The Effect of Different Cement Types on Pervious Concrete

Tennur Demiralp Tuğal

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Approval of the Institute of Graduate Studies and Research

Prof. Dr. Ali Hakan Ulusoy
Director

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

Prof. Dr. Eriş Uygar
Chair, Department of Civil Engineering

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

Prof. Dr. Özgür Eren
Supervisor

Examining Committee

1. Prof. Dr. Özgür Eren

2. Assoc. Prof. Dr. Tülin Akçaoğlu

3. Assoc. Prof. Dr. Ertuğ Aydın

ABSTRACT

Pervious concrete (also known as porous concrete, permeable concrete, no fines concrete, and porous pavement) is a high-porosity concrete used in concrete flatwork applications that allows water from precipitation and other sources to pass directly through, reducing runoff and allowing groundwater recharge. Coarse aggregates are used in pervious concrete, with little or no fine particles. The aggregates are then coated with concrete paste, allowing water to flow through the concrete slab. Pervious concrete has typically been utilized in parking lots, low-traffic areas, residential streets, pedestrian pathways, and greenhouses. This study shows the effects of cement types on both fresh and hardened concrete by using different cement types as the only variable in permeable concrete. CEMI and CEMII cement types are discussed for this study. The number of other components used in concrete, water, cement and aggregate is the same in both concretes. The water/cement ratio is the same for both concretes and is 0.34. The diameter and shape of the aggregate used in the concrete is very important for the protection of the hollow structure to be formed in the concrete. Therefore, 14mm limestone aggregate and 5mm sand were used as coarse aggregate. The amount of fine aggregate used is 10% of the coarse aggregate by mass. In this study, the use of fine aggregate was preferred because it was aimed to obtain high compressive strength. Experimental results showed that concrete using CEMI cement in general had superior properties compared to concrete produced using CEMII cement.

Keywords: Pervious Concrete, No Fine Concrete, Permeable Concrete, Cement, Mechanical Properties, Water Permeability, Durability.

ÖZ

Geçirgen beton (gözenekli beton, geçirgen beton, ince taneli olmayan beton ve gözenekli kaplama olarak da bilinir), yağıştan ve diğer kaynaklardan gelen suyun doğrudan geçmesine izin vererek yüzey akışını azaltan ve yeraltı suyunun yeniden şarj edilmesini sağlayan beton düzleştirme uygulamalarında kullanılan yüksek gözenekli bir betondur. İri agregalar, çok az veya hiç ince parçacık içermeyen geçirimli betonda kullanılır. Bu çalışma geçirimli beton içerisinde farklı çimento tiplerini tek değişken olarak kullanarak çimento tiplerinin hem taze hem de sertleşmiş beton üzerindeki etkilerini göstermektedir. Bu çalışma için CEMI ve CEMII çimento tipleri ele alınmaktadır. Beton içerisinde kullanılan diğer bileşenlerin miktarı su, çimento ve agrega her iki beton içinde aynıdır. Su/çimento oranı her iki beton için aynı olup 0.34 dür. Beton içerisinde kullanılan agreganın çapı ve biçimi beton içerisinde oluşturulacak boşluklu yapının korunması için oldukça önemlidir. Bu yüzden kaba agrega olarak 14mm'lik kireç taşı agregası ve 5mm'lik kum kullanılmıştır. Kullanılan ince agreganın miktarı kütlece kaba agreganın 10% si kadardır. Bu çalışmada yüksek basınç dayanımı elde etmek amaçlandığı için ince agrega kullanımı tercih edilmiştir. Deneysel sonuçlar, genel olarak CEMI çimentosu kullanılan betonun CEMII çimento kullanılarak üretilen betona kıyasla daha üstün özelliklere sahip olduğunu gösterdi.

Anahtar Kelimeler: Gözenekli Beton, Geçirgen Beton, İnce Taneli Olmayan Beton, Çimento, Mekanik Özellikler, Su Geçirgenliği, Durabilite.

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LIST OF SYMBOLS AND ABBREVIATIONS

a	Oven-Dried Mass Prior The Testing
A	Mass of Oven-Dried Sample in Air
A′	Concrete Cross Sectional Area
b	Oven-Dried Mass Of Each Specimens After Testing
B	Mass of Surface-Dry Sample in Air After Immersion
C	Oven-Dried Cumulative Mass Prior To Testing
C	Mass of Surface-Dry Sample in Air After Immersion and Boiling
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_3S	Tricalcium Silicate
$C_3S_2H_3$	Tobermorite Gel
C_4AF	Tetracalcium Aluminoferrite
$Ca(OH)_2$	Calcium Hydroxide
$CaCO_3$	Calcium Carbonate
CaO	Calcium Oxide
CO_2	Carbon Dioxide
d	Oven-Dried Mass of All Specimens After Testing
D'	Apparent Mass of Sample in Water After Immersion and Boiling
D	Density
f_{ck}	Characteristic Compressive Strength
f_{cm}	Compressive Strength of Concrete
f_i	Any Single Compressive Strength Test Result

g_1	Bulk Density, Dry
g_2	Apparent Density
H	Length of Concrete
H_2O	Water
K	Darcy Coefficient
l	Height of Water Above Concrete Sample
L	Total Height
M_c	Total Mass of Steel Cylinder Bowl and Concrete
M_m	Mass of Steel Cylinder Bowl
Q	Permeability Rate
t	Time Determined During the Experiment
T	Theorical Density
U	Void Content
V_m	Volume of Steel Cylinder Bowl
ρ	Density of Water
ACI	American Concrete Institute
CAH	Calcium Aluminate Hydrates
CPG	Specifiers Guide to Pervious Concrete Pavements in the Greater Kansas City Area
C-S-H	Calcium Silicate Hydrate
CSH	Calcium Silicate Hydrates
FHWA	Federal Highway Administration
ITZ	Interfacial Transition Zone
MIKA	Communication with Alumni and Career Research Directorate

PC	Pervious Concrete
RCCRTS	Roller Compacted Concrete Road Technical Specification

Chapter 1

INTRODUCTION

1.1 General

Nowadays, concrete is widely used in all areas because of its many advantages. With the advancement in technology and progress in mold and concrete industries, it is now possible to produce concrete with higher compressive strength, or in other words, capable of withstanding higher pressures. Thanks to the initial fluidity of concrete, it can be molded into almost any shape and size, which is another important benefit that makes it suitable for almost all construction needs.

With the recent developments in the concrete industry, the usage areas of concrete have increased considerably. With its wide range of usage areas, it is seen that many different types of concrete are used in the fields today. Some common types of concrete include:

1. Regular concrete: This is the most common type of concrete and is made by mixing cement, sand, and aggregate with wate. It can be used for in applications, including foundations, walls, and floors.
2. High-strength concrete: This type of concrete is designed to have a higher compressive strength than regular concrete. It is often used in applications where the concrete will be subject to heavy loads or stress, such as in bridges or tall buildings.

3. Lightweight concrete: This type of concrete is made by adding lightweight aggregates, such as expanded shale or clay, to the mix. It is often used in applications where weight is a concern, such as in precast panels or roof decks.
4. Self-compacting concrete: This type of concrete is designed to flow easily into tight spaces without the need for vibration. It is often used in applications where it is difficult to access with traditional equipment.
5. Fiber-reinforced concrete: This type of concrete is reinforced with small fibers, such as steel or synthetic fibers, to improve its strength and durability. It is often used in applications where the concrete will be subject to heavy loads or impact.
6. Decorative concrete: This type of concrete is designed to be visually appealing and can be stamped, stained, or polished to create a variety of patterns and textures. It is often used in applications such as sidewalks, patios and driveways.

There are just a few examples of many different types of concrete available today. The type of concrete used for a particular project will depend on the specific requirements of that project.

Another type of concrete that has recently become very popular, especially on pavements subject to light traffic loads, is pervious concrete. Obla (2010), uses the definition of “When used for flatwork applications, pervious concrete is a unique high porosity concrete that enables wate from precipitation and other sources to pass through, minimizing runoff from a site and replenishing ground water levels.” for permeable concrete in his article on Pervious concrete – An overview. In order to some concrete to be permeable concrete, it must have the main properties. These are porosity, permeability, strength, skid resistance, environmental benefits and cost-effective, respectively. Porosity typically between 15% and 30% which allows water pass through it easily. Permeability helps to reduce runoff and mitigate the effects of urban heat islands. Pervious concrete is strong and durable, with compressive strengths ranging from 3.5 to 28 MPa. The average pressure is 17 MPa (Tennis et al., 2004). Pervious concrete has a rough surface texture that provides good skid resistance, making it safer for vehicles and pedestrians. No fine concrete has several environmental benefits, including the ability to improve water quality by reducing the number of pollutants in runoff. It also helps to recharge groundwater and reduce the demand for potable water. Permeable concrete is a cost-effective solution for stormwater management, as it can reduce the need for expensive stormwater infrastructure such as detention ponds and underground storage systems.

1.2 Importance of the Study

Due to rapid and unplanned urbanization, permeable areas such as parks and forest areas in cities create inadequate living spaces for urban residents. With the increasing use of impermeable pavements on inner city roads and pathways, flooding has increased, and groundwater resources have decreased. For these reasons, searches for more environmentally friendly and sustainable solutions have been started, and recently, permeable concrete roads have been widely used around the world such as United States, Japan, China, and many others (Zhong et al, 2018).

1.3 Aim of the Study

The aims of this research study are to examine the effects of CEMI and CEMII cement types on the mechanical properties and durability of pervious concretes. In the samples prepared for different cement types, cement will be used as the only variable, thus it is aimed to observe the effect of cement more clearly. To estimate the effect of cement types on permeable concrete types, the following experiments were performed on prepared samples:

- Hardened concrete tests (compression, splitting, modulus of elasticity, durability, heat resistance, water permeability, pulse velocity test and rebound hammer).
- Fresh concrete tests (slump, density, void content).
- Obtaining the load-deflection curves.

Through experiments conducted on samples created in laboratory conditions, the mechanical and physical properties of pervious concrete were examined and the most suitable cement type for concrete was analysed.

1.4 Structure of the Study

This research study is organized into five chapters. Chapter one introduces the main subject of the study, while chapter two provides a literature review of the pervious concrete Chapter three covers cost and time management for porous concrete pavements. In chapter four, the experimental work is detailed, including mix design, test methods, and selection of materials. Chapter five analyses and critically discusses the results, followed by the conclusions and recommendations based on the study findings.

Chapter 2

LITERATURE REVIEW

2.1 Pervious Concrete

A new method for regulating, managing, and treating stormwater runoff is pervious concrete, also known as no-fines, gap-graded, permeable, or increased porosity concrete. Pervious concrete may successfully absorb and store stormwater runoff when used in pavement applications, allowing the runoff to seep into the earth and replenish groundwater resources (Federal Highway Administration, 2008). Permeable concrete, which has been popular since the middle of the 19th century, has gained popularity today as a solution to the problems of rainwater accumulating on roads has begun to be found.

A unique variety of concrete with a highly interconnected pore structure is called pervious concrete (PC). Typically, a concrete's empty content is between 15% and 35%. The matrix's porous structure and interconnected pores allow water to flow through it effectively and can provide long-term drainage solutions (Ammar and Kabagire, 2014). The use of the PC in certain applications that require high permeability is very attractive. There is also a growing interest in PC on low-traffic roads, parking lots, driveways, and sidewalks (Ammar and Kabagire, 2014). PC can also be used for sustainable structures thanks to its high insulation performance and noise reduction property. The reduction of heat islands in the residential aeras is another attractive feature of the PC (Ammar and Kabagire, 2014). In terms of environmental performance, PC can also be used to filter contaminants such as chemicals and heavy metals within the permeable structure (Bury and Mawby, 2006; Crouch et al. 2006; Ammar and Kabagire, 2014).

Figure 2. 1: Pervious concrete cylinder showing water passing through (Obla, 2010).

PC mixtures with porosity and permeability values of 15% and 0.1 cm/s (0.04 in/s), respectively, have been shown to achieve functional properties (Andrew and Bradley, 2010; Ammar and Kabagire 2014).

2.1.1 Pore System Characteristics

2.1.1.1 Porosity

Porosity is a critical property of pervious concrete that directly affects its ability to allow water to pass through. Pervious concrete is designed with interconnected voids or pores that provide pathways for water to infiltrate into the underlying soil. The porosity of PC is typically higher compared to traditional concrete or impermeable concrete, allowing for higher permeability and water flow rate. The porosity of no fine concrete can vary depending on several factors, including the mixture proportions, aggregate gradation, and compaction. PC has a volume fraction of 15–30% porosity and a high number of pores with a size range of 2–8 mm. However, it is important to note that achieving an optimal porosity is crucial to ensure the desired performance of the pervious concrete in terms of water infiltration and structural integrity.

Research studies have been conducted to investigate the effects of porosity on the performance of pervious concrete. These studies analyse the relationship between porosity and important properties such as permeability, compressive strength, and durability. They aim to optimize the porosity to balance the hydraulic and mechanical properties of pervious concrete. Depending on compaction, void content, materials, and subbase infiltration rates, PC's permeability can vary from 81 to 730 L/min, with a typical rate of 120-320 L/min/m^2 (American Concrete Institute, 522-R10 2011).

The infiltration of in-situ pervious concrete is tested using the American Society for Testing and Materials ASTM C1701/M test technique based on a falling-head permeability (k) utilising Darcy's law. Figure 2.2 depicts a typical correlation between the permeability of PC and the void ratio (Sonebi et all, 2016; Bassuoni et all, 2010).

Nonlinear behaviour is attributed to the dependence of the infiltration rate on the percentage of gaps and their interconnectedness. The permeability of PC also depends on pore size distribution, pore roughness, and segmentation of the pore cavity (Neithalath et al, 2006; Sonebi et al, 2016).

The link between the cementitious paste and aggregate gives cured PC's strength. The cementitious concentration, w/b ratio, amount of compaction, aggregate gradation, and quality are only a few of the numerous variables influencing PC strength. Any PC mix design must strike a balance between strength and permeability in order to be optimised. It is widely acknowledged that the void ratio, paste strength, and aggregate strength all affect the compressive strength of PC (Tennis et al, 2004; Sonebi et al, 2016).

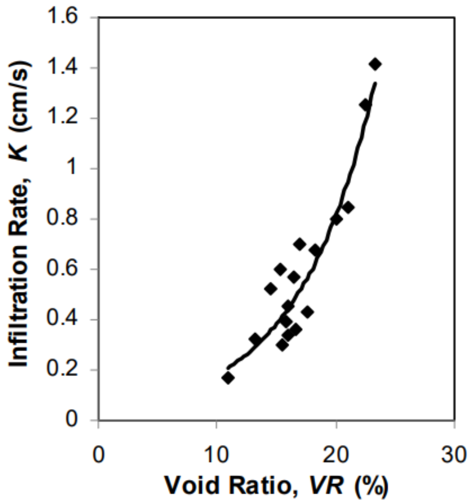

Figure 2. 2: Relationship between void ratio and infiltration rate of PC (Sonebi et all., 2016; Bassuoni et all. 2010).

It should be remembered that the void content will be impacted by the compaction effort and method. Due to the substantially increased volume of voids (15 to 35%), PC has a density that ranges from 1600 to 2000 kg/m^3 (Meininger et al, 1988; Sonebi et al, 2013), which is comparatively lower than that of regular concrete. Figure 2.3 (Bassuoni et al, 2010) depicts a typical connection between the fresh density of PC and the void ratio.

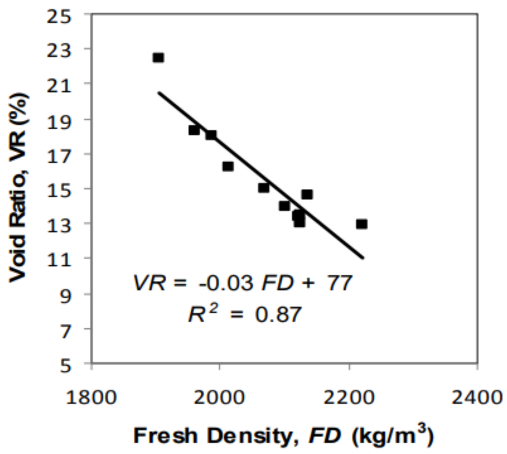

Figure 2. 3: Relationship between void ratio and fresh density of PC.

2.1.1.2 Effect of Porosity on Strength

Concrete's entire void volume has an impact on its strength. (Bury et al, 2006); Lian et al, 2011). From the nanoscale to the macroscale, pores may be found in the intricate microstructure of concrete (Lian et al, 2011). Lian et al. investigated the relationship between porosity and compressive strength in their study. They prepared three different mixtures for this study. The first group was created using simply cement, water, and coarse aggregate. As coarse aggregates, three grades of quartzite, limestone, and dolomite were employed (G_1: 13.2-4.75 mm, G_2: 9.5-6.7 mm, and G_3: 9.5 4.75 mm). The second set was created using additives including 7% silica fume, 0.8% superplasticizer, and some quarry sands by weight of cement as fine aggregate. For this second group, dolomite was employed as coarse aggregate. The water to cement ratio was steadily increased in this second group from 0.30 to 0.38. Samples with various strengths and porosities were produced in this manner.

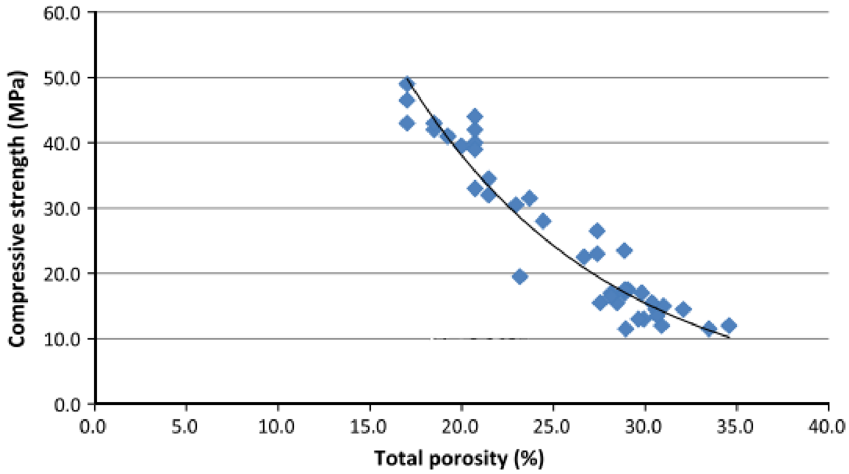

Figure 2. 4: Relationship between compressive strength and total porosity.

When figure 2.4 is examined, it can be observed that as porosity increases, the strength of concrete decreases. There are several factors that affect porosity, including water/cement ratio, type and properties of cement and aggregate used, admixtures, mixture density, mixing time, and mixing method. In this study by Lian at al., different types of aggregates (limestone, quartzite, and dolomite) were used, and the water/cement ratio was increased. This study clearly demonstrates the effect of aggregate type and water/cement ratio on the strength. The highest compressive strength was achieved with an approximate porosity rate of 17.5%. However, it is also evident that a porosity rate of 35% results in the lowest compressive strength.

Based on this study, it cannot be said that the strength is solely dependent on porosity and water/cement ratio.

2.1.1.3 A Relationship Between Porosity and The ITZ Line

There is indeed a relationship between porosity and the ITZ (Interfacial Transition Zone). High porosity generally increases the weak connections within the ITZ, negatively affecting the mechanical properties and durability of concrete. Therefore, it is important to take measures to reduce porosity and improve the quality of the ITZ.

Porosity refers to the quantity and size of voids within the concrete. These voids can lead to the formation of a higher amount of ITZ and less effective bonding between the cement matrix and aggregate particles. This can result in a reduction in the strength, hardness, and durability of concrete.

Hence, it is crucial to implement measures to decrease porosity and enhance the quality of the ITZ. Factors such as controlling the water-cement ratio, selecting appropriate aggregates, ensuring proper mixing and compaction processes, and utilizing additives with low water permeability can reduce porosity and improve the bonding quality within the ITZ. These measures can contribute to enhancing the mechanical properties and durability of concrete.

Composite materials are materials where at least two different components come together to form a new material. Concrete is a composite material formed by the combination of various materials. Concrete consists of aggregate particles (usually sand, gravel, stone) embedded in a cement matrix. The cement matrix is an adhesive that typically contains Portland cement, water, and sometimes additives. The aggregate particles are used to provide strength and volume to the concrete. These two components combine to form the composite structure of concrete.

