good mix design for pervious concrete with balanced composition of materials is needed to achieve a good performance of strength, permeability and durability in the field. In general, the ratio of aggregate to cement is in the range of 4 to 6 which leads to an aggregate amount of 1300 kg/m3 to 1800 kg/m3 [8].

2.2 PERVIOUS CONCRETE CASTING PROCEDURES

The characteristics of pervious concrete are different than those of conventional concrete, therefore conventional casting and sample preparation techniques may be inadequate. The compaction method must be chosen to achieve a consistent and reliable sample with similar characteristics of the pervious concrete in the field [11]. To reach reasonable compressive strengths, the concrete must be well compacted while the permeability properties of the concrete strongly depend on the volume and connection of voids within its structure.The pervious concrete samples are mixed by using mechanical mixer just like the conventional concrete.

2.3. PERVIOUS CONCRETE TESTING PROCEDURES

Pervious concrete testing procedures are determined according to the relevant standards. Some of these tests are specific for pervious concrete. There are different types of tests that are conducted on-site or in laboratories [9].

In this study the following tests are conducted. Aim of these tests are explained in this section. Relevant test procedures will be described in Section 3 of this thesis as step by step.

- Slump test

Slump test is used to measure the consistency of fresh concrete. It is done to check the workability of fresh concrete. Besides, slump test is used to ensure consistency between batches. Figure 2.1 shows how the slump of the concrete mixes in this study is measured.

Figure 2.1. Measuring slump of concrete mixes

- Temperature Measurements

Temperature measurements on fresh pervious concrete mix are carried to ensure consistency between batches.

- Compression test

The compression test is used to measure the 28th day compressive strength of the concrete in hardened state. The compression testing machine which conforms to the standards is used to determine the strength of cylinders that are 150 mm in diameter and 300 mm in height. The test machine is shown in Figure 2.2 and samples used in compression test are shown in Figure 2.3.

Figure 2.2. Compression test machine

Figure 2.3. Samples used in compression test

- Void Content Test

Void content of pervious concrete is one of the indicators of the permeability of concrete. In this study, Archimedes’ principle is used to determine the void content. Cube specimens are used to measure void content. The weight in water,dry weight and void content of the cube specimens are measured . Device in Figure 2.4 provides the weight in water and digital tare in Figure 2.5 indicates the dry weight of specimen.

Figure 2.4. Specific gravity bench used to measure weight in water

Figure 2.5. Digital tare used to weigh cube specimens

➢ Self-cleaning test

Titanium dioxide solution is used to prevent the negative effects of the dirt and toxic gases on the surface of the concrete and the formation of bacteria. The solution is applied on to the surface of the concrete and later methylene blue pigment was dropped on the surface of the concrete.The absorption value of methylene blue pigment as a result of the reaction with titanium dioxide solution under ultraviolet light was observed by a uv-vis spectrophotometer device.

➢ Permeability test

Void content test is not sufficient to measure the permeability characteristics of pervious concrete samples. Permeability test is used to understand if the voids are interconnected and permit easy passage of fluids. The test set-up is shown in Figure 2.6. Moreover, it is observed how long it will take for 1 liter of water to pass through the circular surface of 0.1 meter diameter. The permeability values of cube specimens with different aggregate sizes are determined and the relationship between aggregate size and permeability is examined.

Figure 2.6. Permeability test set-up

3. SAMPLE PREPARATION AND TEST PROCEDURES OF PERVIOUS CONCRETE

3.1. SAMPLE PREPARATION OF PERVIOUS CONCRETE

The intent of this research is to examine the effect of aggregate surface and aggreagte size on the various properties of pervious concrete. Three different sizes of aggregates are used in the production of the test specimens. The surface condition of the aggregates is chosen as tumbled so that the aggregates touch each other at minimum surface. It is believed that this type of aggregate will increase the number of interconnected voids which in turn increases the permeability.

In this thesis, an aggregate- cement (A/C) ratio of 4 is used with a water-to-cement ratio of 0.35. No fine aggregate is used. Three different aggregate sizes: 10 mm, 15 mm and 25mm are used. Figures 3.1 to 3.3 show the composition of used aggregates. As can be seen from these figures the aggregates are similarly sized and there is no distinct variation in size for a single aggregate size. It is believed that by keeping the size of aggregates close to each other, larger voids can be obtained.

Figure 3.1. 10 mm tumbled aggregates used in this study.

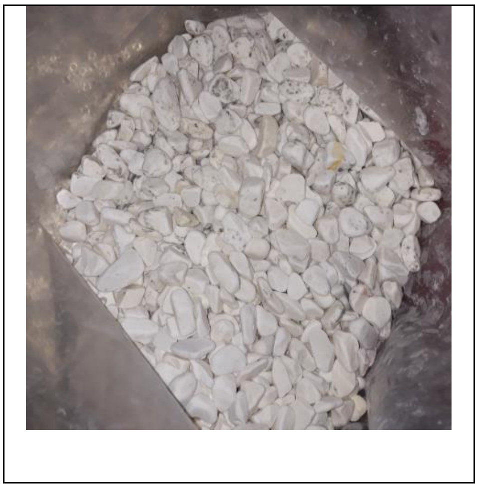

Figure 3.2. 15 mm tumbled aggregates used in this study

Figure 3.3. 25 mm tumbled aggregates used in this study

The pervious concrete mix design used in this thesis is given in Table 2.1.

Table 2.1. Pervious concrete mix design

Material	**Amount per 1m^3 mix (kg)**
Cement	325
Water	115
Aggregate	1300

The portland cement used to cast sepcimens in this study is CEM I 42.5 type cement. It is formed as a result of grinding 95 percent portland cement clinker with 5 percent minor component and 5 percent gypsum. It has a density of 3.10-3.15 gr/cm^3.The pervious concrete mixes in this thesis are prepared by following these steps [9].

- The component weights are prepared and batched.
- Mechanical mixer is covered with a sample batch to prevent material loss.
- Mixer is stopped and cleaned in order to remove excess water and material.
- The coarse aggregates and half of the measured water are added to the mixer.
- Sand and cement materials are slowly added into the rotating drum mixer.
- The remaining half of the water is added.
- Mixing continues for three minutes from start time.
- Mixer is stopped for three minutes.
- Mixer is run for additional two minutes.

