EXPERIMENTAL INVESTIGATIONS OF THE PERMEABILITY CHARACTERISTICS OF SELF COMPACTING CONCRETE MIXES MADE WITH VARYING CONSTITUENTS

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ABSTRACT

Observing some cases in North Cyprus where structures close to sea water are threatened with high tendency of water permeability, which may later cause severe durability problems; there is need to manufacture concrete with high impermeability to ensure its high quality. In addition, providing a systematic experimental data showing the level of impermeability of concrete mixes that are currently in use in North Cyprus. This is expected to make a beneficial contribution to the ready mix concrete sector in the country , as well as to the related literatures.

The influence of varying percentages of blast furnace slag cement and two admixtures (superplasticizer and crystalline water proof admixture) on the level of permeability of concrete mixes was studied to determine the most efficient mix. The study of the permeability self compacting mixes under varying criteria was carried out according to EN12390-8 and also their compressive strength developments were evaluated with ongoing hydration, especially with slow hydrated slag cement that yields the development of concrete microstructure. Both the impermeability and compressive strength characteristics of the samples were been tested for 28 days as standard age of concrete and 7 days to check their early age performances.

The observations obtained from this study showed that with increased slag cement (CEMIII) in a concrete, addition of admixture(s) has little or no significant effect on the impermeability behaviour of the concrete especially at the late age. Contrarily, the addition of admixture(s) to Ordinary Portland cement (OPC)(CEMI) and the partially replaced slag cement (CEMII) gives their best impermeability results with CEMI having its best impermeability behaviour when both admixtures (crystalline waterproofing admixture and superplasticizer) were used and CEMII was at its best impermeability with only superlasticizer. It was observed from the results that the water permeability into the concrete was less in concrete made of slag (CEMII) and was lesser when the percentage of slag was increased (CEMIII). However, the addition of admixture(s) generally improves the compressive strength developments of all the specimens in both their early and late ages especially in slag cements, with CEMIII having the highest compressive strength of all the samples when it was mixed with both admixtures.

Keywords: Self compacting concrete, Water permeability, Granulated Ground Blast Furnace Cement, Compressive strength, Plasticizer, CWA, Concrete Durability.

ÖZET

Kuzey Kıbrıs'ta özellikle denize yakın bölgelerde inşaa edilen binalarda, daha sonra tehlike arz edebilecek dürabilite problemlerine neden olabilecek, beton elemanlarda su geçirimliliği eğilimi tespit edilmiştir. Bu yapılan tespit ile hem geçirimlilik niteliği az, yüksek kaliteli beton üretiminin önemi, hem de Kuzey Kıbrıs'ta üretilmekte olan hazır beton karışımlarını geçirimlilik eğilimleri açısından inceleyen sistematik deneysel veri eksikliğinin önemi ortaya çıkmıştır. Bu çalışmadan elde edilecek sonuçların hem ülkedeki hazır beton sanayisine, hem de ilgili literatüre olumlu yönde katkı koyması beklenmektedir.

Değişen yüzdeliklerle cüruf içeriği ve iki farklı katkı maddesi (süper akışkanlaştırıcı ve kristalize su-geçirmezlik sağlayıcı katkı maddeleri) ile hazırlanmış kendiliğinden yerleşen beton karışımlarındaki geçirimsizlik eğilimi incelenerek en verimli karışımın belirlenmesi için çalışmalar yürütülmüştür. Bu çalışmalar esnasında EN 12390-8 referans olarak alınmıştır. Geçirimsizlik çalışmalarına ilaveten, yine beton mikro-strüktürünün çimento hidratasyon reaksiyonunun devami ile gelişmesine paralel olarak gelişmesi beklenen numunelerin basınç mukavemeti performansıları da gözlemlenmiştir. Hem geçirimsizlik, hem de basınç mukavemeti ölçümleri , standar numune yaşı olan 28 güne ilaveten, erken yaş niteliklerinin de gözlemlenmesi amacıyla 7. günde de yapılmıştır.