The composite structure of concrete is characterized by the embedding of aggregate particles in the cement matrix and the cement matrix flowing between the aggregate particles. The aggregate particles provide compressive strength and rigidity to the concrete, while the cement matrix provides adhesion and cohesion between the aggregate particles. This composite structure determines the properties of concrete. Factors such as the size, distribution, and properties of aggregate particles, the composition of the cement matrix, water-cement ratio, and other additives influence the mechanical properties, durability, and performance of concrete.

Figure 2. 5: Cross-section of PC, illustrating porous structure.

The Interfacial Transition Zone (ITZ) refers to the transition region between the aggregate particles and the cement matrix in concrete. This zone is an important factor that affects the mechanical properties of concrete. In the ITZ, the connection between the aggregate particles and the cement matrix is densified. It is an area where cement hydration occurs on the surfaces of the aggregate particles and chemical interactions take place. This transition zone between the aggregate particles and the cement matrix is a region where the cement matrix does not fully penetrate the aggregate particles and establish complete bonding. The ITZ is a result of weak bonding and incomplete chemical interactions between the aggregate particles and the cement matrix. These weak bonds can lead to the formation of cracks, voids, and permeable areas along the ITZ line. The weak bonds and cracks can reduce resistance to stresses and adversely affect the durability of concrete.

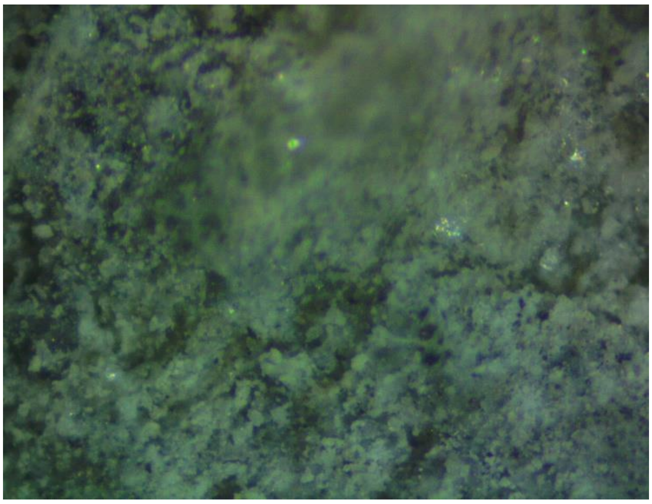

Figure 2. 6: Microstructure of concrete at 3 ages.

There can be some differences in the amount of ITZ (Interfacial Transition Zone) between pervious concrete and normal concrete. Generally, pervious concrete may have a higher amount of ITZ compared to normal concrete. Pervious concrete may have a higher water-cement ratio compared to normal concrete. The higher water-cement ratio allows the cement matrix to penetrate more between the aggregate particles and expands the ITZ region. This can increase the amount of ITZ. The higher amount of ITZ in pervious concrete can increase the porosity of the concrete and enhance water permeability. More ITZ represents a region with weak bonding and incomplete chemical interactions between the aggregate particles and the cement matrix. These weak bonds and cracks can facilitate the penetration of water into the concrete. This explains why the strength of pervious concrete is generally lower than that of normal concrete.

2.1.2 Durability of Pervious Concrete

Permeable concrete is a construction material that has received increasing attention in recent years. This material is considered an environmentally friendly solution due to its high porosity and allowing water to pass through easily. However, the durability of permeable concrete is of great importance for its structural durability and long-term sustainability of its performance.

Durability of permeable concrete is affected by various factors. The first is the correct design and application of the concrete mix. Factors such as the type of aggregate used in permeable concrete, its size and distribution, cement content, water-cement ratio, additives and mixing time affect the durability of concrete. A good mix design can improve the properties of permeable concrete and increase its long-term performance.

2.1.2.1 Mixture Design and Proportioning

With the exception of fine aggregate, the same materials as traditional concrete is utilised to create permeable concrete. As a result, there is still a space between the aggregate's particles, which permits water to pass through as intended.

Many studies have been carried out on what would be the most suitable mix design for permeable concrete. These studies are summarized in Table 2.1.

When conducting a mixture design, the desired permeability is taken into consideration. Generally, pervious concretes require a structure with 15-35% void content. The choice of aggregate type and shape plays a key role in establishing an appropriate void system in hardened concrete. Typically, larger-sized aggregates with a rounded or open structure are preferred. Aggregate size and distribution favor the formation of open voids that influence permeability. The Specification for Pervious Concrete Pavement (ACI 522.1-13) limits the smallest aggregate size used in concrete to not exceed 1 inch (2.54 cm).

The cement content and water-cement ratio are important for achieving the desired strength and performance. A low water-cement ratio provides higher strength and reduces the formation of cracks. However, an appropriate water-cement ratio should be chosen to ensure sufficient workability. Additionally, the selection of additives in pervious concrete mixtures is crucial as they can significantly impact the properties of the mixture.

Table 2. 1: Mixture proportions of PC.

References	Year	Cement (kg/m^3)	Aggregates (kg/m^3)	W/C ratio	Agg./C ratio	Water (W) (kg/m^3)
Yahia & Kabagire	2014	195-535	1500-1700	0.30	-	-
Joshaghani et al.	2015	421.05	1672.28	0.34	3.97	147.35
Khankhaje et al.	2016	340	1460	0.32	-	109
Chandrappa et al.	2016	321-487	1373-1692	0.25-0.35	3.0-5.0	84-161
Taheri & Ramezanianpour	2021	350	1400	0.4	4.0	140
Yu et al.	2021	1591	119.3	0.25	0.08	397.8

An example of the effect of additives is the environmental factor of freezing and thawing, which directly affects the performance of concrete in cold climates. When water freezes, it expands by approximately 9-10% in volume. This expansion occurs due to the hydrogen bonds between water molecules as they transition from a liquid to a solid state. As water molecules freeze and form a regular crystalline structure, they occupy more space and create voids between molecules, resulting in an increase in volume. This expansion characteristic can exacerbate the effects of freeze-thaw cycles and cause detrimental effects on concrete and other materials. To mitigate the effects of freezing and thawing in concrete, air-entraining admixtures can be used. However, the amount of additive to be added to the mixture is crucial. While the additive can have a positive effect on the performance of concrete, it can also have a negative effect on the compressive strength of concrete. There is a relationship between the compressive strength of a given concrete and its air content. For each 1% increase in air content, there is a decrease in strength of 5.5%.

The mixing process, casting, and curing process are also important factors that affect the concrete mixture. When making a pervious concrete mixture, an appropriate mixing process should be used. The optimum mixing time should be able to ensure the homogeneous distribution of aggregate and cement particles. Having sufficient mixing time can affect the formation of the ITZ (Interfacial Transition Zone), which influences the durability and permeability of the concrete. The mixing conditions of concrete, such as ambient temperature, humidity, and distance between the batching plant and the pouring site, directly impact the materials and their properties used in the mixture.

ASTM C94 "Standard Specification for Ready-Mixed Concrete" provides information about the properties and requirements of concrete mixtures. The casting and curing process of pervious concrete mixture are also important. The casting process ensures that the concrete has sufficient density and proper placement of the filling material. Adequate moisture and temperature control during the curing process help achieve the desired strength of the concrete.

2.1.2.2 Applications

Because of the considerable risk of corrosion brought on by the open holes in its structure, PC is typically utilized without any reinforcing. Pervious paving for parking lots, rigid drainage layers beneath outdoor areas, greenhouse floors to prevent standing water, structural wall applications where better acoustic absorption characteristics are desired, base course for roads, surface course for parking lots, tennis courts, zoo areas, animal barns, swimming pool decks, beach structures, seawalls, embankment, etc. are some examples of PC applications (Lund et al, 2017).

PC is typically used as a pavement in areas with light traffic and parking lots. The placement of PC is crucial, and special procedures are implemented to ensure the desired performance is achieved. Due to the low amount of cementitious paste, the concrete should be placed and compacted quickly. However, the compaction effort/technique will affect the void content. The density of PC ranges from 1600 to 2000 kg/m^3, which is lower than that of normal concrete due to the significantly higher volume of voids (15% to 35%) (Meininger et al, 1988; Sonebi et al, 2013). The concrete mixture is placed on a properly prepared surface with adequate density and moisture. The placed concrete is confined around its edges. The surface of the quickly placed concrete should be levelled with a trowel. Precautions should be taken to prevent excessive evaporation or water loss, especially when pouring at high temperatures. The design of permeable concrete pavements is given in Figure 2.7. As can be seen in the figure, a permeable infrastructure should be applied under the top layer of permeable concrete that will allow water to pass through. Thus, the water flow is from the surface to the natural ground.

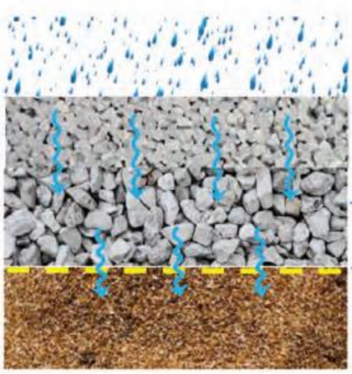

Figure 2. 7: Design of permeable concrete pavements.

Pervious Concrete Pavement, a specification outlined in ACI 522.1-13, provides guidelines and requirements for various aspects of pervious concrete pavement construction. It covers subbase preparation, setting formwork, batching, mixing, and delivery of materials, placing, and finishing of fixed-form pavements, as well as the curing process. The specification aims to ensure that proper procedures are followed to achieve the desired performance and functionality of pervious concrete pavements. The procedures to be considered while placing and finishing fixed-form pavement concrete according to the standard are mentioned below.

- Prior to placing the concrete, moisten the subgrade or subbase with water such that the material is saturated but there is no standing water on the ready subbase.
- Unless otherwise specified, deposit concrete either directly from the transportation equipment or via conveyor onto the subgrade or subbase.
- Do not pour concrete on a subgrade or subbase that is frozen.
- Place concrete between the shapes to a height that is roughly homogeneous.
- Without discrimination, the concrete can be spread using either hand or mechanical instruments.
- Use a vibrating screed, roller screed, or form-riding paving equipment to remove concrete from between forms.

The "Specification for Pervious Concrete Pavement (ACI 522.1-13)" states that mixing, mixing and dispersion should begin immediately with the addition of aggregates to the cement. It means that the casting must be completed within the first 60 minutes after the concrete mixing water or aggregates are added to the cement. It also states that this mixing should be performed in accordance with ASTM C94/C94. It emphasizes that when a hydration stabilizing admixture is used, the time for concrete pouring can be extended to 120 minutes instead of 60 minutes. Indicates that where additional water needs to be added to the concrete on site, the density of fresh concrete should be rechecked according to ASTM C1688.

Design, workmanship, and application processes directly affect the strength and durability of concrete. Therefore, it is crucial to follow the standards during the pre-application, application, and post-application stages.

In pervious concrete, immersion type vibration should not be performed. It is recommended to use lightweight hand rollers during the compaction of pervious concrete. This helps preserve the porous structure defined in the concrete design and ensures optimal performance. Additionally, compaction with a lightweight hand roller helps maintain the position of open voids and spaces within the concrete, allowing water to pass through freely and improving drainage efficiency. This, in turn, helps achieve the desired performance level of the concrete. Figures 2.8 and 2.9 show the concrete compaction and surface smoothing processes during the application.

Figure 2. 8: Placement and compaction of permeable concrete pavement (Uçar et al. 2018).

Figure 2. 9: Coatings of the concrete surface (Uçar et al. 2018).

2.1.2.3 Curing and Maintenance

According to the Specification for Pervious Concrete Pavement (ACI 522.1-13), after placing pervious concrete into the formwork, the curing process should begin within the first 20 minutes, and the surface should be protected against drying immediately after placement. For this protection, polyurethane sheets should be placed over the concrete surface. The curing process should last at least 7 days, and during this period, the road or pathway where the concrete pavement is located should not be opened to traffic. The curing stage can be roughly divided into two steps, which are covering the concrete surface with a vapor-retardant plastic sheet and applying special curing materials by spraying.

Specifiers Guide to Pervious Concrete Pavements in the Greater Kansas City Area (CPG, 2013), provides information about materials to be used for curing. These include:

1. Soybean oil: Construction-grade soybean oil is recommended for curing the pavement. It should be applied according to the manufacturer's recommendation.

2. Alternate surface cure: If soybean oil is not used, alternate curing compounds that conform to ASTM C309 can be used as a surface cure.
3. Internal curing options: The guide mentions two options for internal curing:
    a. Pre-wetted lightweight fine aggregates: These aggregates should comply with ASTM C1761 and be used for internal curing.
    b. Super absorbent polymer (SAP) material: SAP can be used for internal curing in pervious concrete, following the manufacturer's recommendations.

The cleanliness of pervious concrete is important for maintaining its permeability because the porous structure defined in the design of pervious concrete needs to be preserved. Deposits such as dirt, dust, leaves, and mud accumulated during rainfall from external sources can accumulate on the surface of pervious concrete over time and clog the pores. This hinders the passage of water through the concrete and reduces permeability. Additionally, clogged pores can impede effective drainage of rainwater and lead to water pooling. Through the process of cleaning, accumulated dirt, dust, and obstructive materials on the surface of pervious concrete are removed. This keeps the pores open and maintains water permeability. A clean surface allows rainwater to easily pass through and ensures effective drainage. As a result, the performance and water permeability of pervious concrete are preserved at maximum levels.

The routine maintenance of PC can be performed using standard street cleaning equipment that includes a vacuum to remove surface particles (Ferguson et al., 2015). Routine maintenance of PC can be carried out using standard street cleaning equipment that includes a vacuum to remove surface particles (17). In smaller installations, cleaning with pressurized water has been effective, but the width should be sufficient to prevent the released particles from clogging the pavement. Pressurized water is commonly used for permeability maintenance on walkways. Figure 2.10 illustrates routine maintenance of pervious concrete in Olathe, Kansas (Kevern, 2011).

Figure 2. 10: Typical pavement cleaning operations (Kevern, 2011).

2.2 Climate of Cyprus

Cyprus is an island situated in the eastern part of the Mediterranean, south of Turkey and north of Syria. Its geographical location has a significant impact on its climate and rainfall distribution (Michaelides at al, 1999).

The climate of Cyprus is generally classified as Mediterranean. This climate type is characterized by hot, dry summers and mild, rainy winters. Consequently, the island experiences varying amounts of rainfall depending on the seasons.

The winter month are typically when Cyprus receives the most rainfall. This period lasts from November to spring, and during this time, regular precipitation can be observed on the island. These rainfall events are often in the form of showers and occasional can be intense (Michaelides at al, 1999).

In contrast, the summer months usually have lower rainfall amounts, and the region becomes drier. During this period, rainfall is generally sparse and light. Cyprus tends to have hot and sunny weather in the summer.

However, factors like climate change can influence the amount of rainfall. Such changes can alter climate models and precipitation patterns in regions like Cyprus. Therefore, the rainfall amount and distribution in a specific year may be more indicative of long-term trends.

When considering the rainfall analyses from the Turkish Republic of Northern Cyprus (TRNC) Meteorology Department, the average rainfall amount for March 2023 was measured as 45.2 mm (http://kktcmeteor.org). This value is approximately 25% higher than the average values measured in 2022 and subsequent years. The main reason for this is climate change. Despite the observed increase in rainfall amounts, the Mediterranean region is among the most sensitive areas to climate change (Mariotti at al, 2008).

Table 2. 2: Comparison of precipitation values (http://kktcmeteor.org).

Comparison of average rainfall amounts			
	2023 March	2022 March	1991-2020
Total average rainfall amount (mm)	45.2	32.8	35.0

2.3 Water Sensitive City Planning

The sustainable development of urban areas must include effective water management (Schaffer at al, 2010). The scientific community is concerned about urban water-related issues on a global scale (Marlow et al, 2013). Water challenges currently include greater urban floods, over-exploitation of groundwater, urban water shortages, the waste of rainfall resources, and water pollution because of growing urbanisation and the extreme weather phenomena (Jia et al, 2015; Marlow et al, 2013).

Impermeable lands, such as pavement, concrete and compacted soil are reduced infiltration, increased runoff velocity, lack of natural water storage, altered hydrological cycle and increased peak flows. Impermeable surfaces do not allow rainwater to infiltrate into the ground effectively. Instead, they create a significant amount of runoff. When rainfall occurs on impermeable surfaces, the water quickly flows over the land and accumulates in nearby water bodies or stormwater systems. This increased volume of runoff can overwhelm drainage systems and cause flooding. Table 2.3 shows the amount of precipitation from 1975 to 2021 in Cyprus. As can be seen in Table 2.3, it is seen that precipitation generally occurs between December and May. Along with the rains, it is seen that serious floods have occurred in the cities that have recently developed rapidly in these months. The visuals of these floods are seen in figure 2.11. These floods, which are repeated every year, seriously affect the city life socially and financially. Structures such as houses, buildings and other infrastructural elements are damaged such as the collapse of walls, damage to foundations, agricultural lands or lands are depreciated due to soil erosion or land loss. Floods cause damage to infrastructure systems such as water, electricity, and telecommunication lines, bringing with them the necessity of these repairs and job loss. In addition to damage to buildings or infrastructure in the city, floods have many negative effects on human health. Loss of life or injuries may occur due to floods. This is a great moral loss for the communities as well as the financial losses.

These losses can be reduced through flood management strategies and measures. Preventive measures may include early warning systems, flood prediction models, regulations, infrastructure improvements and education. In this way, the impact of material and spiritual losses caused by floods can be minimized.

In the UK, several decentralised approaches that are typically referred to as "Sustainable Urban Drainage Systems" (SUDS) have been created and implemented. These approaches consider both the preservation of natural resources and future demands (Pratt, 1995). One way to address the issue of increasing urban runoff and deteriorated stream water quality brought on by car use is to use permeable pavement systems (PPS) (Brattebo and Booth, 2003).

Permeable concrete allows rainwater to be absorbed into the soil thanks to the cavities and openings in it. Figure 2.12 describes the pervious concrete working mechanism. This facilitates the natural seepage of precipitation underground and allows further sorption of water before it travels to streams in sudden high flows. This reduces the intensity and duration of floods. Another advantage of permeable concrete is that it controls erosion and keeps water from building up on the surface. Water naturally absorbs into the earth and penetrates the concrete.

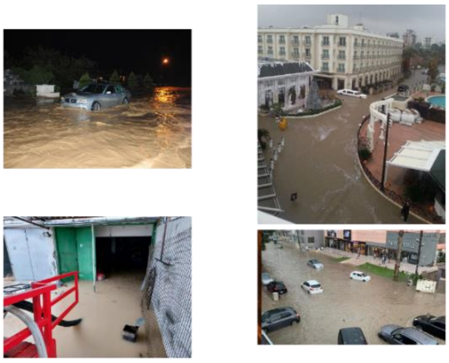

Figure 2. 11: Flood view from cities.

Due to the soil and infill materials in permeable concrete being in contact with the water, this water absorption prevents soil erosion while also purifying the water by filtering it. This preserves some of the contaminants in rainwater and raises the standard of the water.

In many developed countries of the world, permeable concrete is widely used on roads with light traffic load, on sidewalks, in garden garage entrances. Goede and others conducted research on two collector streets that had been in use in the United States for 20 years. Both streets were built using no fine concrete and were subject to equivalent traffic pressures.

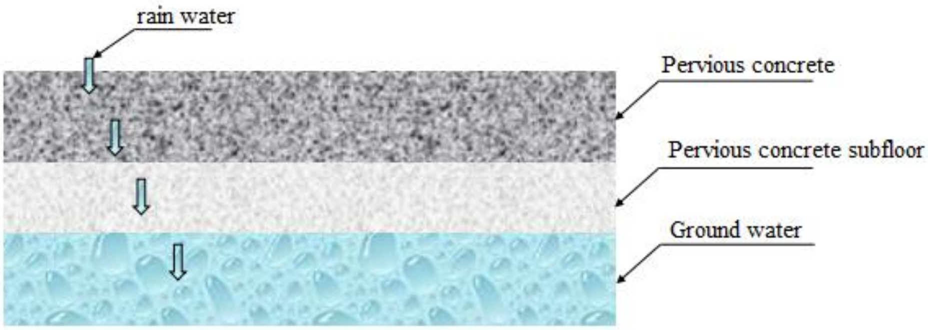

Figure 2. 12: Permeable concrete design and groundwater flow diagram (Tokgoz et al., 2022).