A total of eighteen cylinder pervious concrete samples were obtained,including six 10 mm diameter aggregates,six 15 mm diameter aggregates,six 25 mm diameter aggregates. Standard cylinder molds with a diameter of 150 mm and a height of 300 mm are utilized. In addition to this,three cube pervious concrete specimens from each aggregate size are cast. Standard cube mold which utilized in this study has 150 mm width,length and height. All cast specimens are shown in Figure 3.4 and specimen names are given in Table 2.2.

A standard tamping rod is used for compaction of the specimens. The concrete is filled in three layers, and each layer receieved 10 tamps.

Figure 3.4. Cast specimens used in this thesis

Table 2.2. Cast samples used in this study

Name of Specimen	**Aggregate size (mm)**	**Number of cast cylinders**	**Number of cast cubes**
KPC10	7-10	6	1
KPC15	10-15	6	1
KPC25	15-25	6	1

3.2. TEST PROCEDURES OF PERVIOUS CONCRETE

3.2.1. Slump Test

Slump test has several steps and there are some minor differences in details of performing the test.Slump cone must have a height of 300 mm with a bottom diameter of 200 mm and an upper diameter of 100 mm in ASTM standards. The test must be carried out by filling the slump cone in three equal layers with the mixture in which is temped down 25 times for each layer. The ASTM standards define the rigidity of cone. ASTM standards state that when cone is removed, it must be lifted up vertically without any rotational movement [12].

Test procedure

Test is done by using a metal mould slump cone. It is open at both ends and it has handles. Dimensions of the tool is given as follows.

Internal diameter of top: 100 mm

Internal diameter of bottom: 200 mm

Height: 305 mm

The cone is put on a hard and non-absorbent surface. Then, the cone is filled with fresh concrete in three stages. Each layer is temped 25 times with 600 mm long and 16 mm diameter rod. Lastly, the slump cone is lifted up in vertical direction [12,13]. Application of slump test is shown in Figure 3.5.

Figure 3.5. Cone position in slump test

3.2.2. Compression Test

In this study BS EN 12390-3:2019[14] standard is used. Compression testing machine is used for this test. Test specimen can be cube or cylinder. The test specimen must satisfy the requirements given in EN 12350-1[15], EN 12390-1[16], EN 12390-2[17], or EN 12504-1[18]. This test is applied on hardened concrete.

Test Procedure

- Specimen preparation and positioning

The load bearing surfaces of the test specimens must be moulded according to this standard. After curing specimens must be tested as soon as possible and within 10 hours. The test environment must be at 20±5˚C. If test specimens will be stored in the test facility more than 4 hours than they must be protected from moisture loss. Then, specimens must be positioned so that load applied perpendicular to the direction of casting. The specimen must be centered with respect to the lower platen with an accuracy of 1% designated size of the specimens [14].

- Loading

A constant rate of loading must be selected. After the initial load is applied, load is applied to the specimen without shock and it is increased with the rate of 10% until no greater load is applied. The initial load must be applied as close as possible to the selected rate of loading. The load rate can be affected from failure of the specimen during the final stages of this test. Maximum load applied in kN is recorded.

3.2.3. Void Content Test

The void content of the cube specimens is measured using Archimedes' test method.With this test, the relationship between the diameter of the aggregates of different sizes used in cube-shaped pervious concrete and the percentage of voids was observed.

3.2.4. Permeability Test

Permeability test is carried out to measure of the ease of concrete to permit the passage of relevant fluids. In this study, permeability determined using cube specimens. Permeability of mixes with different aggregate sizes are obtained. The cube specimens used in permeability tests are shown in Figure 3.6, 3.7 and 3.8. A plastic bottle with a diameter of 0.1 meters was placed on the cube specimens.This plastic bottle was fixed by applying silicone to the upper surface of the pervious concrete, and the four side surfaces of each three cube specimens were covered with aluminum foil. These two processes are carried out to transmit water uniformly to the lower surface without any leakage from the side surfaces of the concrete. As a result of these processes, it was measured how long it took for three cube samples with 10 mm, 15 mm and 25 mm aggregates to transmit 1 liter of water poured from the plastic bottle from the upper surface of the cube specimen to the lower surface.

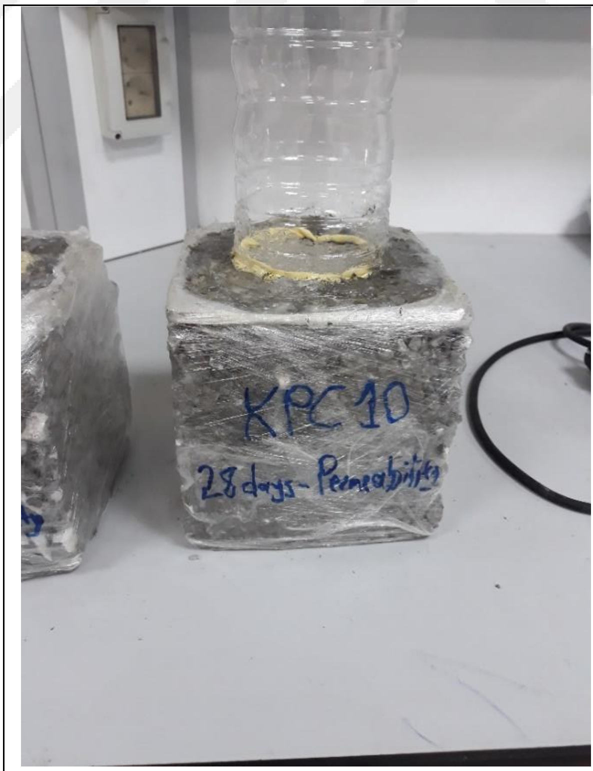

Figure 3.6. KPC 10 specimen used in permeability test

Figure 3.7. KPC 15 specimen used in permeability test

Figure 3.8. KPC 25 specimen used in permeability test

3.2.5. Self-Cleaning Test

Titanium dioxide was obtained by mixing the titanium powder and nitric acid in the beaker. First nitric acid is added to the beaker and the pH value is measured with a litmus paper to ensure that the pH value is 2 as shown in Figure 3.9.