Yürütülen bu deneysel tez çalışması sonucunda elde edilen veriler ışığında; arttırılmış cüruf içerikli çimento (CEM III) kullanıldığında diğer katkı maddelerinin geçirimsizlik niteliği açısından karışımın performansına önemli ölçüde etki etmediği tespit edilmiştir. Öte yandan, CEM III yrine daha az cüruf içeren CEM II kullanıldığında sadece süper akışkanlaştırıcı katkı maddesi içeren karışımın, curuf içeriği olmayan CEM I çimentoları kullanıldığında ise her iki katkı maddesinin beraber kullanımı ile en geçirimsiz karışımın elde edildiği gözlemlenmiştir. Genel anlamda geçirimsizlik niteliğinin cüruf içeriği ile arttığının da gözlemlenmesi yanında, numunelerin basınç mukavemeti performansı için cüruf içeriğine ilaveten iki katkı maddesininde kullanılmasının hem erken (7 gün) hem de standart (28 gün) süresinde olumlu etkileri gözlemlenmiştir.

Anahtar Kelimeler: Kendiliğinden Yerleşen Beton, Su geçirimliliği, Cürufflü çimento, akışkanlaştırıcı, Beton dürabilitesi.

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LIST OF ABBREVIATIONS

BMV: Blue Methylene Value

CEM: Cement

CWA: Crystalline Water Admixture

FA: Fly Ash

GGBFS: Granulated Ground Blast Furnace Slag

OPC: Ordinary Portland cement

SCC: Self Compacting Concrete

TRNC: Turkish Republic Of Northern Cyprus

W/C Ratio: Water Cement Ratio

CHAPTER ONE

INTRODUCTION

1.1 GENERAL CONCEPTS

Concrete is known to be the most widely used construction material in the world because of its low cost, high compressive strength, excellent performance when used together with steel reinforced concrete (Wang, 2013). It is a heterogeneous material obtained by the mixture of cement paste (binder) and aggregates (filler) which constitute around 80% of the concrete. These combine together to form a synthetic conglomerate. Sometimes materials other than aggregates, water and hydraulic cement are added to concrete batch before or during mixing to provide a more economical solution and enhanced concrete properties. These materials are known as additives or admixtures depending on the stage of mix. (Arum and Olotuah, 2006)

Several researches on concrete structures have proven the great importance of water molecules on concrete structures especially in the first ages, helps in cement hydration and consequently hardness of concrete. However, it presence after the end of concrete hydration reaction may be detrimental by transporting noxious substances that can speed up degradation process of matrix which substantially reduces the durability and the useful life of the concrete. Therefore, permeability control is an important consideration in the design of concrete and engineering construction (Magalhaes and Costa, 2013).

Permeability controls the speed of aggressive water penetration into the concrete besides regulating the movement of water during the occurrence of several concrete durability problems. The importance of permeability cannot be under estimated as it is the most important factor to esteem durability under the most diverse conditions of service life of engineering structures. Therefore, concrete must be manufactured considering the environment in which it will be used. (Magalhaes and Costa, 2013)

1.2 DEFINITION OF THE PROBLEM

It is known that permeability is a significant factor affecting the durability of concrete and the duration of the service life.

One of the leading ready mix concrete companies of Turkish Republic of Northern Cyprus (Tüfekçi group) reported a vital problem that is being faced especially in coastal areas of North Cyprus, that reinforced concrete structures are experiencing the problem of water infiltration mainly through the foundations especially during the early stage of manufacture.

It was also observed that different cements, with or without additives are being currently used in combination with certain admixture, however there is no existing experimental data showing the level of permeability of concrete mixes currently being manufactured in North Cyprus. Considering these problems, studies should be carried out to manufacture high quality concrete with high impermeability characteristics ensuring its durability, especially the ones exposed to the danger of water infiltration. Moreover, studies with these defined purposes will provide statistical data that will be used in tackling the problem of water penetration in North Cyprus and other parts of the world facing similar problems as well.