As a result of these investigations, it has been shown that the design service life (20–30 years) of properly designed permeable concrete can be suitable for most residential streets and many collector streets while maintaining its satisfactory structural performance (Zhong et al, 2018; Goede and Haselbach 2012). In Japan, Pervious concrete is frequently used in surface course of roadway (Kajio et al, 1998; Zhong et al, 2018). According to the present strategy, pervious pavement systems will replace all existing pavements in Japan since they increase driving comfort and safety (Nakahara et a,; Zhong et al, 2018).

The most preferred solution for converting an existing concrete pavement to a pervious system is thin bonded pervious concrete overlays. Pervious concrete beats porous. asphalt in laboratory simulation trials for wear resistance to tyre chains and is rutting resistant. China is a country prone to floods due to its geographical location and climate characteristics. The monsoon climate prevails in the southern regions of China.

Table 2. 3: Amount of rainfall from the meteorology office of TRNC.

AMOUNT OF RAINFALL (mm)														
Year	September	October	November	December	January	February	March	April	May	June	July	August	Totalrainfall (yearly)	Averagerainfall (yearly)
1975	0	0.5	38.8	100.4	35.8	40.9	44	63.5	34.1	0	0	3.4	361.4	30.1
1976	22.5	56.6	69.5	92.4	62.8	7.9	42.8	26.2	0	0	1.5	0	382.2	31.9
1977	4.4	2.7	2.9	95.6	102.2	26.3	22	6.8	0	0	0	0	262.9	21.9
1978	0	21.2	6.7	151.3	40.3	39.6	41.5	2.1	12.6	2.7	0	0	318	26.5
1979	5.9	16.8	36.9	127.1	26.9	108.2	33.2	12.8	42.2	0	0	0	410	34.2
1980	1.3	6.7	7	46.4	119.8	57	37.8	7.2	12.3	45.2	0	0	340.7	28.4
1981	0	1.8	66	31.6	30.8	48.1	22.7	17.1	6.4	0.2	0	0	224.7	18.7
1982	2.1	19.7	22.2	27	55	41.2	48.7	18.7	5.8	9.2	0	0.2	249.8	20.8
1983	1.6	10.9	58	23.1	51.7	41.3	50.4	62.7	1.8	0	2.2	3.3	307	25.6
1984	0	0.7	158.7	70.4	46.4	19.4	24.9	13	0	3.4	0	0	336.9	28.1
1985	0.3	24.8	28.4	85.3	34.9	72.2	6.3	4.2	74.4	5.1	0	0	335.9	28.0
1986	0.2	43.2	34	59	23.1	11.6	125.2	33.9	9.7	0.3	0	0	340.2	28.4
1987	0	69.9	10.3	166	83.4	95.3	85.8	7.4	6.8	9.8	0	2.1	536.8	44.7
1988	0.2	33.3	54	89.9	77.5	22	35.9	0	12.1	5.4	0	0	330.3	27.5
1989	0	43	33.4	29.8	20.2	139	29.3	10.6	0.9	0	0	6.4	312.6	26.1
1990	0	4.1	12.8	9.2	71.1	72	45.9	10.8	1.8	0	0	0	227.7	19.0
1991	0	8.6	102.9	277.2	14	53.1	18.8	2.7	44.6	13.4	12.4	0.2	547.9	45.7
1992	0	3.8	61.5	125	66.8	52.3	53.2	7.9	43.5	25.2	0	0	439.2	36.6
1993	0	0	57.2	10.4	106.1	50.8	55	24.5	3.4	2.8	0	6	316.2	26.4
1994	0.5	29	103.6	52.4	17.7	12	7.8	19.3	18.4	0	8	0	268.7	22.4
1995	0	5.8	36.1	5	109	28.8	45.1	19.3	0.3	0	0	0	249.4	20.8
1996	0.8	34.3	41	39.5	11.1	26.5	31.6	38.6	1.7	0.7	0	4.4	230.2	19.2
1997	33.2	28.7	40.4	63.6	43.8	2.9	34.6	14	34.3	0	0	0	295.5	24.6
1998	0.4	0	16.8	85.8	59.2	32.2	20.1	20.7	2.9	10.2	0	5.8	254.1	21.2
1999	17.8	14.8	9.3	23.3	24.7	30.2	44.1	72.2	11.8	0	0	0	248.2	20.7
2000	16.7	38.4	95.6	109.5	45.5	30.6	4.1	14.9	11	0	0	0	366.3	30.5
2001	1.4	9.4	36.5	180.4	84.5	26.5	20.5	50.9	24.7	0	0	0	434.8	36.2
2002	16.6	15.2	26.9	114.5	39.2	58.3	80.8	37	0.4	13.6	0	0	402.5	33.5
2003	0	4.4	7.1	93	259.7	72.3	0.4	8.9	3.7	7.4	0	0	456.9	38.1
2004	0	13.3	74	104.1	97.2	20.4	13	20.2	0	31.7	0	0	373.9	31.2
2005	6.1	4.9	95.6	6.7	99.9	44.5	23.3	12.7	1.3	0	23.1	0	318.1	26.5
2006	6.5	32.8	28.5	16.4	20.4	188	27.5	33.3	56.6	0.4	0	0	410.4	34.2
2007	0	1.6	20.5	59.1	27.2	18.8	8.4	7.3	19.1	0	0	0	162	13.5
2008	13.1	12.9	20.5	45.1	52.4	50.5	43.1	18.8	4.2	0	0	0	260.6	21.7
2009	27.2	12.4	28.8	153.8	69.6	125.4	0.4	9.7	3	3.3	0	0	433.6	36.1
2010	0.3	12	0	50.3	88.8	37.7	45.7	27.2	12.3	5.6	0	0.2	280.1	23.3
2011	28.9	16	80.4	65.5	149.4	59.1	20	8.3	83.4	0.9	1.9	0	513.8	42.8
2012	0	41.6	50.2	111.5	41.3	31.3	3.4	21.6	43.5	0	0	0	344.4	28.7
2013	8.2	4	0.6	45.4	14.3	15	24.6	12.9	38.3	5.8	0.1	0	169.2	14.1
2014	0.1	66.4	28.7	65.8	20.1	10.9	20.5	25.1	32.8	15.1	0	0	285.5	23.8
2015	2.1	66	5.2	54.5	92.9	64	49	9.7	10.6	10.6	1	0	365.6	30.5
2016	1.2	10	36.8	102.3	30.4	8.3	22.3	23.6	16	2	0	0	252.9	21.1
2017	1.1	38.8	90.8	8.1	34	0.7	31.4	9.9	40.8	0.1	0	0	255.7	21.3
2018	10.1	87	30.8	104.1	73.5	18.4	13.7	0.9	10.6	0.9	0	0	350	29.2
2019	1.3	19.8	8.3	195.2	82.6	153	41	67.7	0.2	5.3	0	0.6	575	47.9
2020	0	0	89.6	25.5	105.1	52.9	10.1	7.6	2.3	1.1	0	0	294.2	24.5
2021	13.3	9.6	9.2	85.4	24.2	7	27.7	4.8	0	0	0	0	181.2	15.1

In summer, heavy rains and strong monsoon winds occur. These monsoons can cause rivers to overflow and floods. According to the information shared by Euro news agency, two hundred thousand people were affected in the flood that occurred in Helan province of China in 2021, and many people lost their lives and their homes in the flood disaster that occurred in the Chinese province of Qinghai the following year (https://tr.euronews.com). China, which started to take measures for floods, launched a nationwide initiative called "Sponge City" in 2012.

It is an integration of a set of proprietary stormwater management technologies aimed at reducing stormwater runoff at its source (Wang et al. 2017; Zhong et al. 2018). Permeable concrete has been used as a surface layer for urban pavement applications and highway pavement for the development of the Sponge City (Chen et al. 2010; Zhong et al. 2018).

Figure 2. 13: Flood disaster in central China's Henan province (https://tr.euronews.com).

Chapter 3

CONRETE PAVEMENTS

3.1 History of Concrete Pavements

The Great Wall of China, the Roman Pantheon, and the Egyptian Pyramids are among the first structures to use concrete-like pozzolanic binding materials, but it wasn't until the 19th century that cement was discovered, and the first reinforced concrete structures were built. The first historical instances of concrete roads may be found in the Roman roads constructed in the first century BC using stones and pozzolanic binders. However, the 19th century saw the first efforts at concrete roadways in the modern sense. The oldest concrete road in America was constructed in Ohio in 1891, and it is still in use today (Ağar et. al, 2002).

The Ohio city council allowed for the paving of a short stretch of a roadway (2.5 m wide strip) in 1891 as a test of a novel idea. The experimental concrete pavement worked well and produced a high-quality, long-lasting road that was free of mud and dust. The city council took a very cautious approach to its next move, assuming George Bartholomew would be willing to donate the concrete and deposit a $5,000 bond that guaranteed the pavement would last for 5 years. George Bartholomew was then allowed to pave the square around it. Sand, stone, and cement were dumped onto the square in a mound, and the concrete was mixed with hand-operated screw mixers before being compacted. No heavy machinery was used in the application process.

After one week of curing, the strength of the concrete was tested to be greater than 34.5 MPa (Snell et. al, 2002). Figure 3.1 shows an image showing the oldest concrete road in the United States still in use.

Figure 3. 1: Currently (and still in operation), the oldest concrete roadway in the United States (Snell et. al, 2002).

Figure 3.2 shows the commemoration with a historical statement commemorating seventy-five years of service. Today this post is available on Ohio. This pavement was revolutionary, and the 1893 Chicago International Exhibition won George Bartholomew the First Prize for Engineering Technology Advancement in Paving Materials. Today, this historic pavement is still open for light vehicle traffic (Snell et. al, 2002).

With the advancement of technology over time, concrete road construction has accelerated in line with technological developments such as the advancement of concrete production, transportation, and placement technology (concrete plants, trans mixers, concrete pumps, additives, etc.) In the United States alone (USA), 70,000 km of concrete roads were built between 1960 and 1970.

Figure 3. 2: A historical marker commemorating seventy-five years of service (Snell et. al, 2002).

These developments in the USA were followed by projects in Germany, Belgium, and Japan (Agar et. al, 2002). Table 3.1 shows the developments related to the construction and use of concrete pavements between the years B.C.1. YY and 1990.

Table 3. 1: History of concrete pavements (Agar et. al, 2002).

Years	Developments
B.C.1. YY	Roads built by the Romans using cement-like pozzolanic binders.
1865	First concrete road trials in Scotland.
1880	The first concrete roads started to be built in Australia.
1891	America's first road, which is still in use today, was built in Ohio.
1913	America's first concrete road was built in Arkansas.
1914	3.500 km of concrete road construction has been completed in America; "Roller Compacted Concrete" (RCC) began to be used in road construction.
1924	Concrete road construction program was started in France.
1930	Construction of a 4,000 km long concrete highway started in Germany. Concrete road construction started in other European countries, especially in Switzerland and Belgium.

1950	With the use of sliding formwork, the speed and quality of concrete road construction increased.
1960-1970	Concrete road construction in the USA and Canada began to intensify; 70,000 km of concrete roads were built in the USA.
1990	With the advances in concrete technology, new developments have been made in concrete road construction: The use of fiber in concrete, prestressing technology, and production of fluid-dry concrete have become common.

3.2 Permeable Pavement

With the increasing city population, the amount of impermeable coating in cities increases in direct proportion. With impermeable coatings used on roads, sidewalks and parking areas, permeable natural ground is restricted. Due to the restriction of the permeable ground with an impermeable layer, many negative effects such as floods, valuable land losses, etc. may occur for cities. In these days when the negative effects of global warming are seen in our world, using an impermeable coating makes it difficult for the soil to exchange heat and moisture with the air. This makes it difficulties and just the temperature and humidity of the Earth's surface, especially in big cities, and creates the hot island phenomenon.

Li et al. (2013) have done a series of studies on the effect of permeable and impermeable coatings on both the heat island and stormwater runoff. In this study, they found that permeable concrete pavements have the highest permeability. Even in this study, the water permeability of permeable concrete pavements (0.5 cm s^{-1}) is higher than the water permeability of permeable asphalt pavements (0.1 cm s^{-1}). Another striking result in this study is that the surface temperature seen in permeable layers under wet conditions is lower than in impermeable layers. The reason why the surface temperature of the impermeable layers is higher than the permeable layers is albedo or solar reflection. A main thermal property, albedo, is an indicator of a surface's solar reflective power and is unitless. It is measured on a scale from 0 to 1. As this value increases, it means that the reflectivity is very high. For example, the fact that a white surface has an albedo value of 100% means that it can reflect all the incoming sunlight, in other words, we can say that the coating showed excellent reflection. If we consider the opposite, a black coating surface also has a low albedo value. Figures 3.3 summary of the heat related part of the work done by Li et al. (2013). As shown, this research also included more reflecting pavements, such as concrete (C) and interlocking concrete pavers (A), in addition to the black asphalt materials (B). The remaining six test portions (A2, A3, B2, B3, C2, C3) have permeable pavement, whereas the three test sections (A1, B1, and C1) are impermeable pavement. This supports the explanations made about albedo in the previous paragraph.

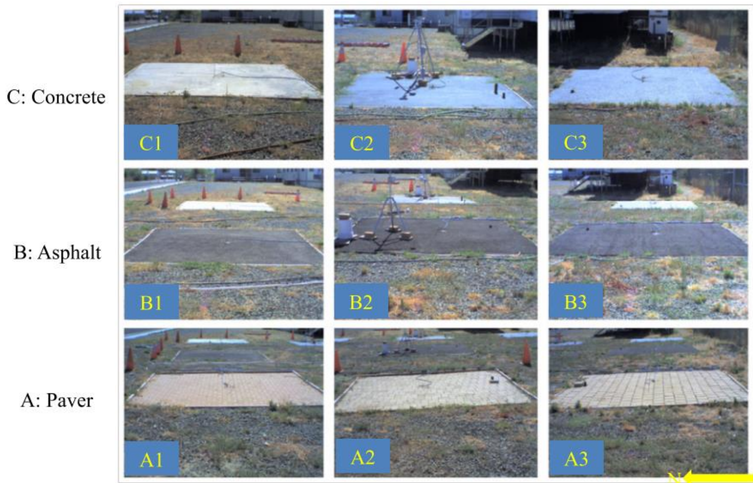

Figure 3. 3: Different type of pavements (Li et. al, 2013).

In fact, asphalt pavements showed higher temperatures not only compared to concrete but even paver pavements. When each type of coating is examined, the lowest surface temperature value was observed in impermeable coatings when dry, but the lowest albedo values were observed in impermeable coatings when considering the albedo or reflectance value.

This study demonstrates that utilising a permeable layer might potentially enhance air quality, eliminate near-surface heat islands, and increase rainwater permeability, as well as human thermal comfort.

The roads using permeable concrete or concrete pavement have many advantages besides heat island, permeability. In the next section, information about the advantages of concrete roads will be given.

3.2 Benefits of Concrete Pavements

PCs prevent rainwater from accumulating on the surface, allowing it to seep into the natural ground, thus having the ability to improve groundwater level water quality by acting as a filter. In addition, thanks to its ability to prevent water accumulation in the road, it reduces aquaplaning. Aquaplaning occurs when water accumulates in front of the vehicle tires at a faster rate than the weight of the vehicle can dissipate. Permeable concrete provides more frictional force than other flat and smooth pavement types. This provides greater slip resistance compared to other coating types.

These advantages might increase road safety on local transportation routes. Government organizations in many nations are advocating green infrastructure initiatives as a potential strategy to comply with water restrictions and standards, as was mentioned in earlier parts. PCs are viewed as a viable instrument in this context for integrating simulated natural processes (like infiltration) into the built environment.

In this section, the beneficial effects of permeable concrete on hydraulic performance, heat island effect, traffic noise and slip resistance will be explained.

3.2.1 Hydraulic Performance, Stormwater Runoff and Water Quality

The test method used to determine the hydraulic properties of permeable concrete significantly affects the hydraulic properties (Xie et al. 2019). Hydraulic conductivity or water permeability is a measure of its ability to allow water to pass through its porous matrix when subjected to a hydraulic gradient. Permeability tests can be determined in the field and in laboratory conditions by following a set of ASTM testing standards. The effect of porosity on the hydraulic performance of PC has come to light with the studies of the researchers both in the laboratory and in the field. As the use of permeable pavements in our environment increases, biodiversity increases, thus regional development is achieved and urban resilience against climate changes increases. The objectives defined in agriculture, forestry and environment can be achieved. The green infrastructure adopted in recent years, especially by large countries such as China, is based on a wide range of water and carbon management. Permeable concrete can be used as a long-lasting and environmentally beneficial tool for green cities in parks, gardens, roads with light vehicle traffic.

3.2.2 Heat-Island Effect Mitigation

PCP has recently emerged as a solution to the heat island problem, an environmental concern associated with the global urbanization trend (Santamouris, 2013; Liu and

Borst, 2018; Xie et al. 2019). Many research scientists have conducted studies comparing the surface temperatures of permeable concrete and an impermeable pavement under the same conditions and have come to the consensus that PCs exhibit relatively lower surface temperatures after irrigation than their impermeable counterparts. Haselbach et al. (2011), analysed heat storage events in various weather patterns using temperature data from a site in Lowa. As a result of these studies, the solar reflectance index (SRI) of PC was 14, while the SRI of conventional concrete pavement was 37 LEED (Leadership in Energy and Environmental Design) is a sustainable green building certification created by the US Green Building Council (USGBC). According to this certification program, a surface with an SRI value of not more than 29 can be considered as a cold surface.

As a result of increasing urbanization in urban areas, which is not compatible with the environment, the contact of water with the soil is cut off and this causes more surface water to evaporate and air temperatures to increase. Using permeable concrete for water and heat control in residential areas can be used as a method to raise groundwater levels and reduce heat islands. Haselbach et al. (2011), is evidence to show that permeable concrete is effective on preventing heat islands.

3.2.3 Traffic Noise Reduction

Transport noise can cause adverse health effects (i.e., general discomfort, slurred speech, and sleep disturbances). It could reduce PC traffic noise. In their laboratory study (2017), Chu et al. revealed that permeable concrete has better sound absorption than porous asphalt. The sound absorption of a permeable concrete pavement is determined by geometric and several other parameters, including the thickness of the porous layer, the size of the aggregates, air voids or porosity, airflow resistance per unit length, and curvature of the material (Arenas and Crocker, 2010).

3.2.4 Skid Resistance Improvement

Pavements made with permeable concrete have higher slip resistance than impermeable pavements (Xie et al. 2019). In their study, Noguyen et al. (2014) found that cement-based permeable concrete has a much higher slip resistance value than its impermeable counterpart. However, similar slip resistance was noted between permeable concrete and impermeable asphalt surfaces in slip resistance tests using a British pendulum tester (Xie et al. 2019). The main reasons for the higher skid resistance of permeable concrete are friction force and water permeability. Thanks to the concrete coating surface texture, it provides more friction than flat and smooth surfaces. The increase in this amount of friction can provide more grip on the walk or vehicle transitions. On the other hand, thanks to its waterproof feature, it also reduces the risk of slipping that may occur due to freezing because water does not accumulate on the surface and that water is not trapped in the concrete in cold climate conditions.

3.3 Cost Comparison

In this section, the initial construction costs and maintenance and repair costs of flexible pavements with asphalt pavement and rigid pavements with concrete pavement will be compared.

When making a cost comparison, first of all, it is necessary to consider the different elements between permeable concrete paved roads and asphalt roads. When applying permeable concrete road, more technical knowledge and expertise is required than asphalt concrete. The special mixture that gives permeability to the permeable concrete and the drainage system, which requires the system to continue in a healthy way, can lead to higher costs when applied correctly. In addition, the application of asphalt roads may lead to lower construction costs at first due to the customary application processes.

When the roads made with permeable concrete pavement are examined in terms of maintenance and repair costs, durability, and service life, it provides more advantages than the roads made with asphalt pavement. With these advantages, the cost increase that may occur in the initial construction cost can be compensated. Water accumulating on the roads may cause deterioration such as cracking, deterioration and erosion on the pavement surface. It is necessary to carry out maintenance and repair works at certain periods for these deteriorations, which are especially common in asphalt pavements. The most important feature of concrete pavements is their long service life and superior durability. Agar et. al., (2002), in a study in which he examined the highway performances in various states of the USA, the data in table 3.2 were obtained. As can be seen in Table 3.2, the service life of concrete roads (time to need repair) is around 20-25 years, while it is 6-14 years for asphalt roads. According to another source, the expected life of the concrete road is 34 years, and the expected life of asphalt roads is 17 years, half of the concrete road.