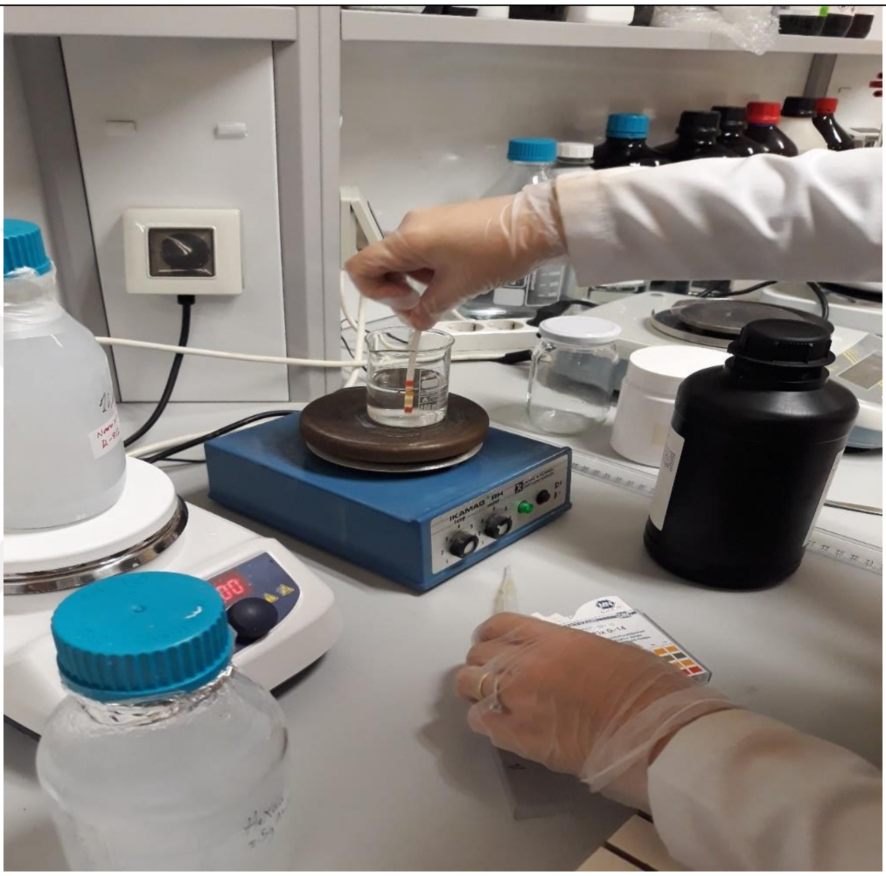

Figure 3.9. Nitric acid pH measurement with test paper

Later, the titanium powder is added to the nitric acid in the beaker and mixed for 15 minutes. The beaker is covered with aluminum foil to protect the reaction from dust and similar particles titanium di-oxide production as shown in Figure 3.10.

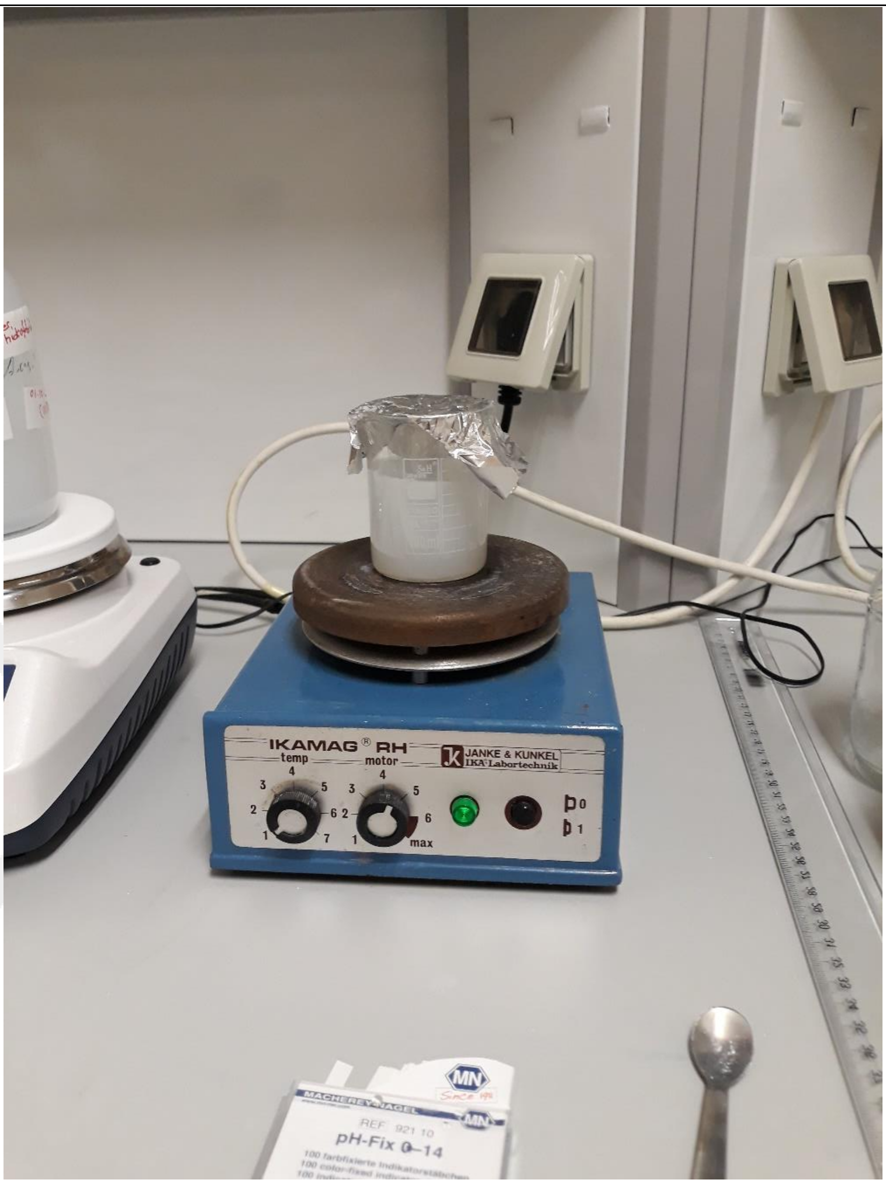

Figure 3.10. Titanium di-oxide production

The resulting titanium dioxide solution is applied to the surface of the sample with a brush. Absorption of titanium di-oxide in KPC 25 cylindirical sample is shown in Figure 3.11.

Figure 3.11. Absorption of titanium di-oxide in KPC 25 cylindirical sample

Methylene blue pigment, known as organic stain in the chemical industry, is used to measure the effectiveness of the titanium di-oxide application. The blue pigment is dropped on the surface of the sample and the absorption value of the methylene blue pigment as a result of the reaction with titanium dioxide solution under ultraviolet light is observed by a uv-vis spectrophotometer device.

4. TEST RESULTS

In this section experimental results and interpretation of these results are given under each sub-sections.

4.1. SLUMP AND TEMPERATURE TEST RESULTS

Measured slump and temperature values for different aggregate sizes are given in Table 4.1.As can be seen from this table slump and temperature values for mixes with different aggregate sizes are close to each other.

Table 4.1. Slump and temperature test results

Name of specimen	**Slump value for fresh pervious concrete (mm)**	**Temperature for fresh pervious concrete (˚C)**
KPC 10	210	24.2
KPC 15	200	24.5
KPC 25	190	24.7

The slumped concrete is in different shapes. They are named as true slump, shear slump or collapse slump as it shown Figure 4.1. Collapse means that sample is too wet or it has workability. In this study, slump type is collapse type of slump as shown in Figure 4.2.This type of slump is accepted and better for pervious concrete.

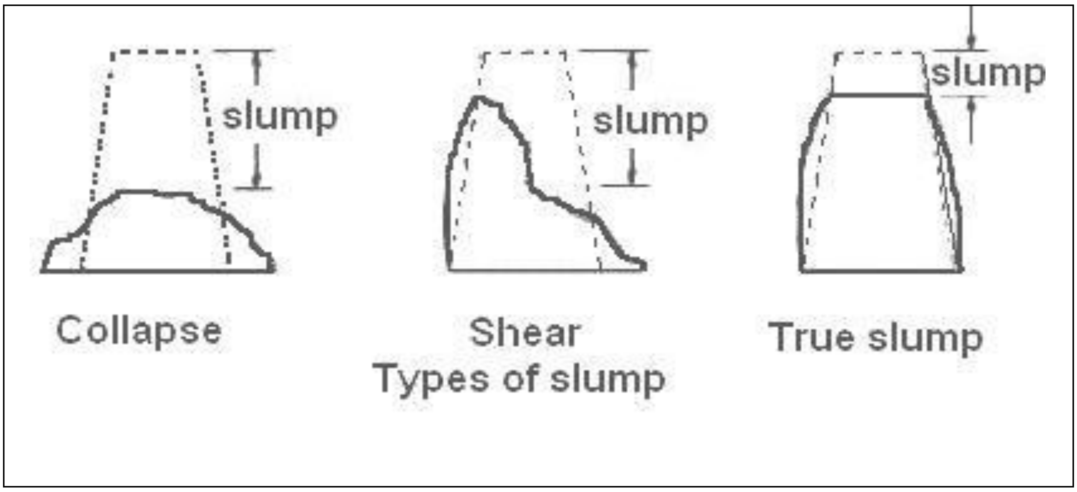

Figure 4.1. Types of slumps (adapted from [19])

Figure 4.2. Collapse type of slump

All results in Table 4.1 show that there is consistency between the concrete mixes of three different aggregate types.

4.2. COMPRESSION TEST RESULTS

Results obtained from compression tests of cylinder specimens are given in Table 4.2. Figures 4.3 to 4.11 show how these results are read for KPC 10,KPC 15 and KPC 25. In addition, in this study, three cylinder specimens from each of the KPC 10, KPC 15 and KPC 25 specimens were used in the compression test. The standard deviation value was calculated for each aggregate size by using the measured compressive strengths and the calculated average compressive strength values. The coefficient of variation was calculated for each sample by the ratio of the standard deviation value to the average compressive strength. The coefficient of variation was calculated to determine the reliability of this test. The measured compressive strengths for each sample, calculated average compressive strengths, standard deviation values and coefficients of variation are given in Table 4.2. As a result of the compressive strength test applied to the cylindrical samples, it was determined that the compressive strengths also differ depending on the three different aggregate diameters used in this thesis.Standard deviation is calculated according to Equation (4.1) and coefficient of variation is calculated according to Equation (4.2), respectively.

$$S = \sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2\left(\frac{1}{n-1}\right)} \tag{4.1}$$

where:

S – standard deviation for compressive strength

n – number of cylindirical specimen

x_i– compressive strength (MPa)

$\bar{x}$–average compressive strength (MPa)

$$CV = \left(\frac{S}{\bar{x}}\right) \times 100 \tag{4.2}$$

where:

CV −coefficient of variation (%)

S – standard deviation for compressive strength (MPa)

$\bar{x}$–average compressive strength (MPa)

Table 4.2. Measured compressive strengths and calculated average compressive strengths,standard deviation and coefficient of variation values for cylindirical specimens

Specimen Name	Cylindrical specimens used in compression Test	Maximum applied axial force V(kN)	Compressive strength f_c (MPa)	Average compressive strength $f_{c\text{-}ave}$ (MPa)	Standard deviation for compressive strength	Coefficient of variation for compressive strength (%)
KPC 10	KPC 10-1	207.10	11.72	13.54	2.34	17.27
	KPC 10-2	285.90	16.18			
	KPC 10-3	224.90	12.73			
KPC 15	KPC 15-1	221.70	12.54	12.63	2.44	19.33
	KPC 15-2	267.10	15.11			
	KPC 15-3	180.80	10.23			
KPC 25	KPC 25-1	124.70	7.06	5.54	1.34	24.23
	KPC 25-3	88.60	5.02			
	KPC 25-4	80.00	4.53			

As can be understood from Table 4.2 the coefficient of variations of compression tests are 17.27 % , 19.33 % and 24.23 % . CV<10 % is very good, 10 %–20 % is good, 20 %–30 % is acceptable, and CV > 30 % is not acceptable [20]. The calculated coefficient of variations correspond to the acceptable range according to the ranges mentioned in [20].