Figure 3.4 shows the foundation permeable concrete pavement system. As seen in the figure, it usually consists of a porous concrete top layer covering a gravel layer of uniformly sized aggregate placed on top of the existing soil sub-base, usually separated by a layer of Geotextile.

Table 3. 2: Comparison of road pavements in various US states in terms of service life (Service Life-Year) (Agar et. al., 2002).

Establishment-State	Concrete	Asphalt
Wisconsin	20-25	12-14
Minnesota	35	20
Kentucky	20	12
New York	20-25	10-13
Colorado	27	6-12
FHWA (1985)	13-30	6-20
FHWA (1971)	25	15

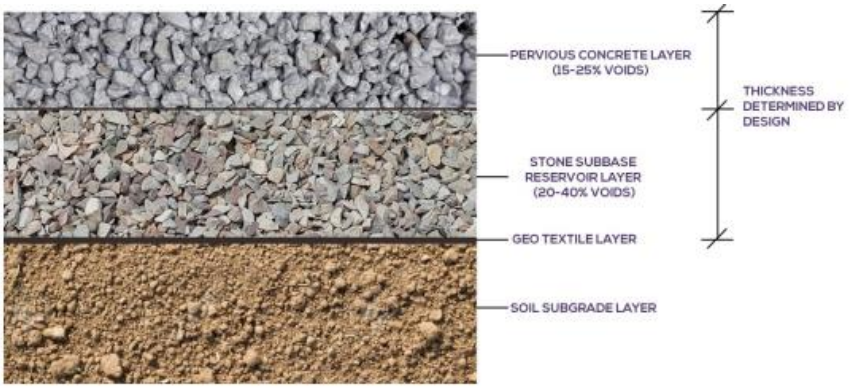

Figure 3. 4: Typical section of a pervious pavement (Ahmed, T., & Hoque, S. 2020).

There are many factors that affect the construction cost of roads. The main ones are pavement type and thickness, road length and width, ground conditions, topography (Excavation and filling costs) and traffic load.

Eastern Mediterranean University has an area of 780 million square meters on average, and approximately 105 thousand square meters of this area is the roads within the campus. In Table 3.3, the area and length information of the roads in the campus are given.

Table 3. 3:Length of the roads in the EMU campus.

Roads	Area (m^2)	Length (m)
Adnan Saygun Street	2,619.51	236.29
Albert Einstein Street	7,925.98	649.47
Aristoteles Street	3,318.91	325.00
Charles Darwin Street	28,141.30	1,964.29
Emu 3-4 Dormitory -I	1,384.70	142.35
Emu 3-4 Dormitory -II	2,795.32	276.00
Faculty Of Education Parking Area Service Road	683.50	107.13
Galileo Galilei Street	3,420.51	295.42
Ibn-I Sina Street	8,299.57	998.48
Jean -Jacques Rousseau Street	1,790.44	238.00
Leonardo Da Vinci Street	7,526.18	613.50
Ludwig Beethoven Street	3,819.40	334.94
Mimar Sinan Street	8,025.00	885.00
Pablo Picasso Street	5,579.63	473.17
Prime Living Dormitory -I	1,693.07	144.00
Prime Living Dormitory -II	1,336.24	145.79
Socrates Street	4,938.00	431.08
Vincent Van Gogh Street	5,507.61	441.84
William Shakespeare Street	2,032.11	161.98
Wolfgang Amadeus Mozart Street	3,781.83	2,490.09
Total	104,618.81	11,353.82

All the roads and car parks in the campus are made using asphalt. In Tables 3.4 and 3.5, area information about the parking spaces reserved for administrative buildings and faculties is given. These data were extracted using satellite images. Considering all these data, approximately 167000 square meters of area in the campus is reserved for vehicle transportation. Terhell et. al, (2015) took the costs in Table 3.6 as reference in their study on the costs of water permeable coatings. In this study, cost, and benefit analyses of different types of permeable coatings were conducted over a 25-year period to find the most cost-effective alternative.

Table 3. 4: Area Information About the Parking Spaces for Faculties of EMU.

Faculty	Area (m^2)
Communication Faculty	1,886.92
Electrical And Electronics Engineering	1,702.31
Faculty Of Architecture	6,826.40
Faculty Of Arts and Sciences, Graduate Education and Training Research Institute, Information Technology Directorate	3,370.41
Faculty Of Business and Economics and Central Lecture Halls	1,066.07
Faculty Of Civil Engineering, Faculty of Computer Engineering	3,387.23
Faculty Of Education	7,882.58
Faculty Of Fine Arts and Design	1,505.33
Faculty Of Health Sciences, Faculty of Pharmacy	11,658.51
Faculty Of Industrial Engineering	970.24
Faculty Of Medicine	2,732.34

Foreign Languages and English Preparatory School	3,442.96
Mechanical Engineering, Department of Fine Arts Education	1,469.48
School Of Computing and Technology	690.85
Tourism Faculty	789.56
Total	49,381.19

Table 3. 5: Area Information About the Parking Spaces for administrative buildings of EMU.

Administrative Buildings	Area (m^2)
Rector's Office, Registrar's Office, HR / Financial Affairs	5,131.97
Department Of Visual Arts and Visual Communication Design	1,282.89
Özay Oral Library	1,061.35
Social And Cultural Activities Center	2,900.78
Mika	1,468.43
Continuing Education Center	221.56
Lala Mustafa Pasha Sport Complex	875.26
Total	12,942.24

Table 3. 6: Permeable pavement cost (Ternell et. al, 2015).

2015 values			
Surface type	Limitations/Application	Material average Cost / ft^2	Average Life (years)
Porous Asphalt	low weight capacity	$1.11	17.5
Pervious Concrete	Small to large projects	$6.66	25
Concrete Pavers	Small to large projects	$11.10	25-30

Construction costs for three different (porous asphalt, pervious concrete and concrete pavers) pavements for the civil and computer engineering car park are given in Table 3.7.

Table 3. 7: Budget based on 2015 values.

Surface type	Material average cost / m^2	Design budget
Porous Asphalt	$12.33	$41,764.55
Pervious Concrete	$74	$250,655.02
Concrete Pavers	$123.33	$417,747.08

Considering the initial construction cost, if pervious concrete is used instead of porous asphalt concrete for the covering of the car park, it requires 6 times more budget, and about 10 times more for the use of concrete pavers. In this case, considering the initial construction costs, the use of pervious concrete or concrete pavers may seem disadvantageous. However, considering the benefits of permeable concrete and long repair periods, it shows that the use of pervious concrete can result in lower budgets than asphalt pavements.

Chapter 4

METHODOLOGY – EXPERIMENTAL STUDY

4.1 Introduction

In this section, information about laboratory test methods for this research will be given. The materials used in the test samples will be introduced and the test stages will be mentioned.

4.2 Materials

The following sections define the materials used in this experiment:

4.2.1 Cement

In this study, CEM II Portland slag 42.5N quality cement and CEMI 42.5R quality cement were used. The chemical compositions of both cement types are presented in Table 4.1.

Table 4. 1: Chemical compositions of cements.

Oxide Compound	CEM I	CEMII
SO3	27.11	25.65
CaO	15.20	13.56
Al2O3	6.18	7.52
Fe2O3	2.97	2.51
MgO	16.00	14.77
CaCO3	-	-
MgCO3	-	-

4.2.3 Mixing Water

Tap water, which does not contain harmful substances such as alkalis, acids, oils, was used in the mixtures of the samples prepared for use in the laboratory study. ASTM C1602/C1602M-22 provides information on the water quality to be used in concrete produced using hydraulic cement. According to this standard, the water to be used in the production of concrete must be potable. There should be no substance in the water that will change the colour and smell of the water.

4.2.4 Course and Fine Aggregate

Well graded crushed limestone from Beşparmak Mountains of TRNC with a diameter of 5 mm as fine aggregate and 14 mm diameter as coarse aggregate was used for the two mixtures prepared in the laboratory using different cement types. ASTM C33/C33M-18 is the standard that gives the requirements for aggregates to be used in concrete.

4.3 Trials

In all trials, samples were poured in 3 pieces of 150 mm cubed concrete for the compression compressive strength test and 3 pieces of 100mm PCV pipes for the determination of permeability. Compressive strength tests were carried out on the 7th day of each casting, and permeability tests were carried out on the 28^{th} day of each casting.

Cube samples were prepared by using 3 samples of 15 cm cube formworks for each mixture and these samples were subjected to a compressive strength test on the 7th day after the casting day. The compressive strengths of the samples prepared using the Mix1 mixture were found as 2.60 MPa, 3.26 MPa, and 3.41 MPa, respectively. With a prediction for this mix (Mix1), if the 7-day average concrete compressive strength is 3.09 MPa, the 28-day compressive strength can be expected to be approximately 4.5 MPa (if the 7-day compressive strength constitutes 70% of the 28-day compressive strength). This compressive strength is well below the expected target strength.

The 7-day compressive strengths of the concrete samples made using the Mix2 mixture calculation are 3.50 MPa, 5.48 MPa, and 5.67 MPa, respectively. The average compressive strength on the 7th day of the concrete samples created using the Mix2 mixture calculation is 4.88 MPa, and the estimated compressive strength on the 28th day is approximately 7 MPa. This compressive strength is also not sufficient for concrete roads.

Limestone aggregates with sizes 20mm, 14mm and 10mm were used in Mix1 and Mix2 mixture calculations. The reason for the low compressive strength of the concrete samples prepared with these mixtures may be the diameters of the triple aggregate sizes used. In the literature studies, using only 2 different size aggregates as coarse aggregate in permeable concrete and using fine aggregate up to 10% of the coarse aggregate amount have positive effects on the compressive strength.

As a result of the information given in the previous paragraph, Mix3, Mix4, Mix5 and Mix6 concrete mixtures were prepared. In these mixtures, 0.28 w/c ratio was used in Mix3 and Mix4, and 0.34 w/c ratio in Mix5 and Mix6. Only 10mm aggregates were used in Mix3, while 10mm and 5mm aggregates were used in Mix4. Only 14mm aggregates were used in Mix5, and 14mm and 5mm aggregates were used in Mix6.

Thus, it is desired to see the effect of fine aggregate on the compressive strength of permeable concrete.

Concrete samples prepared using the Mix3 mixture showed an average compressive strength of 6.84 MPa on the 7th day, and the compressive strength made with Mix 4 was found to be approximately 8.5 MPa. Considering the average compressive strengths, it is expected that the concrete samples prepared using Mix3 mixture will show a compressive strength of 9.5-10 MPa on the 28th day, while the concrete samples prepared using Mix4 mixture will exhibit a compressive strength of 12-12.5 MPa. However, both 28-day compressive strength is not sufficient for concrete roads.

The 7-day compressive strengths of the concrete samples prepared with Mix5 concrete mixture are 9.5 MPa, 10.21 MPa, and 10.80 MPa, respectively. Using these three values, the average compressive strength was calculated as 10.17 MPa. The compressive strengths of 3 cube concrete samples of 15 cm prepared with Mix 6 mixture are 15.4 MPa, 19.10 MPa and 19.70 MPa. The average compressive strength of the samples created using the Mix6 concrete mix calculation is 18.10 MPa.

During the trials, 18 concrete samples were prepared using 6 different mixture calculations, Mix1, Mix2, Mix3, Mix4, Mix5 and Mix6. For these samples, a 7-day compressive strength test was performed, and estimations were made regarding their 28-day compressive strength. The samples prepared with the Mix6 mixture calculation give the highest 7-day compressive strength.

Therefore, in the continuation of the laboratory studies, it was decided to use Mix6 as the mixture calculation of the samples to be prepared to be used in the fresh and hardened concrete tests to be carried out in order to examine the effects of two different cement types (CEMI and CEMII) on the mechanical and physical properties of concrete. The mixture amounts to be used in the main experiments are shown in Table 4.3. In the continuation of the study, using the mixtures given in Table 4.3, two same type samples were prepared for each type of test by using both CEMI and CEMII cements. For example, 3 cubes of 15 cm containing CEMI cement and 3 cubes of 15 cm containing CEMII cement were created for the 3-day compressive strength test.

Table 4. 2: Trial mix designs with CEMII (Portland composite) cement.

Type of concrete	Quantities (Per m^3)						
	CEMII cement (kg)	Water (kg)	w/c	Coarse Aggregate			
				20mm (kg)	14mm (kg)	10mm (kg)	5 mm (kg)
Mix 1	533	160	0.30	332,10	664,90	110,70	-
Mix 2	571	160	0.28	320,70	641,40	106,90	-
Mix 3	643	180	0.28	-	-	1177	-
Mix 4	643	180	0.28	-	-	1177	118
Mix 5	505	172	0.34	-	1323	-	-
Mix 6	505	172	0.34	-	1191	-	132

Table 4. 3: The mixture amounts to be used for the main experiments.

Type of concrete	Quantities (Per m^3)							
	Cement (kg)		Water (kg)	w/c	Coarse Aggregate			Fine Aggregate
	CEMI	CEMII			20 mm (kg)	14 mm (kg)	10 mm (kg)	5 mm (kg)
Mix A	505	-	172	0.34	-	1191	-	132
Mix B	-	505	172	0.34	-	1191	-	132

4.4 Casting and Curing

As can be seen in Table 4.4, 3 different types and 6 different sizes of sample casting were made for the mixtures prepared for both different cement types. Cube samples of 150 mm were used for the tests of compressive strength, load deformation, stress-strain, and energy absorption, splitting tensile strength, evaluation of durability of rock for erosion control using sodium sulphate or magnesium sulphate, ultrasound transition speed, and rebound hammer. Cylinder samples of 150x300 mm were used for the test of elasticity modulus. Cylindrical specimens of 105x150 mm were used to determine the water permeability and potential resistance to impact and abrasion of permeable concrete. Plate samples of 160x90x100 mm were used in the pavement skid resistance test to find the skid resistance of concrete. Samples of 10x10x10 mm were used to determine the resistance of concrete to heat.

Table 4. 4: Information about laboratory tests on specimens.

Laboratory Test	Standard	Type of specimens	Size of specimens (mm)	Number of specimens
Compressive strength *Load deformation* *Stress-strain* *Energy absorption*	ASTM C39	Cube	150	18
Modulus elasticity	-	Cylinder	150X300	8
Density, void ratio (HARDENED CONCRETE)	ASTM C 642-21	During the test, the sample pieces broken in the strength test will be used.	-	-
Slump	ASTM C143	-	-	-
Water permeability	-	Cylinder	105x150 (during the test 100 mm dia. pipe was used for formwork)	6
Splitting tensile strength	ASTM C496	Cube	150	6
Density and void content of FRESHLY MIXED pervious concrete	ASTM C1688	Cube	-	-
Evaluation of durability of pervious concrete using sodium sulphate	ASTM D5240	The samples used in the permeability test will be taken out of the mold and used.	-	-
Ultrasound transition speed	ASTM C597	Cube	150	Samples to be broken will be used before the strength test.
Rebound hammer	ASTM C805	Cube	150	Samples to be broken will be used before the strength test.
Pavement skid resistance test	ASTM E2340	Plate	160x90x100	2
Heat resistance	-	cube	100	20
Determining potential resistance to degradation of pervious concrete by impact and abrasion	ASTM C1747	Cylinder	105x150	6

Before casting, all formworks were cleaned of their existing dirt and all formworks were lubricated to prevent concrete from sticking to the mold during demoulding. After the samples were poured, they were kept in the curing chamber for 24 hours. During the pouring of the samples prepared for the CEMI cement type, the laboratory temperature was 29 C^{o} and the relative humidity was 29.2%. On another day, while the concrete mixture prepared for CEMII was transferred to the formworks, the ambient temperature was 30.4 C^{o} and the relative humidity was 51.7%. Figure 4.1 shows the cubic specimens after the casting.

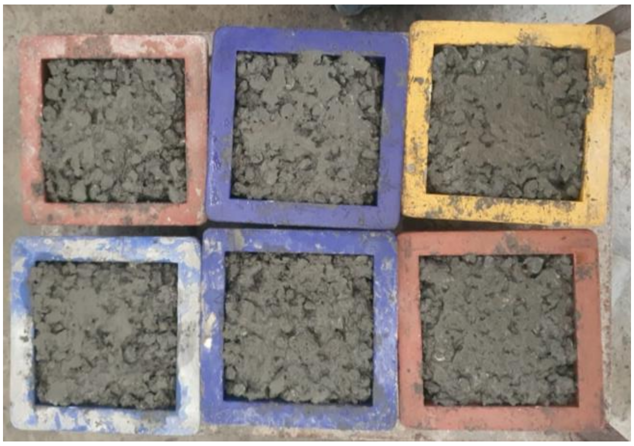

Figure 4. 1: Cubic specimens after the casting.

After both cement mixtures were transferred to the formworks, they were kept in the humidity chamber for 24 hours and then removed from the mold and placed in the curing pool. When MixA specimens were kept in the humidity room, the room temperature was 28.9 degrees, the humidity was 66.3%, and the humidity room temperature for MixB specimens was 30.6 and the humidity was 71.3%.

Figure 4. 2: Keeping the samples in the humidity room.

Figure 4.2 shows that the keeping the specimens in the humidity room. Thermo-hydrometer was used to determine the temperature and humidity of the environment. Figure 4.3 shows the device used in the measurements.

Figure 4. 3: Device were used to measure the temperature and humidity of the air.

4.5 Test of Fresh Concrete

4.5.1 Slump Flow Test

The consistency of fresh concrete is the measure of the fluidity gained by the concrete due to the water and chemical additives (such as plasticizers or superplasticizers) used in the concrete mix. Here, the consistency is not only dependent on water, but also the particle shape and granulometry of the aggregate used in the concrete. After the mixing process was completed in the mixer, the fresh concrete sample was compressed into a metal cone and then the cone was removed, and the sample collapsed. Figures 4.4 and Figure 4.5 show the steps of placing the sample in the cone, lifting the cone, and measuring the slump, respectively.

Figure 4. 4: Placing the sample in the cone.

Figure 4. 5: Testing concrete for slump.

4.5.2 Density and Void Content of Freshly Mixed Pervious Concrete

With this test method, it is aimed to determine the density and void content of fresh concrete. ASTM C1688/C1688-14a was adhered to throughout the test. Standard Procedure includes 2 different methods as A and B. The main information for both procedures is given below:

- For Procedure A, the Proctor hammer from a height of 305mm will be dropped vertically onto the sample 20 times for each layer.
- For Procedure B, the Marshall hammer from a height of 457 mm will be dropped vertically onto the sample 10 times for each layer.

The prepared fresh concrete mix is placed in 2 equal layers in a metal cylinder container of known volume (0.7±0.6 L), and reductions are made for each layer using the preferred procedure. During the laboratory experiments for the mixtures prepared for both different types of cement, procedure A was preferred, and a proctor hammer was used. Figure 4.6 shows the steel bowl and proctor hammer used during the experiment.

Figure 4. 6: The steel bowl and proctor hammer used during the experiment.

4.6 Test of Hardened Concrete

4.6.1 Density, Absorption, and Voids Tests

With the hydration reaction that starts with the interaction of water and cement, concrete begins to harden and gain strength. Density, absorption and void ratio determinations were made on the hardened concrete for the mixtures prepared for both different types of cement. The methods in ASTM C642-21 were considered in the experiments.

Determination of density, absorption and void ratio of hardened concrete is necessary to comment on properties of concrete such as durability, mechanical properties, structural performance, absorption and concrete quality.

3-day-old samples were used in the experiment. Firstly, compressive strength was determined on the specimens used, and then ASTM C642 procedures were started to be applied. According to the standard, the samples to be used during the test cannot be less than 350 cm^3 or 800g. Considering this restriction, the weights of the specimens used in the experiment are given in Table 4.5.

Table 4. 5: Weights of the specimens used in the experiments.

Type of Concrete	M1	M2	M3
MixA	3400 g	880 g	1379 g
MixB	1385 g	1989 g	1451 g

During the experiment, 4 different weights were determined as oven dry mass, saturated mass after immersion, saturated mass after boiling and immersed apparent mass.

During the determination of the dry mass in the oven, the specimens were dried for 24 hours in an oven at 110±5 °C and the weight was measured. After the weight measurement, a second drying process was carried out in a 110±5 °C oven and the weight was measured. Each time, the samples taken from the oven were allowed to cool down to 20-25 °C and weighed. Table 4.6 shows the oven dry weights obtained for both mixtures.

Table 4. 6: Oven dry weights obtained for both mixtures.