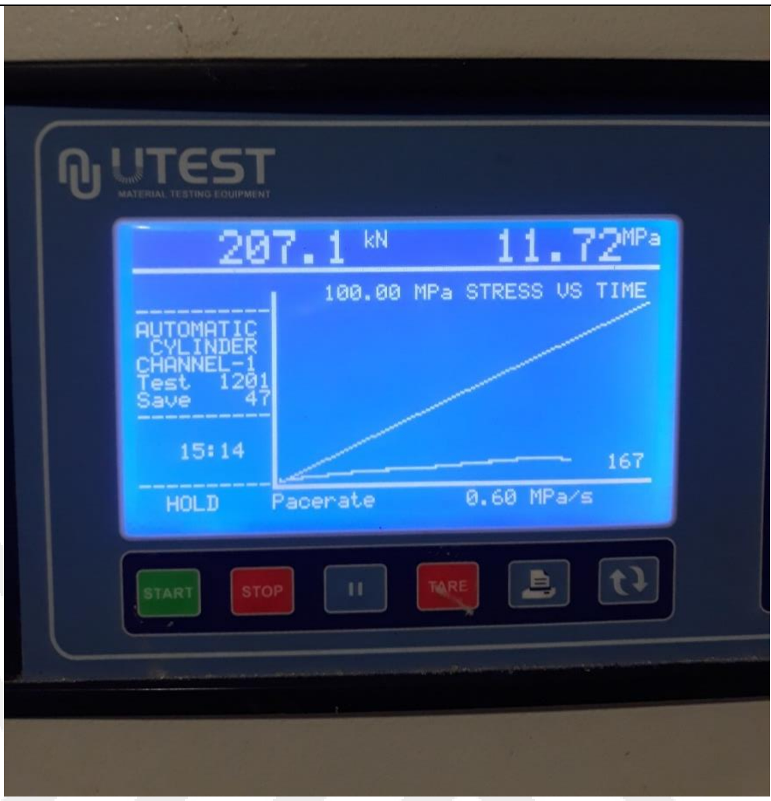

Figure 4.3. KPC 10 specimen results for V1-10 and fc1-10

Figure 4.4. KPC 10 specimen results for V2-10 and fc2-10

Figure 4.5. KPC 10 specimen results for V_{3-10} and f_{c3-10}

Figure 4.6. KPC 15 specimen results for $V_{1\text{-}15}$ and $f_{c1\text{-}15}$

Figure 4.7. KPC 15 specimen results for V2-15 and fc2-15

Figure 4.8. KPC 15 specimen results for $V_{3\text{-}15}$ and $f_{c3\text{-}15}$

Figure 4.9. KPC 25 specimen results for V1-25 and fc1-25

Figure 4.10. KPC 25 specimen results for $V_{3\text{-}25}$ and $f_{c3\text{-}25}$

Figure 4.11. KPC 25 specimen results for $V_{4\text{-}25}$ and $f_{c4\text{-}25}$

4.3. VOID CONTENT TEST RESULTS

Figures 4.12 to 4.17 show the measured weight of cube specimes in water and in dry condition, respectively. The weight of the KPC 10 specimen in water is in Figure 4.12 and the dry weight is in Figure 4.13. The weight in water of the KPC 15 specimen is in Figure 4.14 and the dry weight of the KPC 15 specimen is in Figure 4.15. Weight in water of the KPC 25 is in Figure 4.16 and dry weight of the KPC 25 is in Figure 4.17.

Void contents of three cube specimens were evaluated according to Kovac M. and Sicakova A. [21] as given in Equation (4.3).

$$Vr = (1-(w2-w1)/\rho V)\cdot 100 \tag{4.3}$$

where:

Vr - porosity (%)

w2 - dry weigth of sample (kg)

w1 - mass of weight submerged in water (kg)

ρ - density of water (kg/m^3)

V – volume of specimen (m^3)

The density of water is taken as 1000 kg/m^3 and the volume of the cube specimens is calculated as 0.0038 cubic meters.

Figure 4.12. KPC 10 specimen weighing 4400 grams in water

Figure 4.13. Dry weight of the KPC 10 cube specimen measured as 7.47 kilograms together with the 0.2 kg weight value of the digital tare

Figure 4.14. KPC 15 specimen weighing 4670 grams in water

Figure 4.15. Dry weight of the KPC 15 cube specimen measured as 7.92 kilograms together with the 0.5 kg weight value of the digital tare

Figure 4.16. KPC 25 specimen weighing 4309 grams in water

Figure 4.17. Dry weight of the KPC25 cube specimen measured as 7.1 kilograms together with the 0.2 kg weight value of the digital tare

As a result of the measurements and carried out for cube samples with three different diameter aggregates, it is determined that samples with different aggregate diameters have different void contents. Volume of specimens, density of water to be used in void content calculation and measured dry weight and weight in water values and calculated void content values are shown in Table 4.3.

Table 4.3. Measured dry weight and weight in water values and calculated void content values for three cube specimens

Specimen name	Dry weight of the specimen (kg)	Weight of specimen in water (g)	Density of water (kg/m^3)	Volume of specimen (m^3)	Void content (%)
KPC 10	7.27	4400	1000	0.0038	24.47
KPC 15	7.42	4670	1000	0.0038	27.63
KPC 25	6.90	4309	1000	0.0038	31.82

4.4. SELF-CLEANING TEST RESULTS

Figure 4.18 shows the absorption of the methylene blue pigment as a result of the reaction with titanium dioxide solution.It was observed that the methylene-blue pigment disappeared after 1 day under UV light, and color change was observed after 2 hours as a result of the uv-vis spectrophotometry test, and the absorption value decreased from 0.259 to 0.117. This 55 percent decrease is indicative of the photocatalytic effect of titanium dioxide.

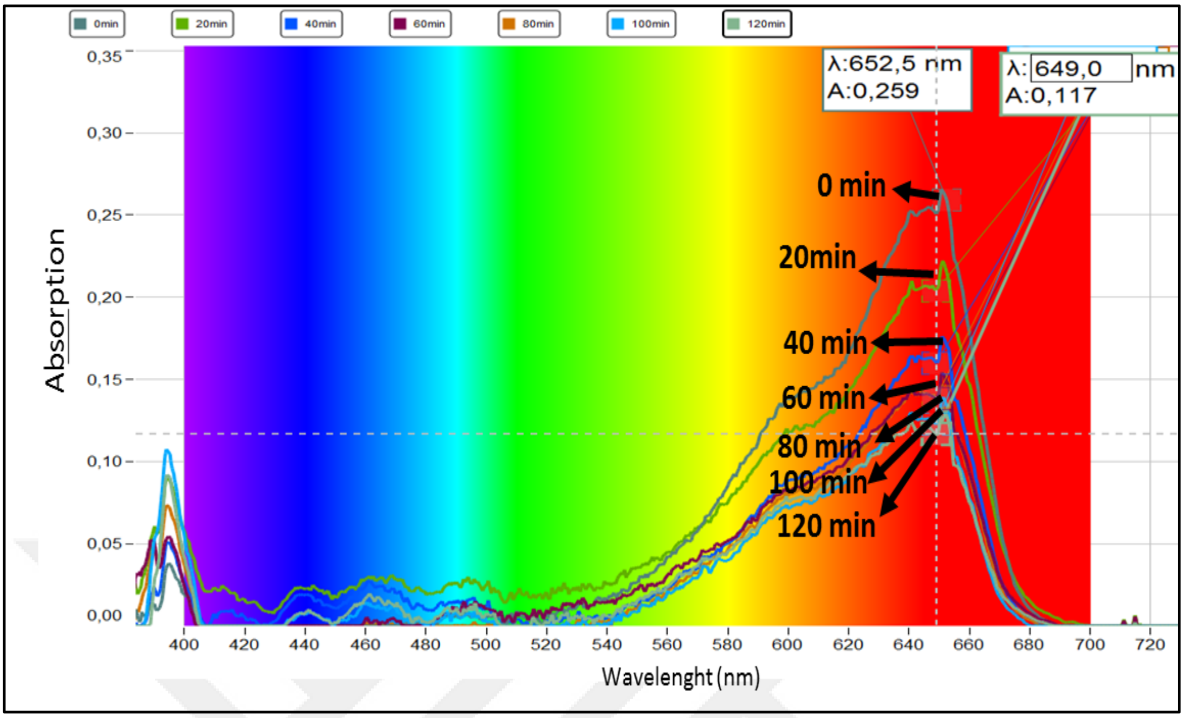

Figure 4.18. Self-cleaning test results

4.5. PERMEABILITY TEST RESULTS

Permeability test results are shown in Table 4.4.

Table 4.4. Permeability of various mixes

Name of specimen	Diameter of circular surface area contact within water (m)	Circular surface area in contact with water (m^2)	Flow time of 1 liter of water from the circular surface (min)	Permeability (l/min/ m^2)
KPC 10	0.10	0.00785	0.267	477
KPC 15	0.10	0.00785	0.217	587
KPC 25	0.10	0.00785	0.183	696

Figures 4.19, 4.20 and 4.21 show specimens in permeability test set-up to identify flow time. The calculated permeability values of the KPC 10, KPC 15 and KPC 25 specimens are in Table 4.6. As a result of the tests, it is observed that the measured permeability values changed depending on the aggregate diameter used.

Figure 4.19. KPC 10 cube specimen with flow time of 0.267 minutes for 1 liter of water

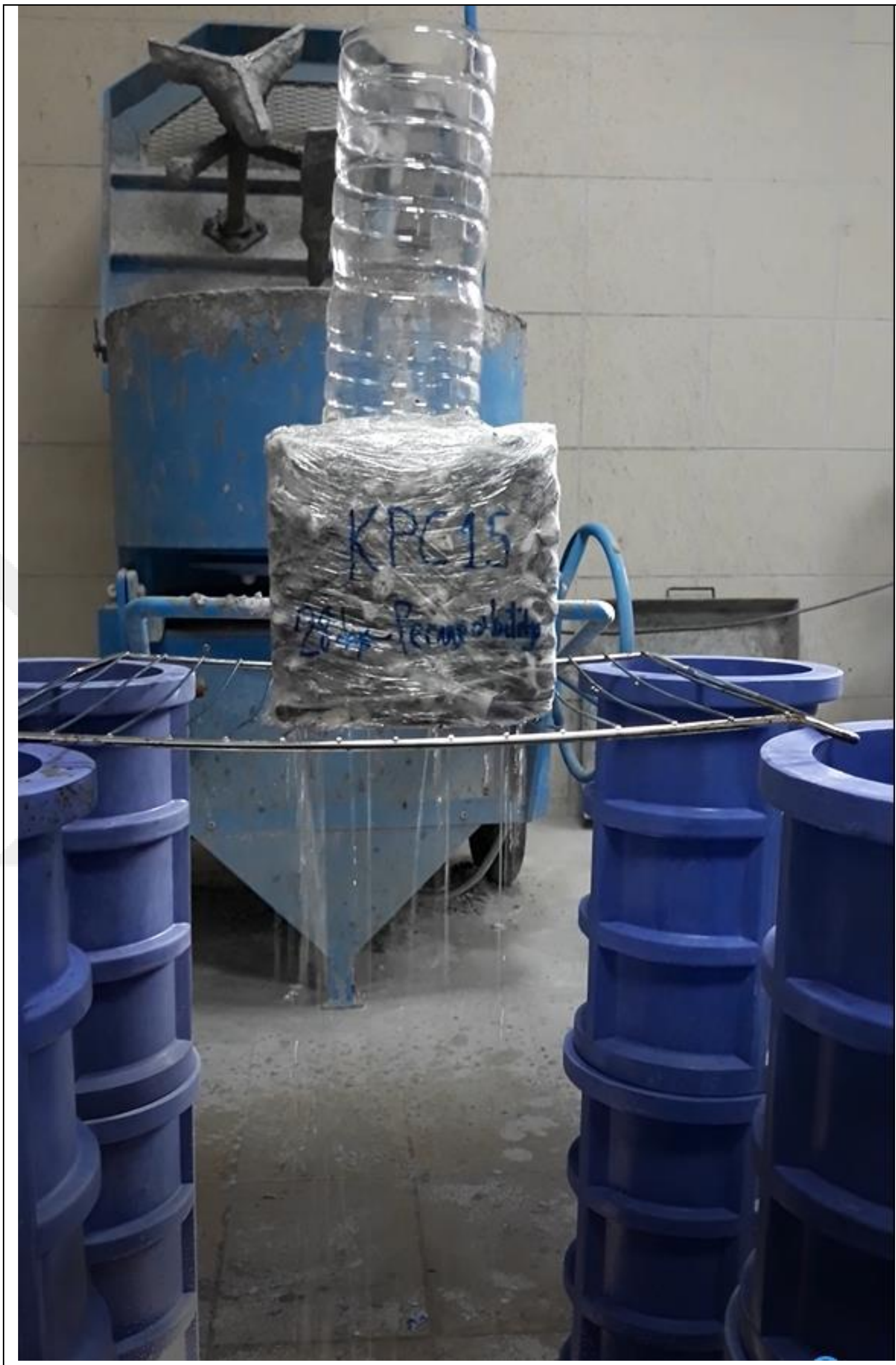

Figure 4.20. KPC 15 cube specimen with flow time of 0.217 minutes for 1 liter of water

Figure 4.21. KPC 25 cube specimen with flow time of 0.183 minutes for 1 liter of water

5. DISCUSSION OF TEST RESULTS

5.1. DISCUSSION OF COMPRESSION TEST RESULTS

The results of the compression test performed by taking the average of three cylindirical samples of each of 10 mm, 15 mm and 25 mm samples are shown in Figure 5.1. It has been observed that the compressive strength value obtained decreases as the aggregate diameter increases as expected. Pervious concrete mixtures can develop compressive strengths in the range of 500 psi to 4000 psi (3.5 MPa to 28 MPa), which is suitable for a wide range of applications [22]. As a result of the compressive strength test, it was seen that the values obtained for all three types of aggregates were in accordance with the value ranges mentioned in [22].