Type of Concrete	M1 (g)		M2 (g)		M3 (g)	
	First	Second	First	Second	First	Second
MixA	3223.6	3210.6	805.6	805.2	1283.4	1279.4
MixB	1385.0	1304.0	1989.0	1879.0	1451.0	1373.0

After the dry mass determination, the samples for the saturated mass were kept in water for 48 hours and the sample surfaces were dried using a damp cloth and weighed before measuring the weight. After the first weighing, the samples were kept in water for another 24 hours and a second weight measurement was made. Table 4.7 shows the saturated mass weights obtained for both mixtures.

Table 4. 7: Saturated mass weights obtained for both mixtures.

Type of Concrete	M1 (g)		M2 (g)		M3 (g)	
	After 48h	After 24h	After 48h	After 24h	After 48h	After 24h
MixA	3406.40	3409.0	857.8	858.2	1357.2	1358.0
MixB	1375.0	1378.0	1992.0	1993.0	1460.0	1462.0

Boiling was performed on the samples after the saturated mass was determined after immersion. Tap water was used during boiling. The samples were boiled in a container of tap water for 5 hours and allowed to cool with natural heat loss for at least 14 hours. In the same way, the surfaces were dried using a damp cloth before weight measurement. Table 4.8 shows the saturated mass after boiling weights obtained for both mixtures. Figure 4.7 shows the process of boiling the samples. After the weighing of the samples from the boiling process was completed, the immersed apparent mass was measured without any treatment on the samples. During the measurement, the samples were placed in a wire basket and suspended in water using a steel rope, and their apparent mass in the water was weighed. Table 4.9 shows the immersed apparent mass in water after boiling weights obtained for both mixtures.

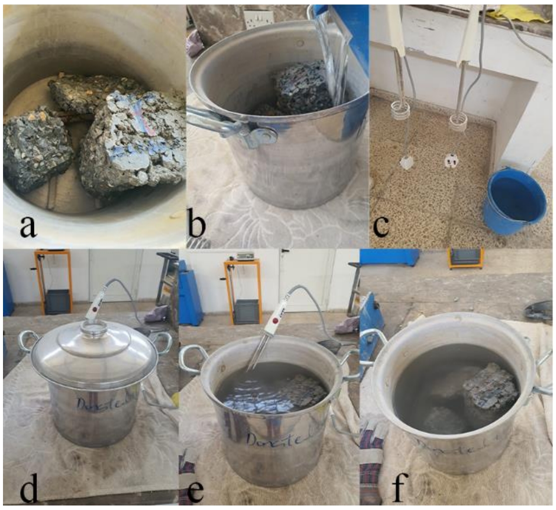

Figure 4. 7: Process of boiling the samples. (a)Placing the sample in the steel container. (b)Placing tap water in a steel container. (c)Resistances used in boiling water. (d)Boiling the sample the process of boiling water. (f)Allowing the sample to cool at room temperature.

Table 4. 8: Saturated mass after boiling weights obtained for both mixtures.

Type of Concrete	M1 (g)	M2 (g)	M3 (g)
MixA	3433.80	861.60	1367.20
MixB	1383.20	2006.80	1472.80

Table 4. 9: Immersed apparent mass in water after boiling weights obtained for both mixtures.

Type of Concrete	M1 (g)	M2 (g)	M3 (g)
MixA	2839.0	1326.20	1635.0
MixA	1633.20	1993.20	1680.80

4.6.2 Water Permeability

For PC, water permeability is a mandatory feature. There are many data in various literatures about what the water ratio should be. Generally, this void ratio between 15% and 30% as mentioned in Chapter 2 is sufficient for the water permeability of the permeable concrete. However, the interconnection of these gaps is one of the greatest conditions. There is a direct connection between the void ratio and the water permeability. For concrete, water permeability can be defined as how fast the concrete can drain water. The most important factor affecting this speed is the interconnected voids in the concrete. The shape of the cavities, their connections with each other, aggregate distribution, and compression of the concrete are other factors that will affect the water permeability of the permeable concrete.

An apparatus has been invented to detect the permeability of water in the laboratory environment. Mixtures prepared for both different types of cement were first poured into 100mm PVC pipes at a height of approximately 15 cm. Then they were cured in accordance with ASTM C192. The water permeability test was carried out on samples of 28 days. Water permeability measurement in Figure 4.8 The apparatus used is shown.


Figure 4. 8: Water permeability apparatus.

The 100mm pipe piece seen in this apparatus is removed, and the pipe piece in which concrete is poured is placed in its place, and then the fountain in the middle is opened and water is filled until the amount of water in the outlet unit and the inlet unit is equalized. The diagram of the apparatus created is shown in Figure 4.9. In the continuation of the experiment, as seen in the figure, water is started to be supplied to the system from the inlet on the right side of the apparatus. As soon as water starts to flow from the outlet unit on the left, the valve in the middle is closed and 1 L of water is poured into the apparatus.

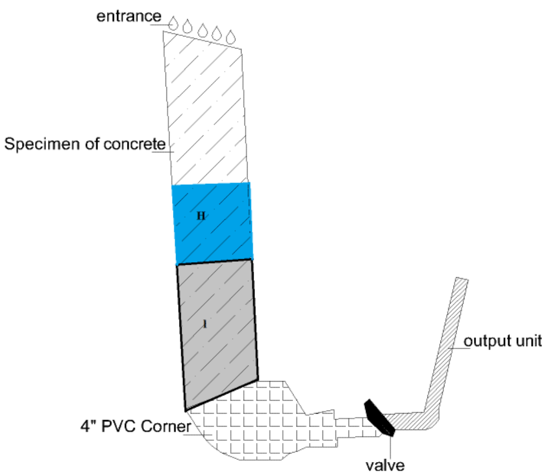

Figure 4. 9: The diagram of the water permeability test apparatus.

4.6.3 Ultrasound Transition Speed

With this test method, it is aimed to have an idea about the defects (cracks, air spaces, etc.) in the concrete by using ultrasonic sound waves. This test is a non-destructive test and can be applied to existing concretes with empty sides on both sides. The aim here is to have an idea about the internal structure of concrete.

An electro-acoustic transducer, which creates ultrasonic stress waves, is required to carry out the experiment. Ultrasonic stress waves are transferred to the concrete with the help of 2 sensors of the transducer. One of them gives the blows created by the waves to the concrete, and the other meets the waves. This is why it is very important that the sensors look at the same height and exactly opposite each other on the concrete surfaces during the test. Figure 4.10 shows the schematic of ultrasonic pulse velocity apparatus.

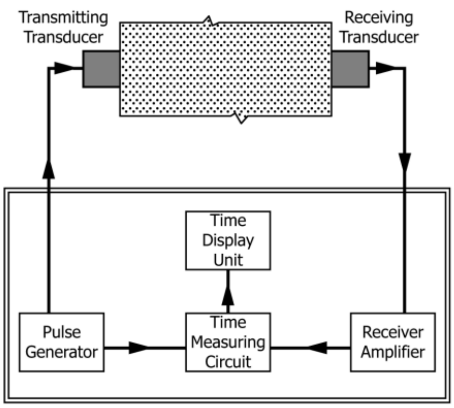

Figure 4. 10: Schematic of ultrasonic pulse velocity (PUNDIT) apparatus (ASTM C597).

The test apparatus, as seen in Figure 4.10, comprises of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measurement circuit, a time display unit, and connecting connections. The pulse velocity apparatus used during the experiments is shown in Figure 4.11.

Figure 4. 11: Pulse velocity (PUNDIT) apparatus.

With the Pundit test, it is possible to estimate the strength of the concrete. During the estimation, the strength of the concrete does not depend on the physical condition of the concrete.

4.6.4 Rebound Hammer Test

With this test method, predictions can be made about the hardened concrete strength. ASTM C805 was adhered to in the tests performed on the samples prepared for two different cement types. The main purpose here is to make hits using the rebound hammer on the hardened concrete surface and to determine the rebound number of each hit. Figure 4.12 shows the rebound hammer used during the experiment. Thanks to the rebound on the hammer, the number of recoils can be read.

Figure 4. 12: Rebound hammer apparatus used for the experiment.

It should be ensured that the sample is stable during the test. Because the metal part at the end of the hammer is in motion and by the movement of the piston in the hammer, it hits the concrete surface and kicks back. The distance this part recoils is measured and reported as a dimensionless recoil number in the test result.

During the experiments carried out in the laboratory, before the compressive strength test was carried out, 150 mm cube samples were compressed using a press (without applying any extra load) and hits were made on their surfaces with a rebound hammer. Due to the PC has the large number of voids on surface, large differences were often observed between the strokes made with the hammer. The reason for this is that voids and coarse aggregates can be seen quite clearly on the concrete surface, and the hits that correspond to the voids have low rebound and those that correspond to the voids have a high rebound number. Figure 4.13 shows the compression of the sample using the press and the hits made with the rebound hammer.

Figure 4. 13: The compression of the sample using the press and the test made with the rebound hammer.

This test gives ideas about the homogeneity of the concrete as well as its strength. During the rebound hammer test to be carried out on permeable concrete, the reading of far values for both structures (voids and aggregate) is due to the permeability property of the concrete.

Another major factor affecting the rebound number is the humidity of the test surface and the textural differences that the type of mold used will create on the surface to be tested. Care was taken to ensure that there was no deformation in the formworks used during the experiments and that their surfaces were smooth. In addition, the samples were kept in an open area in order to naturally remove the moisture on the surfaces of the samples removed from the curing pool on the test day, and then the experiments were started.

4.6.5 Pavement Skid Resistance Test

The skid resistance of the road surface is very important for the healthy conduct of vehicle and pedestrian traffic. Low skid resistance may cause vehicles to skid on the road in possible rainy weather conditions. This can result in accidents resulting in serious injury or death to people walking on sidewalks on the side of the road or at crosswalks inside the road or intersection.

The skip resistance of a coating material that has not yet been applied at any age or in a laboratory environment can be determined on existing spilled roads. The most common of these is the British pendulum experiment. In this study, a British pendulum device was used to determine the skid resistance of hardened concrete samples belonging to both different concrete mixtures. The device used during the experiment is shown in Figure 4.14.

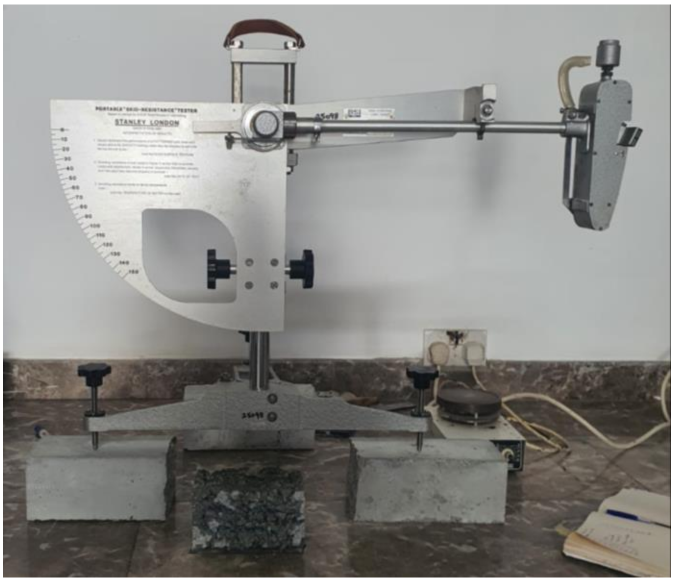

Figure 4. 14: British pendulum tester.

When the device is examined closely, it is seen that there are 3 legs that are used to adjust the desired height and the device is levelled. The pendulum mechanism, which gives its name to this device, is located on the front of the device and is connected to the device body with a locking and friction ring. Released using the release button, the pendulum creeps over the rubber coating on the arm and thus serves to simulate the movement of a car tire traveling on the road. There is a scale on the right side of the device. The amount of slip is measured with the drag pointer that moves with the pendulum. Figure 4.15 shows the sections described above on the device.

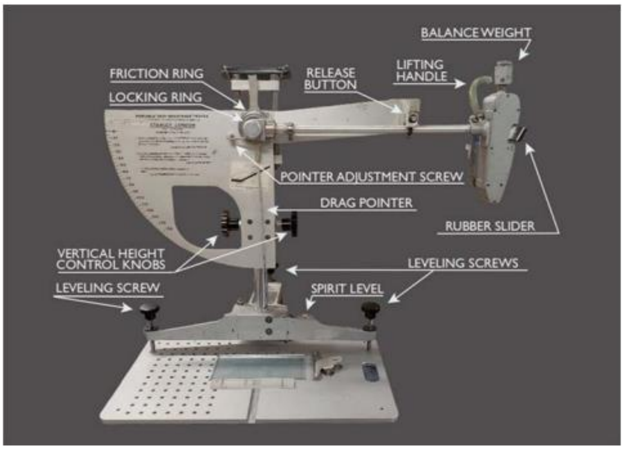

Figure 4. 15: Sections of British pendulum tester (ASTM E303).

According to the standard, the sample to be used in the laboratory should have a minimum size of 89x152 mm. 160x90x100 mm slabs were used to determine the shear resistance of concrete mixtures prepared for two different cement types. Skid resistance was measured on 28-day-old concretes when dry, wet and surface roughness were removed. It is aimed to obtain the weakest possible conditions by removing the surface roughness. In addition, the samples were kept under the sun for 3 hours and the effect of temperature on skid resistance was tried to be determined. Figure 4.16 shows the wetting of the samples and the removal of surface roughness.

Figure 4. 16: The wetting of samples and removal of surface roughness.

It is very important to note the ambient temperature as well as the slip resistance during the experiment. High or low temperature has serious effects on skid resistance. While the rubber coating will be able to grip more easily at high temperatures, there is a risk of freezing at low temperatures.

4.6.6 Determining Potential Resistance to Degradation of Pervious Concrete by Impact and Abrasion

Impact and abrasion resistance of concrete is a factor that extends the life of concrete. High impact and abrasion resistance can prevent surface defects that may occur on the road surface or pavements and minimize negative situations (such as accident or injury) that may occur for both vehicle and pedestrian traffic. The coatings used in areas with heavy vehicle traffic should have high abrasion and impact resistance so that the maintenance and repair costs in the following years can be lower.

ASTM C 1747/C1747M-13 standard is adhered to for the determination of abrasion and impact resistance in the laboratory. Cylindrical specimens of 105x150 mm were prepared for the experiment. During the experiments, 3 samples were used for each type of cement mixture. These samples were taken out in the curing pool on the 7th day, allowed to dry the surface and weighed. Figure 4.17 shows the pre-experiment weighing of samples. After weighing, the samples were placed in the Los Angeles machine and rotated 500 revolutions at a speed of 30 to 33 r/min. During the rotation, steel balls were not placed in the machine, and it was aimed to measure the concrete's own potential. After 500 rotations, all samples in the machine were emptied and sieved using a 25mm (1") sieve. Figure 4.18 shows the sieve used and the materials remaining on the sieve after sieving.

Figure 4. 17: The pre-experiment weighing of samples.


Figure 4. 18: Before and after placing the samples in the machine during the test and sieving.

The samples that were forced to rotate in the machine were sieved using a 25mm sieve taken from the machine, and the samples remaining on the sieve were also exposed to compressed air (to remove the fine material on it) and a second weighing was made. The materials remaining on the sieve after 500 rotations are shown in Figure 4.19.


Figure 4. 19: Specimens remaining on the sieve after 500 rotations.

4.6.7 Heat Resistance

In line with the use of concrete material in a vital place (industrial structures, high-grade railways or highways, etc.), it is very important that it can withstand high temperatures. The heat resistance of the concrete should be in a way that will facilitate the intervention of the fire in case of a possible fire. However, considering that the hydration reaction must continue in order for the concrete to gain its strength, the water required for the hydration reaction at a possible high temperature will evaporate away from the environment, the hydration reaction will stop, and the cement and aggregates in the concrete will undergo metamorphosis and the concrete will lose its existing strength.

In this study, the behavior of existing MixA and MixB samples under high temperatures was not investigated. For this, 10x10x10 cm cube samples were prepared and these samples were burned at 300, 600 and 900 degrees Celsius using a special furnace for 3 hours.

Pundit test was done and the weights were measured, the samples were made ready to be fired and 2 samples for each temperature were exposed to the same temperature at the same time. Figure 4.20 shows the firing of the samples.

Figure 4. 20: The heating process of the samples in oven.

After each sample was fired, it was waited to be cooled down and again the pundit test was performed and their weights were measured. Finally, they were subjected to the compressive strength test. Figure 4.21 shows the appearance of the MixA samples after firing, and Figure 4.22 shows the appearance of the MixB samples after firing.

Figure 4. 21: Apperence of the MixA samples after firing. "a" is under 300^{o}C, ". b" is under 600^{o}C, and "c" is under 900^{o}C.

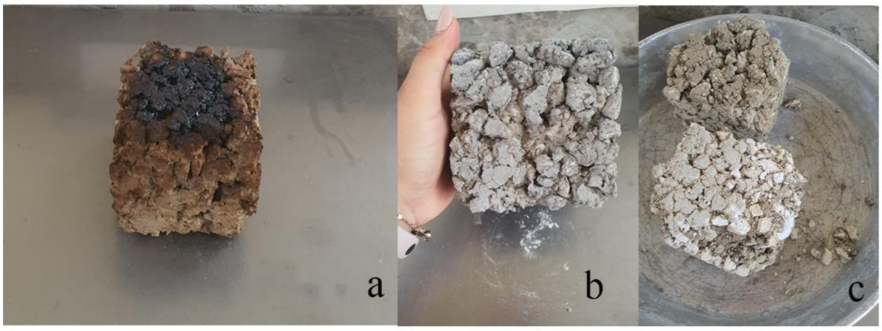

Figure 4. 22: Apperence of the MixB samples after firing. “a” is under 300^{o}C, “b” is under 600^{o}C, “c” is under 900^{o}C.

4.6.8 Evaluation Of Durability Of Pervious Concrete Using Sodium Sulphate

The durability of concrete has been a subject of interest for many researchers for a long time. The compatibility of the concrete with the environmental conditions in which it is applied is very important for the longevity of the concrete. For a concrete that does not lose its properties for many years, it can be assumed that its durability is high. Factors such as water permeability of concrete, exposure of concrete to high temperatures, resistance of concrete against chemical effects (sulfate effect) affect durability.

In this study, since the MixA and MixB specimens produced in the laboratory are intended to be used on roads with light traffic volume and on pedestrian pavements, the behavior of concretes under the influence of sodium sulfate was investigated. ASTM D5240 was used as a reference during the experiment. In the experiment, the samples prepared for the permeability test were removed from the PVC pipes after the test and 5x5x5 cm cubes were prepared. Thus, the resistance of the concrete sample, whose water permeability was measured, against chemicals was also measured. Sodium sulfate solution was used as attenuator during the experiment. While preparing the solution, 250 g of anhydrous sodium sulfate was used for each 1 liter of water. Figure 4.23 shows sodium sulfate in powder form and sodium sulfate solution.

Figure 4. 23: Sodium sulfate in powder form and sodium sulfate solution. a. sodium sulphate, b. sodium sulfate powder phase, c. sodium sulfate solution.

During the experiment, 3 cubic samples were prepared for each concrete type. The samples were kept in the solution for 16-18 hours, then removed from the solution, filtered for 15-20 minutes and dried in an oven at 110±5°C with 2 hour intervals. This cycle was repeated 5 times and at the end of the 5th iteration, the samples were washed with plenty of water, cleared of the solution, and dried in an oven at 110±5°C.

4.6.9 Compressive Strength, Load Deformation and Modulus of Elasticity Tests

The MPa unit is used to express the compressive strength of concrete. This unit expresses the load that the concrete can safely carry in mm^2. In this study, the compressive strength was determined on the 3rd, 7th, 14th and 28th days for both different types of hardened concrete mixes. 3 cube samples were used for each slaughter day. The average of these 3 cubes was taken for each day’s strength. ASTM C39 standard was used as a reference for compressive strengths. During the experiments, cube samples of 150 mm were used. A sensitive sensor was used to detect the load deformation in each sample breaking during the crimping.

During the compressive strength tests, sensitive sensors were used to have information about the load deformation curve and the modulus of elasticity. Cylindrical specimens of 150x300 mm were used for the determination of the modulus of elasticity, and cube specimens of 150 mm were used for the load deformation. Figure 4.24 shows the using sensor during the experiments.

Figure 4. 24: Using sensor during the experiments. a. Placed sensor for load deformation b. Placed sensor for elasticity modulus.