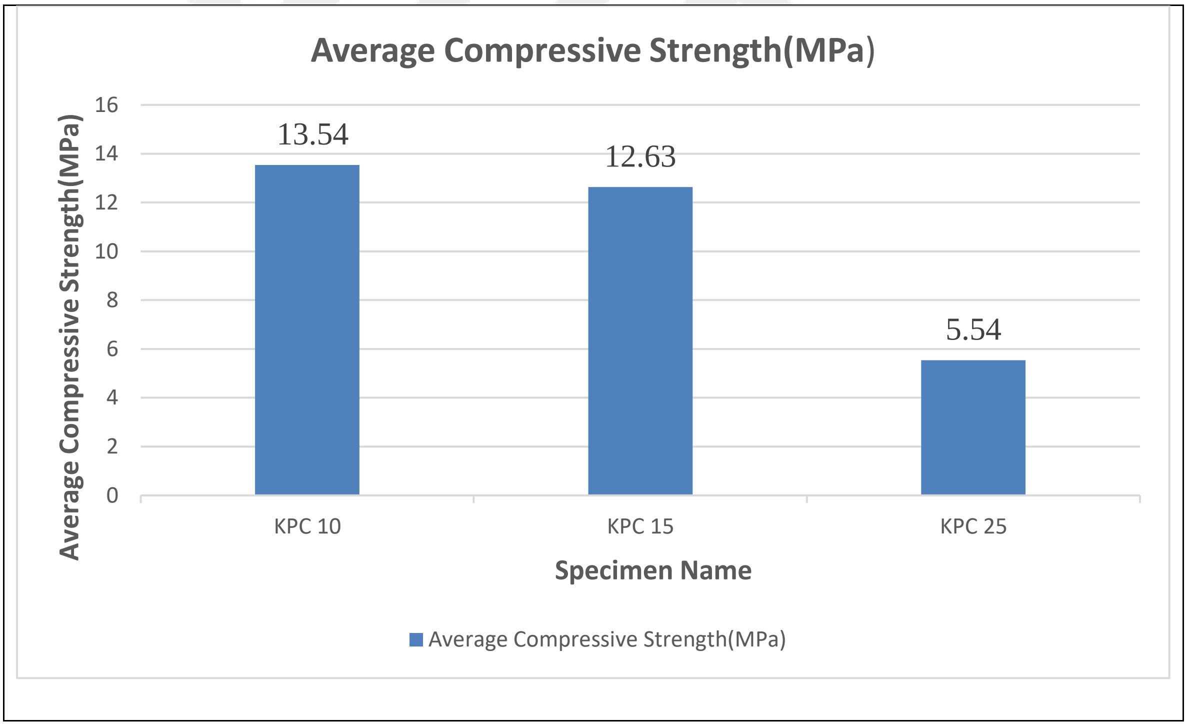

Figure 5.1. Comparison of compression test results

5.2. DISCUSSION OF VOID CONTENT TEST RESULTS

The void content results obtained by using the Archimedes test for cube samples with 10 mm, 15 mm and 25 mm aggregate diameters are shown in Figure 5.2. It was observed that the value of the obtained void percentage increased as the aggregate diameter increased as expected. In pervious concrete fine aggregate is non-existent or present in very small amounts (<10% by weight of the total aggregate). Also, there is insuffcient paste to fill the remaining voids, so pervious concrete has a porosity anywhere from 15 to 35% but most frequently about 20% [22]. As a result of this test, it is seen that the percentage of void values obtained for all three types of aggregates were in accordance with the value ranges mentioned in [22].