4.6.10 Splitting Tensile Strength Test

Splitting tensile strength tests were carried out to measure the resistance of concrete against cracking. During these experiments, cubes of 150 mm were used. For each type of concrete, 3 cubes were broken on the 28th day and their strengths were averaged. 4.25 shows the apparatus used during the experiment and the placement of the sample in the pressure machine.

Figure 4. 25: The apparatus used during the experiment and the placement of the sample in the pressure machine.

Chapter 5

RESULTS and DISCUSSION of RESULTS

In this section, the experimental results and the comparison of these experimental discussions will be included.

5.1 Tests of Fresh Concrete

5.1.1 Slump Flow Test

This test was carried out for concrete samples prepared for both different types of cement. Zero slump was measured for both mixtures. The reason why the slump cannot be measured can be shown as the low water/cement ratio of the concrete mixes. A dry or nearly dry mixture was obtained with the high cement content and low water content used in the mixtures.

It is not undesirable to achieve low slump in permeable concrete. Some concrete with a high fluidity can move under its own specific gravity and fill the voids necessary for permeability.

5.1.2 Density and Void Content of Freshly Mixed Pervious Concrete

Density and void ratio determination for fresh concrete was made in accordance with ASTM C1688. The values obtained at the end of the experiments are shown in table 5.1.

The equation given by ASTM C1688 for the determination of density and void ratio of fresh concrete is given in equation 5.1 and 5.2.

Equation 5.1:

$$D = \frac{M_c - M_m}{V_m} \tag{5.1}$$

Here;

D: Density

M_c: Total mass of steel cylinder bowl and concrete

M_m: Mass of steel cylinder bowl

V_m: Volume of steel cylinder bowl

Equation 5.2:

$$U = \frac{T - D}{T} \tag{5.2}$$

Here;

U: Void content

T: Theorical density

D: Calculated density.

For the mixtures prepared for both different cement types, the measurements made during the test and the density and void ratios calculated by considering the equations 5.1 and 5.2 are given in table 5.1.

Table 5. 1: Density and void ratio for both different concrete types.

Type of concrete	M_m (kg)	M_c (kg)	V_m (m^3)	U (%)	T (kg/m^3)	D (kg/m^3)
MixA	4.781 kg	20.778	0.007	14%	2000	2,285.28
MixB	4.781 kg	20.951	0.007	16%	2000	2,310.86

CEMI cement contains 30-35% more clinker than CEMII cement. In this case, more calcium silicate hydrate (C-S-H) gel is formed with the hydration reaction that occurs with the combination of cement and water. The resulting gel takes more volume in the concrete, and this can be seen as a small decrease in the void ratio.

The reason the fresh concrete MixB prepared with CEMII has a 2% higher void ratio may be due to the slag it contains. Cement reacts with water and forms different compounds because of this reaction. Pozzolans also react with the calcium silicate hydrate (C-S-H) gel formed because of this reaction. This reaction proceeds slower than the hydration rate of the cement, but it can provide benefits such as less carbon emission and more strength to the concrete in later ages.

5.2 Test of Hardened Concrete

5.2.1 Density, Absorption, and Voids Content Tests

ASTM C642 gives formulas for post-immersion absorption, immersion and post-boil absorption, bulk dry density, post-immersion bulk density, post-immersion and post-boiling bulk density, apparent density, and permeable void volume. Equations in the standard are shown from equations 5.3 to 5.9.

Equation 5.3: Absorption after immersion.

$$\% = \frac{B-A}{A} x100 \tag{5. 3}$$

Equation 5.4: Absorption after immersion and boiling.

$$\% = \frac{C-A}{A} x100 \tag{5. 4}$$

Equation 5.5: Bulk density, dry.

$$g_1 = \frac{A}{C-D'} x\rho \tag{5. 5}$$

Equation 5.6: Bulk density after immersion.

$$Bulk\ density\ after\ immersion = \frac{B}{C-D'} x\rho \qquad (5.6)$$

Equation 5.7: Bulk density after immersion and boiling.

$$Bulk\ density\ after\ immersion\ and\ boiling = \frac{C}{C-D'} x\rho \qquad (5.7)$$

Equation 5.8: Apparent density.

$$g_2 = \frac{A}{A-D'} x\rho \qquad (5.8)$$

Equation 5.9: Volume of permeable pore space (voids).

$$\% = \frac{g_2-g_1}{g2} x100 \qquad (5.9)$$

Here;

A: Mass of oven-dried sample in air, g

B: Mass of surface-dry sample in air after immersion, g

C: Mass of surface-dry sample in air after immersion and boiling, g

D': Apparent mass of sample in water after immersion and boiling, g

g_1: Bulk density, dry, Mg/m^3

g_2: Apparent density, Mg/m^3

ρ: Density of water = 1 Mg/m^3 = 1 g /cm^3.

Dry mass in the oven-dry (A), mass in air after immersion (B), mass in air after immersion and boiling (C), and apparent mass after immersion and boiling (D) measured as a result of experiments using concrete samples prepared for both different cement types it is shown in Table 5.2. While calculating the above weights, the average of the 3 sample values referenced for each mixture was taken. Absorption, density and void ratios calculated using the equations given on the previous page are shown in

Table 5.3. Test results of MixA concrete samples prepared using CEMI cement type and MixB concrete samples prepared using CEMII cement type showed close values. However, it is seen that the reason for the partially higher density observed in the MixB samples is the pozzolanic reaction that continues after the hydration reaction, and thus the concrete continues to gain strength.

Table 5. 2: Dry mass in the oven-dry (A), mass in air after immersion (B), mass in air after immersion and boiling (C), and apparent mass after immersion and boiling (D) measured as a result of experiments.

Type of concrete	Oven-dry mass, A (g)	Mass in air after immersion, B (g)	Mass in air after immersion and boiling, C (g)	Apparent mass in water after immersion and boiling, D (g)
MixA	1765.07	1766.33	1887.53	1063.81
MixB	1518.67	1520.67	1620.93	924.69

Table 5. 3: Absorption, density and voids content calculated using equations.

Type of concrete	Absorption after immersion (%)	Absorption after immersion and boiling (%)	Bulk density, dry (Mg/m^3)	Bulk density after immersion	Bulk density after immersion and boiling	Apparent density (Mg/m^3)	Volume of permeable pore space (voids, %)
MixA	0.07	6.94	2.14	2.14	2.29	2.52	14.87
MixB	0.13	6.73	2.18	2.18	2.33	2.56	14.69

On the other hand, 0.18% less permeable void ratio of MixB compared to MixA can show that the hydration reaction is completed and the pozzolanic reaction continues. As the reaction continues, the voids in the concrete decrease.

5.2.2 Water Permeability

As a result of the water permeability tests, the water permeability time of 1 L of the sample prepared with MixA is 18 seconds, and the water permeability time of 1 L of the sample prepared with MixB is 15 seconds.

The permeability can be expressed by Darcy's law. Darcy's law gives an equation related to the water transmission rate of permeable materials. This equation is shown in equation 5.10.

Equation 5.10:

$$Q = KxA'x\frac{H}{L} \tag{5. 10}$$

Here:

Q: Permeability rate (m^3/s)

K: Darcy coefficient (m/s)

A′: Concrete cross sectional area

H: Length of concrete (m)

L: Total height (m)

Before calculating the water permeability for concrete samples, it is necessary to calculate the Darcy coefficient. The equation (5.11) used to calculate the Darcy coefficient is shown below.

Equation 5.11:

$$K = \frac{l}{t}x\log_e(1+\frac{H}{l}) \tag{5. 11}$$

Here:

K: Darcy coefficient (m/s)

l: Height of water above concrete sample (m)

t: The time determined during the experiment (s).

According to Equation 5.10, the Darcy coefficient was calculated as 0.01856 for the MixB sample and 0.01546 for the MixA sample. As a result of all these, the permeability was calculated as 1.748x10^{-3} m^3/s for MixA sample and 2.099x10^{-3} m^3/s for MixB sample.

According to the tests carried out on the hardened concrete samples according to ASTM C642, the void amount obtained for the MixA was 14.87% and the void amount obtained for the MixB was 14.69%. As mentioned at the beginning of the experiment, the direct relationship between the permeability and the void ratio confirmed the water permeability test results. Thus, it can be said that the permeability system works in a healthy way in both concrete types.

5.2.3 Ultrasonic Pulse Velocity test

ASTM C597 states that the impact velocity value is related to the elastic properties and density of the concrete. This relationship can be explained by Equation 5.12.

Equation 5.12:

$$V = \sqrt{\frac{Ex(1-\mu)}{\rho x(1+\mu)x(1-2\mu)}} \qquad (5.\ 12)$$

Here:

V: Ultrasonic pulse velocity

E= dynamic modulus of elasticity

μ= dynamic Poisson’s ratio

ρ= density.

As seen in Equation 5.12, the velocity value of concrete depends on the dynamic elastic modulus, density and poisson’s ratio of the concrete.

Ultrasound transition speed experiments were carried out on the 3rd, 7th and 28th days for both different types of cement. The values measured during the experiments are shown in table 5.4. The ultrasonic velocity value is calculated in m/s and is calculated by dividing the distance between the two measured surfaces by the signal transmission speed in second. During the test, 150 mm cube specimens were used, and the same specimens were subjected to compressive strength test after the test. In the experiments, 3 specimens were used for each day. The ultrasonic pulse velocities calculated for each specimen are given in table 5.5. There is a relationship between the pulse velocity value obtained for concrete and the quality of concrete. This relationship is shown in table 5.6. Considering all the values considered after the test and the comparison in table 5.7, it can be said that the quality of all concretes is excellent (75%) in general.

Table 5. 4: Transit time values measured during the experiments.

Age	MixA			MixB		
	Sample-I (µs)	Sample-II (µs)	Sample-III (µs)	Sample-I (µs)	Sample-II (µs)	Sample-III (µs)
3 days	31.3	22.6	31.2	34.4	25.6	42.8
7 days	45.0	33.4	34.1	42.0	31.2	32.3
14 days	31.7	32.6	31.7	33.7	25.1	32.6
28 days	30.3	30.0	29.7	29.7	32.9	30.4

Table 5. 5: Ultrasonic pulse velocities calculated for each specimen.

	MixA			MixB		
	3 days			3 days		
Ultrasonic pulse velocity (km/s)	4.792	6.637	4.808	4.360	5.859	3.505
	7 days			7 days		
Ultrasonic pulse velocity (km/s)	3.333	4.491	4.399	3.571	4.808	4.644
	14 days			14 days		
Ultrasonic pulse velocity (km/s)	4.731	4.601	4.732	4.451	5.976	4.601
	28 days			28 days		
Ultrasonic pulse velocity (km/s)	4.950	5.000	5.050	5.050	4.559	4.934

These comparisons are shown in table 5.7. Based on all these, it can be assumed that the quality of the materials used in the mixtures is in accordance with the concrete production quality, the w/c ratio is optimum, the correct procedure is applied in the moisture room and curing pool after the concrete is placed in the formworks is sufficient. All these are factors affecting the quality of concrete.

Table 5. 6: Classification of concrete according to ultrasonic pulse velocity tests.

UPV (km/s)	Quality
>4.5	Excellent
3.5-4.5	Good
3.0-3.5	Not bad
<3.0	Bad

Table 5. 7: Quality of concretes.

	MixA			MixB		
	3 days			3 days		
situation	excellent	excellent	excellent	good	excellent	excellent
	7 days			7 days		
situation	not bad	good	good	good	excellent	excellent
	situation			14 days		
situation	excellent	excellent	excellent	good	excellent	excellent
	28 days			28 days		
situation	excellent	excellent	excellent	excellent	excellent	excellent

5.2.4 Rebound Hammer Test

On the 14th and 28th days, the rebound hammer test was performed on the cube samples prepared for both different mixtures, on only one of the 3 randomly selected samples. Tables 5.8 and 5.9 show the readings and the calculated rebound numbers during the experiments on the MixA and MixB specimens, respectively.

Table 5. 8: Readings and the rebound numbers for MixA specimens.

	MixA Readings										Rebound number
14 days	19	17	24	33	15	24	36	34	18	28	25
28 days	44	26	13	30	34	10	29	34	10	28	28

Table 5. 9: Readings and the rebound numbers for MixB specimens.

	MixB Readings										Rebound number
14 days	12	10	13	23	14	14	19	21	14	10	13
28 days	23	14	16	10	32	22	18	10	15	23	18

The readings taken at the end of the experiment are averaged to calculate the rebound number. With the readings between ±5 units of this average, a second average is calculated, and this second arithmetic average taken as the rebound number is assumed. For example, the rebound number was calculated in equations 5.13 and 5.14 for 14-day MixA specimens. For this, first the arithmetic average of all readings is taken.

Equation 5.13:

$$\sum n/n = \frac{19+17+24+33+15+24+36+34+18+28}{10} = 24.8 \quad (5.\ 13)$$

A second arithmetic mean is calculated over the values corresponding to the ±5 value of this found value.

$$\sum n/n = \frac{24+24+28}{3} = 25.33 \cong 25 \quad (5.\ 14)$$

In Figure 5.1, the graph showing the relationship between the cylinder concrete compressive strength and the rebound number is given. Concrete compressive strengths taken from this graph were found to be 14.58 MPa for the 14-day MixA sample, 18.45 MPa for the 28-day MixB sample, 10.12 MPa for the 14-day MixB sample and 14.01 MPa for the 28-day MixB sample. Considering the compressive strengths obtained for both concrete mixtures, the 14-day compressive strength of the concrete sample prepared with MixA mixture is 69% higher than MixB. When looking at the 28-day compressive strength, it is seen that this rate increases to 76%.

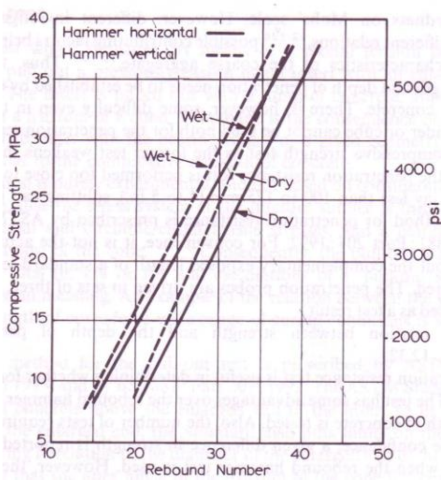

Figure 5. 1: Relationship between the cylinder concrete compressive strength and the rebound number (Neville, 2002).

The main principle of the rebound hammer test is to determine the compressive strength of the concrete based on its surface hardness. However, the voids and aggregates created on the surface to give the concrete its permeability feature directly and significantly affect the surface hardness.

According to ASTM C805, there should be a maximum of 12 units between readings taken on the hammer. However, it is quite difficult to read these values from a 150 mm permeable concrete cube sample. For this reason, an error rate was calculated for the experiment. This error rate was calculated as 55.34% for the 14-day, 41.92% for the 28-day MixA samples, and 17.62% for the 14-day and 12.17% for the 28-days MixB samples.

Considering these error rates, the estimated compressive strength for the 14-day MixA sample is 14.58 MPa, and the estimated compressive strength for the 28-day MixA sample is 18.45 MPa. Estimated compressive strengths of 14 and 28 days old MixB samples are 10.12 and 14.01 MPa. Estimated compressive strengths and compressive strengths after the compressive strength will be done under the heading of compressive strength test.

When the strengths obtained for both concretes are taken into account, it is not a coincidence that the strength gain of the samples containing CEMII type cement is lower than the samples containing CEMI cement. One of the main reasons for this can be explained as the higher clinker content of CEMI cement, and the quicker hydration reaction compared to CEMII and earlier strength gain.

5.2.5 Pavement Skid Resistance Test

Table 5.10 shows the skid values measured during the experiment. Graphs were created using the BPN values obtained under four conditions. Graphs were created using the BPN values obtained under four conditions. These generated graphs are shown in Figures 5.2, 5.3, 5.4 and 5.5. When the graphs are examined, it can be seen that MixA has high shear resistance under all conditions, which may be primarily due to the high amount of clinker in the MixA and earlier strength gain. The surface hardness of MixA is higher than that of MixB, which can cause a stronger friction between the rubber and the concrete surface. This can affect skid resistance.

Table 5. 10: The skid values measured during the experiment.

Readings (Room conditions)						Readings (After sun heating)					
	BPN values						BPN values				
MixA	82	81	82	83	83	MixA	80	79	76	78	75
MixB	76	71	75	79	72	MixB	73	75	74	72	72
Situation	Dry					Situation	Dry				
Temperature	33 °C					Temperature	45°C				
Readings (Room conditions)						Readings (After sun heating)					
	BPN values						BPN values				
MixA	74	75	73	72	71	MixA	63	67	74	79	80
MixB	66	69	65	68	71	MixB	65	67	66	69	70
Situation	Wet					Situation	Dry and removing surface roughness.				
Temperature	32°C					Temperature	45°C				

The error rate calculated according to ASTM E303 is 12%. The fact that this ratio is small indicates that the application of the test procedure in the laboratory environment was carried out in accordance with the standard. Again, as shown in figure 5.2, as a result of the experiments conducted on MixA and MixB samples at dry room temperature, it is seen that the 5 readings taken from the MixA sample are close to the average.

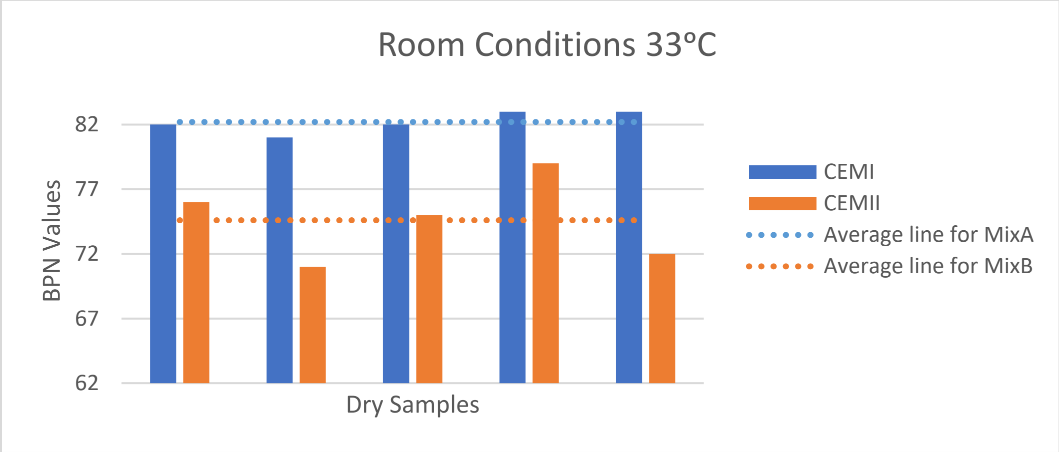

Figure 5. 2: BPN values in the room and dry conditions.

However, under the same condition, only 3 of the 5 readings taken from the MixB sample are average or above values, and the other 2 are below average values. The skid resistance of the MixA sample is higher than the samples tested at room temperature (33°C) and dry.

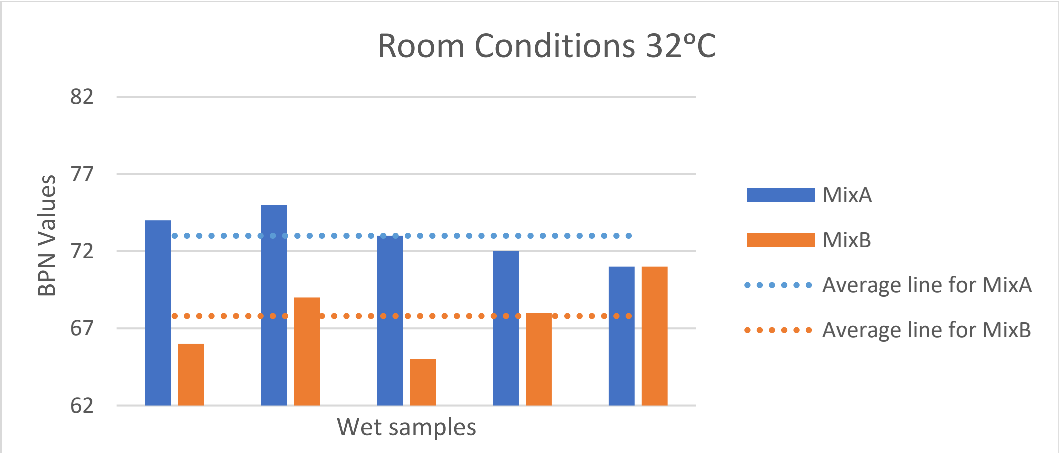

Figure 5. 3: BPN values in the room and wet conditions.