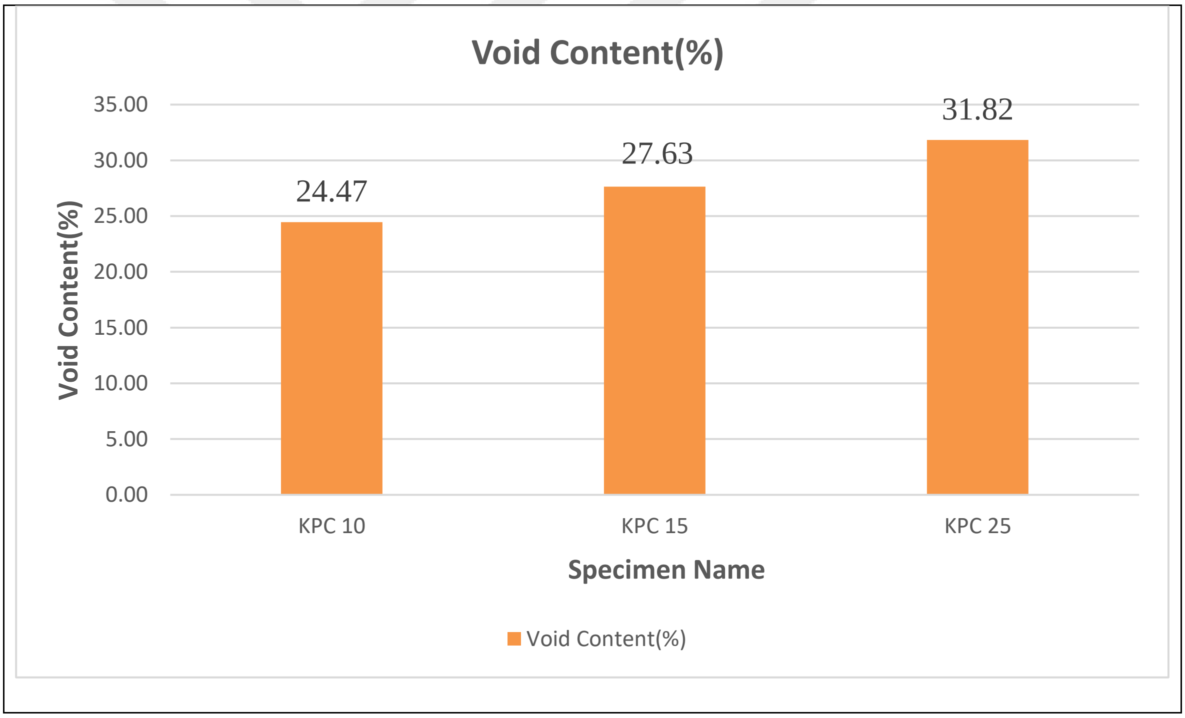

Figure 5.2. Comparison of void content test results

5.3. DISCUSSION OF PERMEABILITY TEST RESULTS

The results of the values obtained by performing the permeability test of cube samples with 10 mm, 15 mm and 25 mm aggregate diameters are shown in Figure 5.3. It was observed that the permeability value obtained increased as the aggregate diameter increased. The infiltration rate (permeability) of pervious concrete will vary with aggregate size and density of the mixture, but will fall into the range of 80 to 720 liters per minute per square meter [22]. As a result of the permeability test, it was seen that the permeability values obtained for all three types of aggregates were in accordance with the value ranges mentioned in [22].

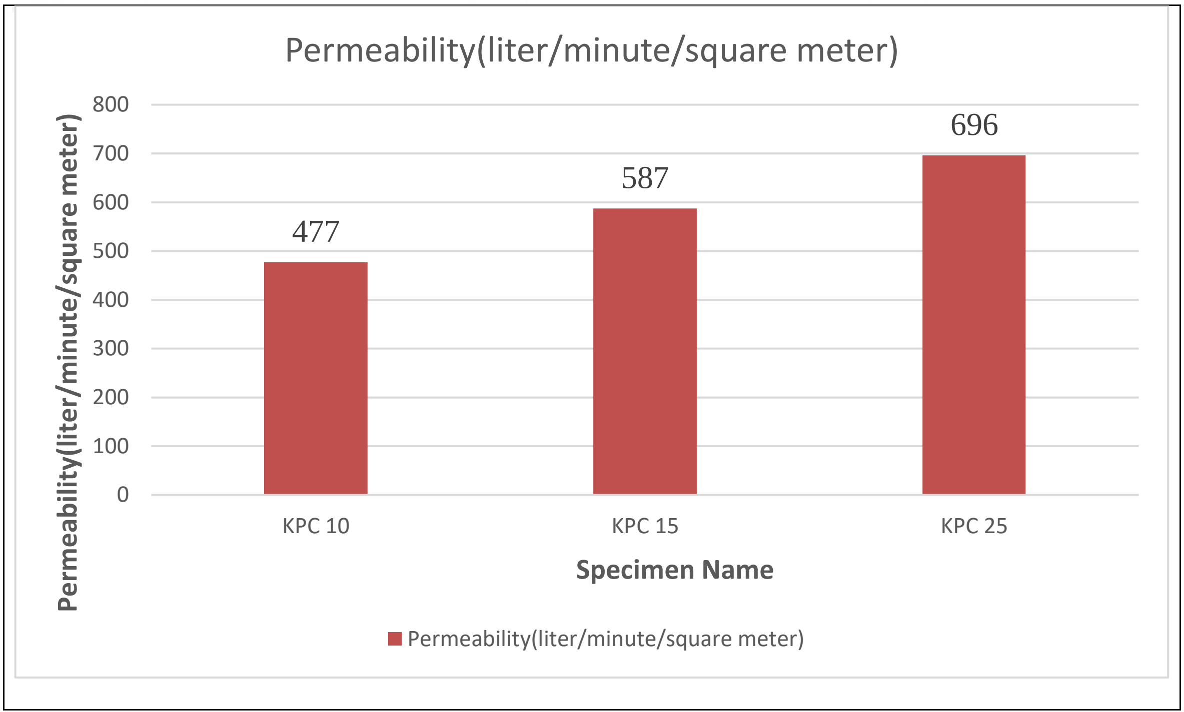

Figure 5.3. Comparison of permeability test results

5.4. DISCUSSION OF SELF-CLEANING TEST RESULTS

According to studies conducted, better retention of titanium dioxide particles on the sample surface and higher toluene removal efficiency is obtained when samples have higher porosity [8]. In this thesis, titanium dioxide is applied on the surface of pervious concrete sample to observe the retention of titanium dioxide particles on a surface. As the waiting time under ultraviolet light increases, the decrease in absorbance value indicates a self-cleaning effect.

Self-cleaning test results show that the application of titanium dioxide gives excellent results in pervious mix design used in this study.

6. CONCLUSION AND FUTURE WORKS

In this thesis, pervious concrete was produced by using tumbled aggregates of three different sizes. These aggregates are different from the traditional aggregates because they have a tumbled and smooth geometry. Compression test is performed on the cylindirical pervious concrete specimens according to the relevant procedures. The void percentage was determined by the Archimedes' principle using cube specimens. Additionally, permeability test is carried out to understand the effect of aggregate size and surface geometry on the permeability of concrete. The relationship between the water permeability of the cube specimens and the aggregate diameter was examined.

Later, titanium dioxide is applied to specimen to understand the effectiveness of this self cleaning concrete application.In addition to this,the purpose of applying the titanium dioxide solution to the specimen is to observe the reduction of the pollution that will occur on the surface of the concrete with the photocatalytic effect it creates on the surface.

It has been observed that the compressive strength of specimens decreases as the aggregate diameter increases. However, the compressive strength values of the cylinder samples in this study are suitable for the design as they are within the recommended and specified value ranges.

The void content results showed that the value of the obtained void percentage increased as the aggregate diameter increased. The calculated void content values of the three cube samples are at the values desired for pervious concrete and deemed appropriate for the design.

The results of the permeability tests of cube samples showed that the permeability value obtained increased as the aggregate diameter increased. The values calculated based on the permeability test results for the cube samples with three different aggregate sizes are among the appropriate values for pervious concrete design.

In this study cold climate conditions are not taken into consideration specifically. The pervious concrete usage in cold weather environments are causing concerns due to freeze-thaw cycle. The volumetric expansion of freezing process might cause fractures and cracks on pervious concrete. The addition of small amount of aggregates to the pervious concrete mixtures might prevent this problem. Also, drainage and sub-base are important to decrease the possibility of freeze thaw damage on pervious concrete. Therefore, freeze-thaw effect can be researched as future works on pervious concrete.

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