In accordance with the experiments conducted at room conditions and on samples whose surfaces are wetted, it is seen that 3 of the 5 readings taken from the MixA sample are close to or more than the average value, and 5 of the 5 readings taken from the MixB sample are again the same as the MixA sample, and 3 of the 5 readings are close to the average value or more. However, since the BPN values are lower for the MixB sample, it can be said that the skid resistance of the MixA sample is higher. As a result of the experiments carried out on samples with a dry surface under the sun and at higher temperatures, MixA and MixB samples exhibited almost the same behaviour. Looking at Figure 5.3, it can be seen that 3 of the 5 BPN readings taken from the MixA and MixB samples are close to or above the average value. However, as in the previous two conditions, the MixA sample shows higher skid resistance.

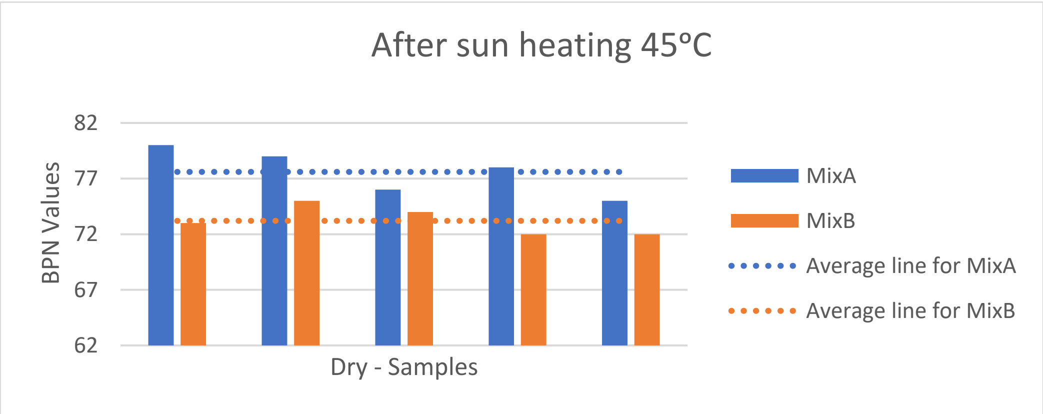

Figure 5. 4: BPN values under the sun and dry conditions.

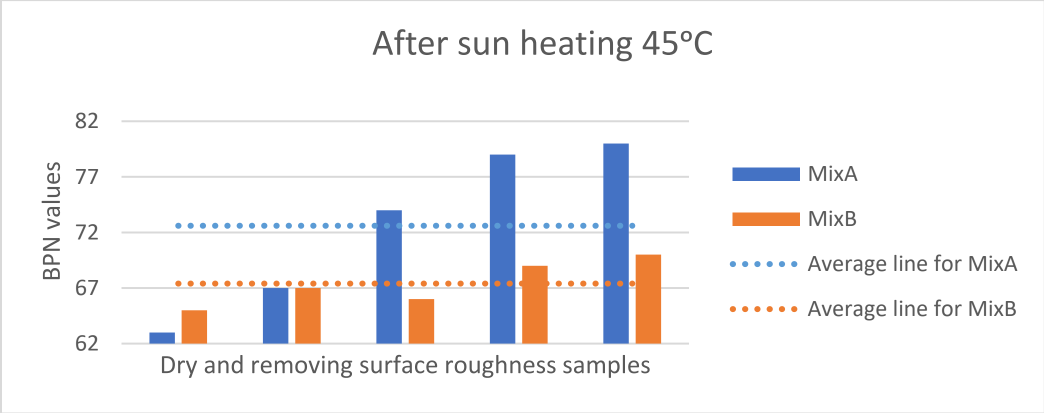

Figure 5. 5:BPN values under the sun, dry and removing surface roughness.

The BPN values obtained during the experiments carried out on the samples under the condition that the MixA and MixB samples were kept on a dry surface under the sun, in a dry state and where surface fluctuations were eliminated, are shown in Figure 5.5. Looking at Figure 5.5, it can be seen that this is the worst condition created for MixA and MixB samples. It can be seen in the figure that 3 out of 5 readings for the MixB sample are below the average value. However, 3 out of 5 readings for the MixA sample are above average. If a comparison is made for the samples exposed to these conditions, we can say that the MixA sample showed better behaviour than the MixB sample.

When the graphs are examined, it can be seen that MixA has high shear resistance under all conditions, the main reason for this may be the high amount of clinker in MixA and gaining strength earlier. The surface hardness of MixA is higher than MixB, which may cause stronger friction between the rubber and the concrete surface. This may affect skid resistance.

5.2.6 Determining Potential Resistance to Degradation of Pervious Concrete by Impact and Abrasion

The samples were measured as M1-3141g, M2-3131g and M3-3177g for MixA in the weighings made before they were put into the LosAngeles machine. These weights are M1-3193g, M2-3264g, M3-3113g for MixB. At the end of the experiment, 6500g samples remained on a 25mm sieve for MixA and 5522g samples for MixB.

At the end of the experiment, 6500g samples remained on a 25mm sieve for MixA and 5522g samples for MixB. The total mass loss was calculated as 31% for MixA and 58% for MixB samples. The reason for the lower mass loss seen for MixA sample may be due to the stronger and denser cement paste in the concrete compared to MixB sample.

5.2.7 Heat Resistance

The values obtained after combustion were compared by using the Pundit, weight determination and compressive strengths made before the experiment.

Pre-experiment weights and ultrasonic pulse velocity values of the samples are given in Table 5.11.

Table 5. 11: Pre-experiment weights and ultrasonic pulse velocity values of the samples.

	PUNDIT (µs)		MASS (g)		Temperature
	S1	S2	S1	S2	(°C)
MixA	20.5	19.7	2038	1991	300
MixB	14.1	13.8	1787	1669	
MixA	11.6	21.5	2157	2216	600
MixB	14.0	15.5	1691	1728	
MixA	20.0	20.4	2245	2178	900
MixB	20.9	21.8	1980	1766	

Aggregates of both samples are shown in Figure 5.6 before and after combustion. The reason why limestone metamorphoses into lime under high temperature is the decomposition of calcium carbonate ($CACO_3$) into carbon dioxide (CO_2) and calcium oxide (CaO) with heat. Here calcium oxide is lime. Ultrasonic velocity values, weight and compressive strengths obtained after the experiment are given Table 5.12.

Figure 5. 6: Deterioration of the aggregate after 3 hours of burning at 900 degrees. a. before firing. b. View of aggregate after firing for MixA. c. View of aggregate after firing for MixB.

In order to compare the data obtained at the end of the experiment, the same experiments were carried out on 2 control cubic samples of 100 mm dimensions. In these experiments, the average compressive strength of the control samples was measured as 32.29 MPa for MixA and 10.89 MPa for MixB. The average weight of control samples is 2010g for MixA and 1697g for MixB. The ultrasonic velocity value was measured as 3.300 for MixA and as 4.341 for MixB.

Table 5. 12: Ultrasonic velocity values, weight and compressive strengths obtained after the experiment.

	Pundit (μs)		Mass (g)		Compressive Strength (MPa)		Temperature (°C)
	S1	S2	S1	S2	S1	S2	
MixA	33.0	37.6	1916	1875	16.32	21.02	300
MixB	35.7	31.4	1562	1679	5.65	5.92	
MixA	72.1	75.6	1944	1983	12.32	4.03	600
MixB	99.1	97.5	1507	1561	*	*	
MixA	33.2	*	1728	1558	1.97	1.66	900
MixB	*	*	*	1545	*	*	

*unable to measure.

In order to compare the data obtained at the end of the experiment, the same experiments were carried out on 2 control samples of 10x10x10 cm dimensions. In these experiments, the average compressive strength of the control samples was measured as 32.29 MPa for MixA and 10.89 MPa for MixB. The average weight of control samples is 2010g for MixA and 1697g for MixB. The ultrasonic velocity value was measured as 3.300 for MixA and as 4.341 for MixB.

Considering the ultrasonic velocity value, compressive strength and mass loss of the samples exposed to high temperature, it may seem that MixA has the more resistance to temperature at 900 ^{o}C, but it can be said that MixB is weaker than MixA, since physical integrity cannot be observed in MixB under the same temperature.

5.2.8 Evaluation of Durability of Pervious Concrete Using Sodium Sulphate

Before starting the experiment, the existing samples were dried in an oven (110±5^{o}C) and put into the solution. Pre-test sample weights were measured as 187g for M1, 155g for M2 and 167g for M3 for MixA. For MixB samples, these values were measured as 162g for M1, 140g for M2 and 173g for M3. Table 5.13 shows the measured masses at the end of the cycles for both concrete types.

Table 5. 13: The measured masses at the end of the cycles for both concrete types.

	Mass of MixA samples (g)			Mass of MixB samples (g)		
	M1	M2	M3	M1	M2	M3
1st cycle	198/194	163/160	176/173	170/169	148/146	182/181
2nd cycle	198/197	164/162	176/175	172/171	149/148	184/183
3rd cycle	199/198	164/163	177/176	173/172	150/149	185/184
4th cycle	199/198	164/163	177/176	173/172	150/149	185/184
5th cycle	191	158	170	166	144	176

Note: a/b: Weight measured after 2 hours of drying / Weight measured after 4 hours of drying.

ASTM D5240 provides formulas for calculating loss of strength and average loss of strength after testing. These equations are shown in equations 5.15 and 5.16.

Equation 5.15:

$$\%soundness\ loss = \frac{a-b}{a} x100 \tag{5. 15}$$

Here:

a: oven-dried mass prior the testing

b: oven-dried mass of each specimens after testing

Equation 5.16:

$$\%average\ soundness\ loss = \frac{c-d}{d} x100 \tag{5. 16}$$

Here:

c: oven-dried cumulative mass prior to testing

d: oven-dried mass of all specimens after testing.

Calculation done between 2-6% for CEMI and CEMII concrete using the above equations. The average strength loss was calculated as 4% for CEMI concrete and 5% for CEMII concrete. When these results are compared with the ultrasonic velocity speed experiment, it is seen that the results of both experiments are a proof to each other.

5.2.9 Compressive Strength, Load Deformation and Modulus of Elasticity Tests

When the compressive strengths are examined for both concrete types, there does not appear to be a stable increase in strengths. The reason for this is the cavities in the concrete and the deformations that occur in the cross-section during mold removal. However, considering the strengths taken on the 28th day in general, the 28-day compressive strength of the concrete prepared using MixA is 31.77 MPa, while the 28-day compressive strength of the concrete prepared with MixB is 12.49 MPa. As a result of all these, it can be said that the concrete obtained by using the MixA mixture can be used on roads with heavy traffic volume according to RCCRTS, while the concrete obtained by using the MixB mixture can be used in areas with low and light vehicle volume, such as small number of parking lots and garden driveways. Table 5.14 shows the strength results of the compressive strength test.

Table 5. 14: Results of the compressive strength test.

Days	Compressive strength (MPa)	
	MixA	MixB
3 days	30.98	9.50
7 days	28.97	10.12
14 days	32.65	8.60
28 days	31.77	12.49

The estimated compressive strengths made by the rebound hammer test are 22.65 MPa for 14 days and 27.27 MPa for 28 days for MixA mixture. The 14-day average strength is 32.65 MPa and the 28-day compressive strength is 31.77 MPa. Likewise, the 14-day estimated compressive strength for MixB is 3.42 MPa and the 28-day estimated compressive strength is 12.33 MPa. The average compressive strength of 14 days was 8.60 MPa and the compressive strength of 28 days was 12.49 MPa for MixB concrete samples. Although hammer tests can be performed starting from the 14th day according to ASTM C805, it can be assumed that hammer tests for permeable concrete can give more realistic results on the 28th day. Figure 5.7 and 5.8 shows the compressive and rebound hammer strengths of MixA and MixB.

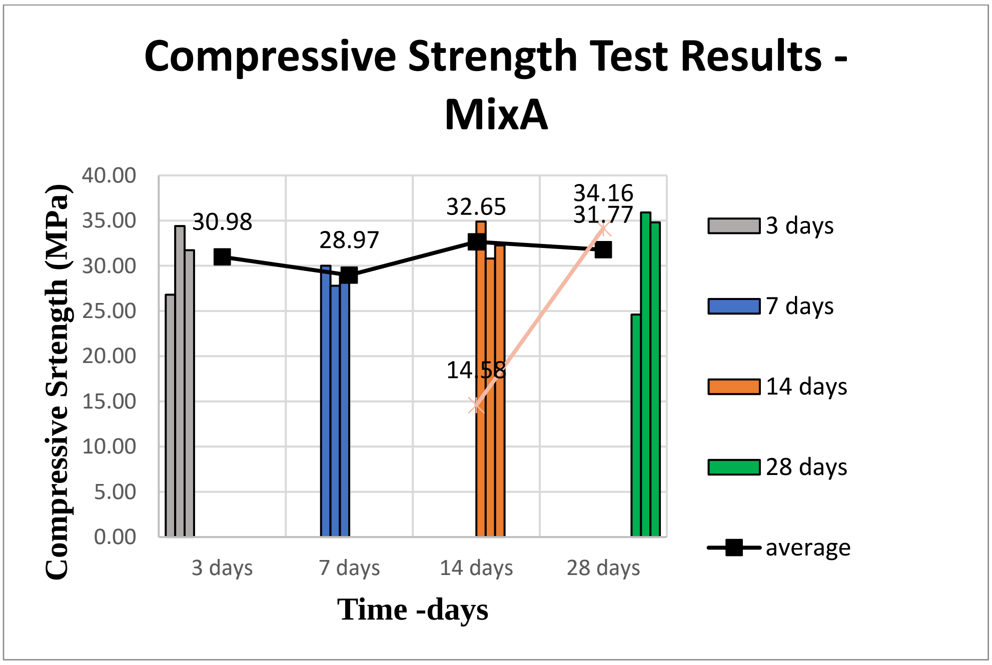

Figure 5. 7: Compressive strength and rebound hammer strengths of MixA.

As a result of the rebound test performed on the cube samples prepared for compressive strength, it is seen that the difference between the compressive strength and estimated compressive strength on the 14th day of MixA and MixB is greater than on the 28th day. The main reason for this is hydration and pozzolanic reaction. Pozzolanic materials enter a second reaction with the C-S-H gel formed by the interaction of clinker with water, and this reaction takes place more slowly than the hydration reaction. However, during the 28-day period, both reactions are balanced, and the proportional difference becomes less. Because of the 35% clinker in CEMI cement, it needs more space in the mixture for the reaction to continue. In other words, cement expands in volume during its reaction with water, and at the end of the 28^{th}

day, the reaction slows down due to the decrease in the micro voids in the concrete paste, which may cause both reactions to balance and the proportional difference to decrease during the 28-day period.

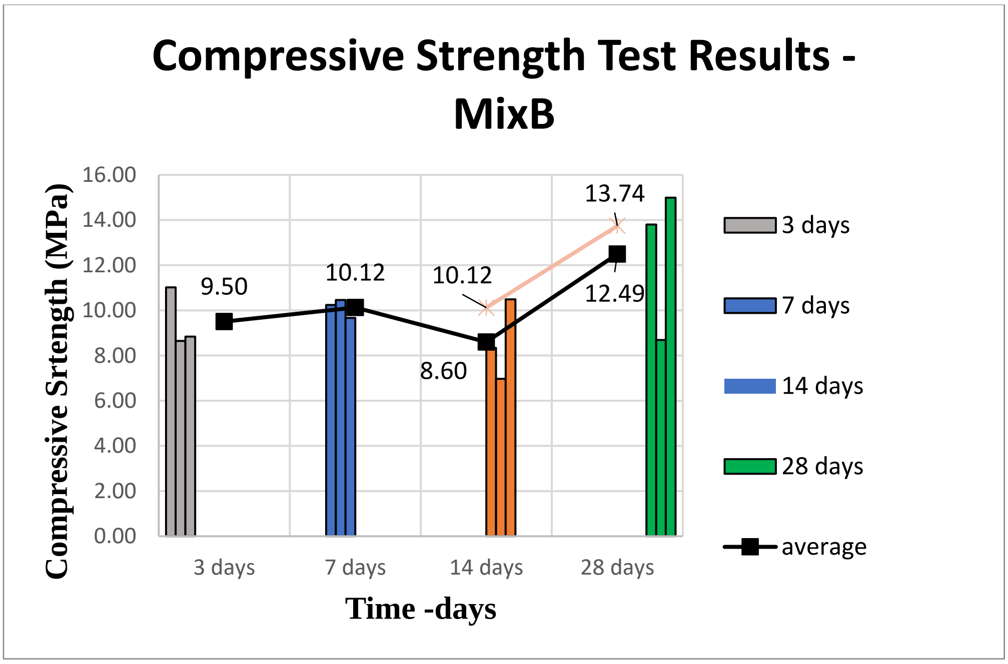

Figure 5. 8: Compressive strength and rebound hammer strengths of MixB.

However, this is not sufficient to detect the difference between the compressive strength of concrete samples of two different mixtures. For this reason, a core test was needed during laboratory studies. The amount of compaction of concrete seriously affects its compressive strength and water permeability.

Based on these results, the specimens used in the permeability test were removed from the PVC pipes after the permeability test, their lengths were equalised and capped with the help of a saw, and they were subjected to the compressive strength test, since there may be a difference in the compression of the specimens of both mixtures during their placement in the moulds and this compression ratio may directly affect the compressive strength. Thus, the compressive strength giving the current permeability has been determined. Prepared cylindrical samples are shown in Figure 5.9.

Figure 5. 9: Samples prepared for compressive strength after permeability test.

Concrete Society Technical Report No.11-Concrete Core Testing for Strength publications were used to calculate the compressive strength of these prepared samples, and a compressive strength was calculated considering the slenderness coefficient. As a result of all these, the average compressive strength was calculated as 34.40 MPa for MixA samples and 19.64 MPa for MixB samples. Here, the assumption is made that the cube strength is the real value. Considering the 28-day core and cube strength of the MixA concrete sample, the error rate is approximately -21.875%. The reason why this value is negative indicates that the core strength (estimated strength) is approximately 21.88% higher than the actual value. This rate is 57.2% for the 28-day MixB concrete sample.

Permeable concrete contains many interconnected or closed spaces. The amount and distribution of these voids can directly affect the compressive strength of concrete. This distribution is directly affected by the compaction of concrete. Samples of both mixtures were placed in the moulds in 2 layers and compressed by dropping the proctor hammer 5 times on each layer. Using a vibrating device to compress the samples may cause the voids in the concrete to be filled with fine and coarse aggregate and permeability may not be ensured. For this reason, compression with proctor hammer was preferred.

B.J. Putman and A.I. Neptune (2011) conducted a study in which they compared the methods of compaction of permeable concrete. In line with this study, they created pavement coverings of 400 m^2 and 1035 m^2 in Aiken and Augusta and took cylinder samples during concrete pouring in both regions. During casting, the cylindrical samples were compressed in the mold by using a proctor hammer, a 15.9 mm steel skewer, and by tamping and dropping from 50 mm. After these studies, when the plate-shaped samples taken from the road pavement cast in place were compared with the cylinder samples, it was noticed that the cylinder concrete samples compressed by bottling showed more differences compared to the cylinder concrete samples compressed using a proctor hammer. The reason for this difference was the holes formed in the concrete samples compressed with a skewer. As can be seen from this comprehensive study, the most accurate method for compacting concrete samples is the proctor hammer.

One of the main reasons for the compressive strength between MixA and MixB concrete samples may be the difference in the void structure formed in MixB samples during compression in MixA. As mentioned earlier, compaction is done using a rebound hammer. The weight of the proctor hammer varies between 2.5 kg and 4.5 kg.

Many factors can affect compaction, such as the height at which the hammer is dropped and the uneven distribution of impacts on the surface due to the irregularity of the surface during filling into the moulds. These two main reasons can reduce the cube compressive strength of MixB specimens.

Another important factor is the w/c ratio. CEMII cement contains 35% less clinker than CEMI cement and requires less water to react. As the w/c ratio increases in the mixture, the concrete strength decreases. The same amount of water and cement was used in MixA and MixB. The only difference between the two mixtures is that MixA is mixed using CEMI cement and MixB is mixed using CEMII cement. Due to these two main reasons, there may be great differences between the compressive strengths of both mixture samples.

Ahmed Ibrahim and others (2011) prepared 24 different mixtures in which Portland cement was used as a binder and compared the effects of the components forming the mixture on compressive and tensile strength and permeability. Here, the values taken for PC7 and PC8 samples are like the compressive strength results obtained during the thesis studies.

PC7 and PC8 mixtures have the same aggregate diameter and the same amount of cement and coarse aggregate. The only variable between mixtures is the w/c ratio. PC7 has a w/c ratio of 0.3 and PC8 has a w/c ratio of 0.4.

The 28-day compressive strengths for both mixtures are 1.79 MPa for PC7 and 3.92 MPa for PC8, respectively. When the compressive strengths obtained in this study by Ahmed Ibrahim et al. are compared, PC8 has 2.19 times more strength than PC7.

As a result of the discussions with the factory laboratory where the cement was supplied, it was learned that the CEMII cement type required less water to react than the CEMI cement type. During this thesis study, cement type was used as the only variable and the water-cement ratio was kept constant. During this thesis study, cement type was used as the only variable and the water-cement ratio was kept constant. Therefore, there are differences in the 28-day compressive strength of the cube samples of MixA and MixB mixtures. The 28th day average compressive strength of the MixA cube concrete sample is 31.77 MPa and the 28th day average compressive strength of the MixB cube concrete sample is 12.49 MPa. When the compressive strengths are compared, MixA has 2.54 times more strength than MixB.

Considering all these, it can be explained why the difference between the compressive strengths of the cube samples of both mixtures is so significant. As a result of the experiments carried out in the laboratory for the thesis study, concrete samples of MixA and MixB mixtures have density, void ratio and water permeability values close to each other. Likewise, in the study conducted by Ahmed Ibrahim et al., it is seen that the values obtained for PC7 and PC8 are quite close to each other. Table 5.15 shows water permeability, density, and compressive strength for Ahmed Ibrahim and others (2011) and our studies. According to all these results, the main reason why the MixB concrete sample is 2.59 times lower than MixA on the 28th day is that the MixB mixture requires less water than MixA since it was prepared with CEMII type cement. However, the same amount of water was used in both mixtures while preparing the samples.

Table 5. 15: Water permeability, density, and compressive strength for Ahmed Ibrahim and others (2011) and our studies.

Type of concrete	Density (kg/m^3)	Permeability	Compressive strength (MPa)
MixA	2,285.28	0.0017	31.77
MixB	2,310.86	0.0021	12.49
PC7	1,682.72	0.0203	1.79
PC8	1,752.95	0.0214	3.92

The average compressive strength of 28-day MixA cube concrete samples are 41.96% lower than the hammer strength estimate. Likewise, this value is 12.17% for the 28-day MixB concrete sample. The rebound hammer is used to estimate the strength of concrete quickly and non-destructively. The main purpose of the test is to estimate compressive strength using surface hardness. However, there are many voids and aggregates on the surface of permeable concrete. For this reason, the concrete surface is rougher than impermeable concrete. All these factors affect the throw back of the hammer and may cause the compressive strength estimated from the experiment to be far from reality. Therefore, core compressive strength and rebound hammer test results may be incompatible. These two main reasons may cause MixB samples to show higher strength and MixA samples to show lower strength.

The graphs created by obtaining the data required to draw deformation and load curves and loading-unloading curves with the help of sensors are shown in Figures 5.10, 5.11, 5.12 and 5.13 below. When the graphs are compared, it is seen that MixA concrete can withstand forces exceeding 600 N on its 14th day at its highest. However, MixB concrete can withstand forces of approximately 350 N on its 28th day. These results again bring into account the difference between the cube compressive strengths of MixA and MixB concrete.

As the concrete material is subjected to load, irreversible deformations occur inside the concrete body. When the graphs in Figures 5.10 and 5.11 are examined, it can be said that the concrete shows plastic deformation for the parts from the starting point of the curves to the highest point.

It can be said that this concrete undergoes deformation with the load on it, but if this load is removed, some of that deformation can be eliminated. The top point of the graph is the yield strength. It says that concrete can withstand up to that load at most, and that after being exposed to that load, the material will collapse.

In Figures 5.12 and 5.13, the behaviours of MixA and MixB concretes under loading and unloading loads are displayed.

In Figure 5.12, it is seen that the 28-day samples show ε_0 elastic deformation when loaded under a constant stress, and then show a ductile behaviour when the stress is kept constant and reloaded, and their physical integrity is impaired after the yield point.

The tangent of the curve up to the yield point of the concrete gives the modulus of elasticity of the concrete. Stress and strain curves of MixA and MixB concrete are given in Figure 5.10.

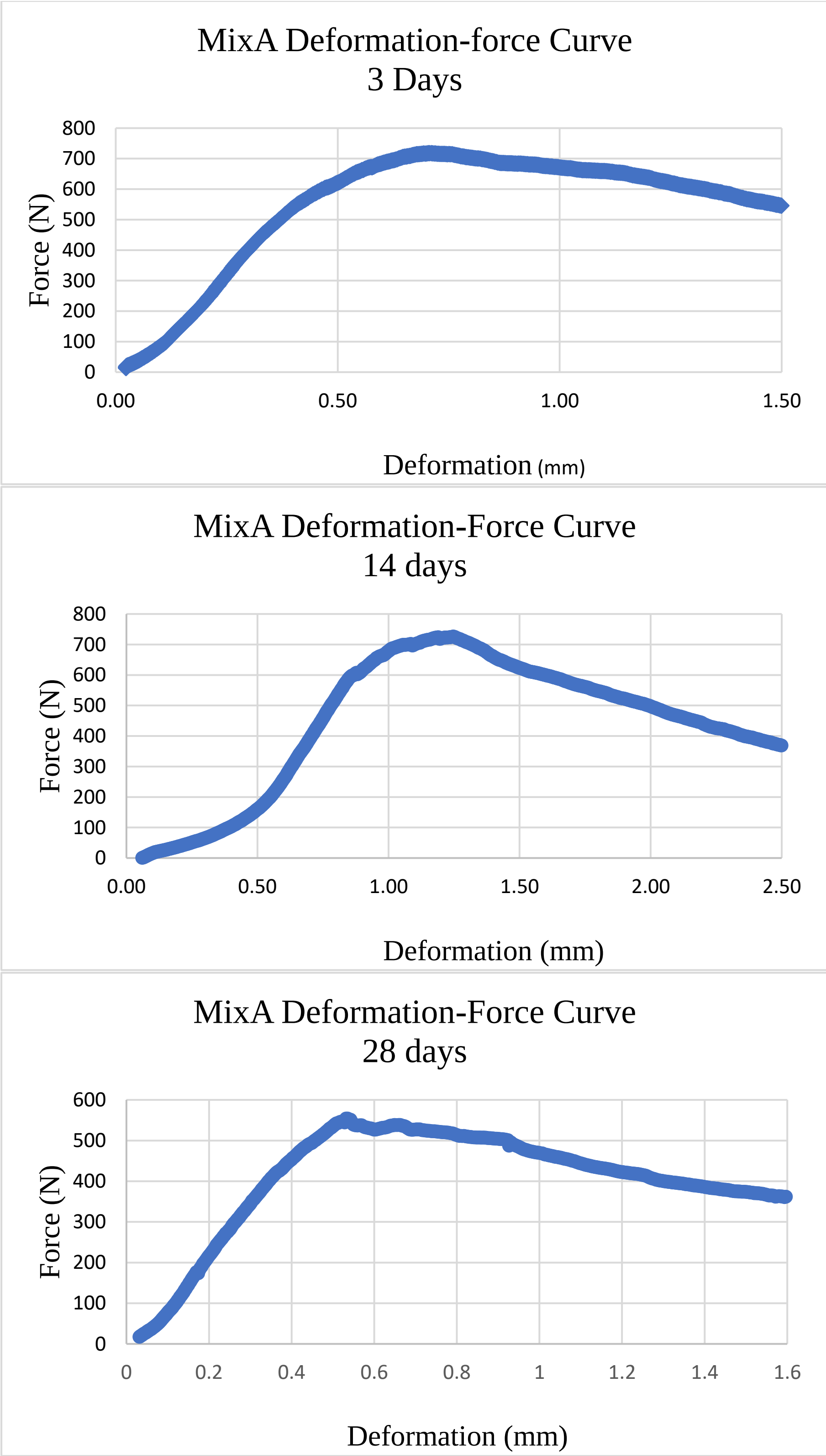

Figure 5. 10: MixA samples' load deformation curves at 3,14 and 28 days.

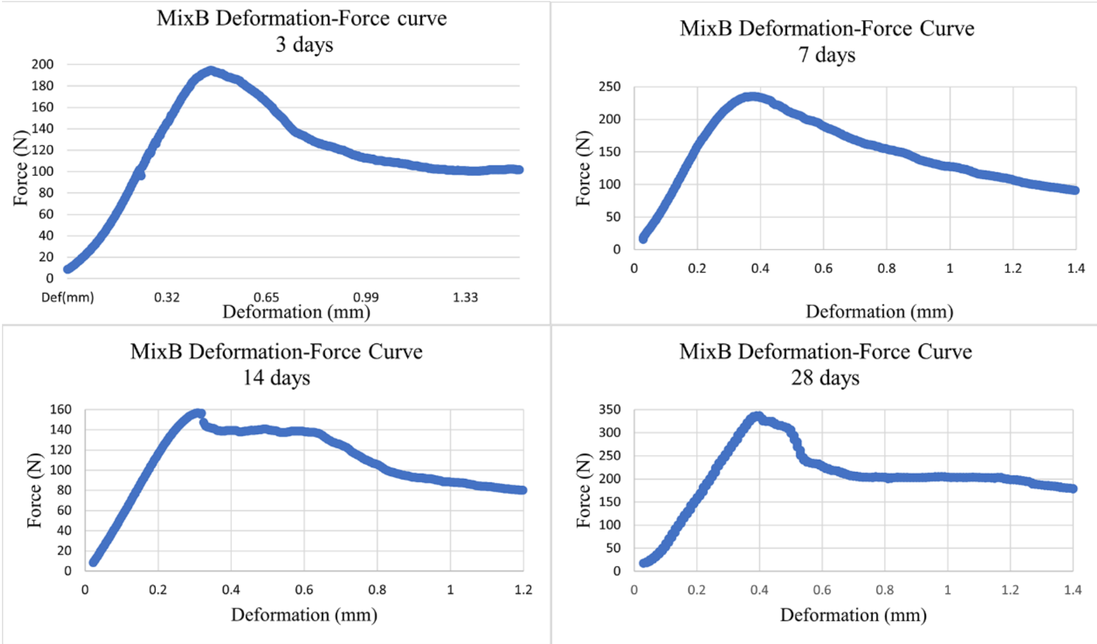

Figure 5. 11: MixB samples' load deformation curves at 3,7,14 and 28 days.

Stress and strain curves of MixA and MixB concrete are given in Figure 5.13. Using the values obtained from these curves, the modulus of elasticity was calculated as 3,415.67 MPa for MixB concrete and 10,336.54 MPa for MixA concrete.

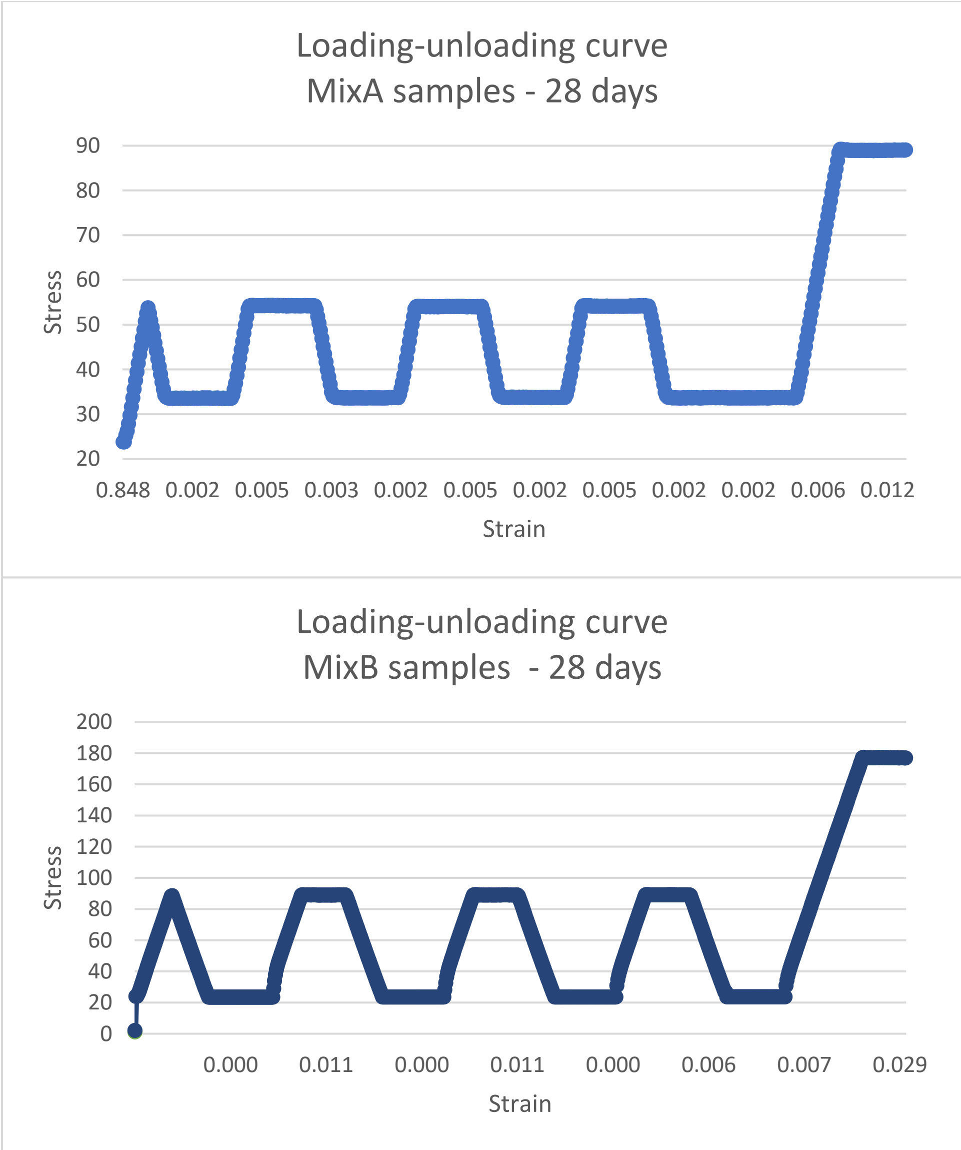

Figure 5. 12: Loading-unloading curve MixA and MixB samples.

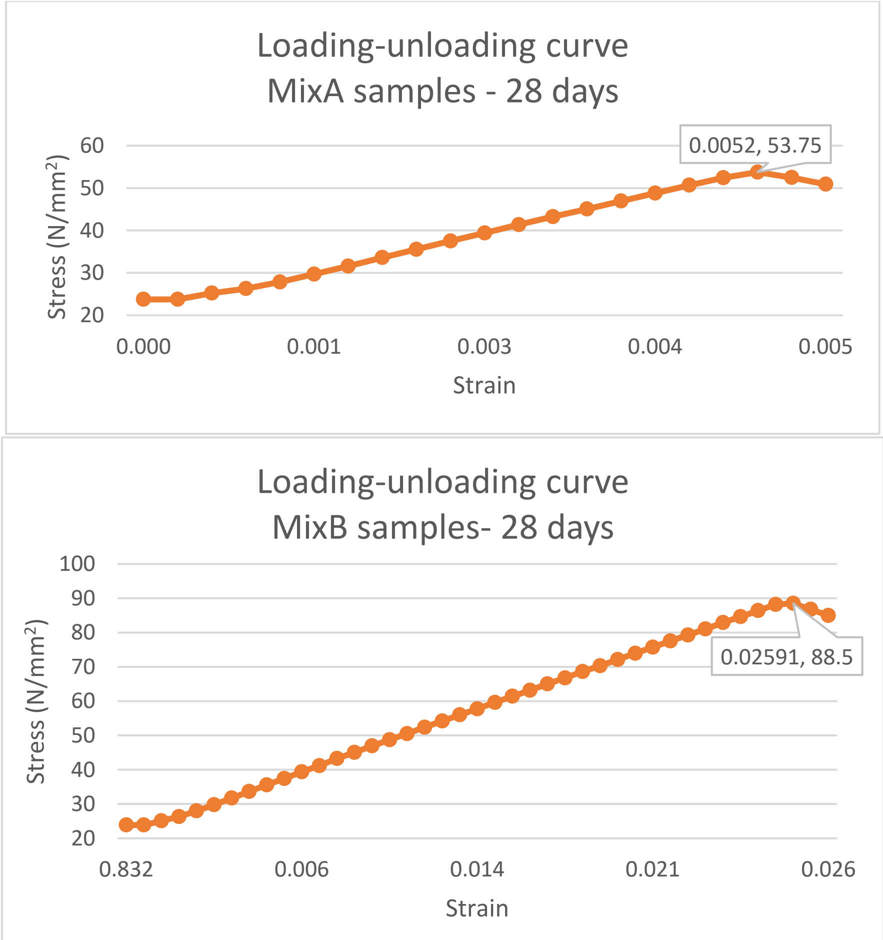

Figure 5. 13: Stress and strain curves of MixA and MixB concrete.

5.2.10 Splitting Tensile Strength Test

The splitting tensile strength of MixA concrete for 28 days was calculated as 3.977 MPa, and the splitting tensile strength of MixB concrete was calculated as 2.91 MPa. The splitting tensile strength of a normal strength concrete varies between 10-15% of its compressive strength. This ratio is 12.52% in MixA concrete and 11.73% for MixB concrete. In other words, the tendency of the tensile strength to be between 10-15% of the compressive strength is valid in permeable concretes as in normal strength concretes.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this study, 2 different permeable concrete mixtures were prepared using a constant water/cement ratio. Two different cements, MixA and MixB, were used in these mixtures, keeping the fine and coarse aggregates constant. Necessary laboratory studies were carried out to determine the mechanical and physical properties of the prepared mixtures in the fresh and hardened phases and led to the following conclusions and recommendations. These are presented below.

1. It is very difficult to obtain high compressive strength due to the large amount of space that permeable concrete contains for water permeability. However, using fine aggregate up to 10% by mass of coarse aggregate increases the compressive strength. However, reductions in water permeability can be seen due to the greater gap closure feature of this fine aggregate. Therefore, when calculating the concrete mix, which element is more vital should be considered.
2. Large-scale aggregates used in the concrete mixture increase the permeability of the concrete. However, the large voids created by these aggregates on the concrete surface may adversely affect surface sensitive test materials such as Rebound hammer or Pundit. For this reason, it is very important for the quality of concrete to interpret each test by comparing it with each other.

3. Concrete prepared with CEMI cement showed higher compressive strength compared to concrete prepared with CEMII cement. The reason for this can be given as the clinker ratio in CEMI cement (21% more than CEMII) and the ability to gain strength in a short time due to the high early strength of CEMII cement.
4. Different cement types had no effect on the fluidity of concrete. But CEMI cement needs more water to react and CEMII cement needs less water. However, in this study, the same water/cement ratio was used for both cement types. Therefore, MixB concrete had easier workability as a result of laboratory studies.
5. The density of the concrete mixture made with CEMII cement, both in fresh and hardened consistency, was found to be higher as a result of the density tests. This can be related to the fact that the slag, which is the pozzolanic material, continues to react after the hydration reaction.
6. Concrete mix made with CEMI cement has higher water permeability.
7. Concrete mix made with CEMI cement has higher water permeability. The fact that MixA concrete has a lower density can show that the amount of space where water permeability is provided is higher.
8. Concrete mix made with CEMI cement has higher water permeability. The fact that MixA concrete has a lower density can show that the amount of space where water permeability is provided is higher. Likewise, it has been determined as a result of the experiments that the permeability of sound waves of MixA concrete is higher than that of MixB concrete.

9. The surface hardness of concrete made with CEMI cement is higher than that of MixB concrete. As a result of this, the wear resistance of MixA concrete is higher than that of MixB concrete.
10. Higher compressive strength and sound wave transmission properties were determined in the concretes made with CEMI cement at temperatures of 300, 600 and 900 C. However, both types of concrete (MixA and MixB) are not resistant to temperatures higher than 600 degrees Celsius.

6.2 Recommendations

1. Reducing cement using a pozzolanic material and increasing strength without affecting water permeability
2. To obtain a high-strength permeable concrete by using three different aggregate sizes.
3. Production of permeable concrete using pigments, especially in areas that will be used by pedestrians (such as pedestrian crossings or sidewalks).

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