1.3 OBJECTIVES AND THE SIGNIFICANCE OF THE STUDY

The objective of this study is to investigate the impermeability performance of concrete mixes made in North Cyprus with various cement types, crystalline water proofing admixture and plasticizer, by carrying out detailed and systematic experimental investigations. In addition, aiming to suggest an efficient (e.g. most impermeable amongst the tried mixtures) concrete mix that will meet the needs required in North Cyprus, a significant contribution is expected to be made to the related literature in the world on the issue of concrete impermeability with the data to be obtained from these experimental studies.

1.4 STRUCTURE OF THE STUDY

This study is mainly focused on the investigation of the permeability and compressive strength of concrete manufactured with available materials in North Cyprus. This study consists of five chapters. In chapter one, the general concept of the study, definition of problem, objectives of the research and the significance of study are discussed. Chapter two focuses on general concrete overview, concrete permeability, effects of slag on concrete, concrete durability and inter-relationship between permeation of concrete and concrete durability. Chapter three discusses the details on the materials and methodology used throughout this experimental study. Chapter four is dedicated for the results obtained and discussions. Finally, in chapter five, conclusions are made from the results obtained in this study and some future recommendations are suggested for future studies.

CHAPTER TWO

LITERATURE REVIEW

This chapter will be focused on the literature review on concrete, concrete permeability and its potential to cause durability problems, as well as previous studies on concrete permeability, factors affecting concrete permeability and related tests procedures. It will further discuss on other properties of concrete which include compressive strength and workability.

2.1 OVERVIEW ON CONCRETE

American Concrete Institute (ACI) defines concrete as a composite material that consists essentially of binding medium within which are embedded particles or fragments of aggregates usually combine of fine and coarse aggregates (Dolen, 2011).

Concrete is an important element in construction materials, widely used in various aspect of engineering construction. So it is very necessary to consider its durability as it directly has significant effect on economy, serviceability and maintenance. In other word, it is very important to lay more emphasis on the permeability characteristics of concrete, as it has much bearing on its durability. Aggressive chemicals are well known to attack concrete only in solution form. The penetration of this aggressive fluid is dependent on the degree of permeability of concrete (Seshadri et al, 2013).

In engineering, a well designed and manufactured concrete is expected to be water resistant, containing discontinuous pores and micro cracks. When it is subjected to extreme loading or weathering, it deteriorates through a variety of physical and chemical process substantially reducing the concrete durability (Wang et al, 2013). Pores in concrete include air voids, capillary pores and gel pores. This is one of the most important attributes of concrete materials, pore structures in concrete possesses a definite proportion and has serious implication on transmission of aggressive substances within the concrete. Researchers have shown that pore structures in concrete affects permeability, frost resistance and physical mechanical performance of concrete (Duan et al, 2013). It is generally recognised that the foremost prerequisites for durability of concrete is that , it should be dense and impermeable to liquid and gasses with high resistance to the infiltration of ion species such as chloride and sulphate (Obsorne, 1998)

In 1930, air entraining agent was developed which greatly contributes to concrete resistance to permeability and improves its workability. This was an important contribution in which the durability of modern concrete is improved. Air entrainment is an agent when added to concrete mix, creates many air bubbles that are extremely small and closely packed, of which most of them remain in the hardened concrete (Gromicko and Shepard, 2015).

2.1.1 BRIEF HISTORY OF CONCRETE

The early concrete structures were built by the Nabataea traders or Bedouins who occupied and controlled a series of oasis and developed a small empire in the region of south Syria and north Jordan in around 6500BC. They later discover the advantages of hydraulic lime i.e cement that hardens underwater and by 700BC, they were building kiln to supply mortar for the construction of rubble wall houses, concrete floors and underground cistern (Gromicko and shepard, 2015).

Figure 2.1: An ancient Nabataea building in North Jordan (Gromicko and shepard,2015)

The Babylonians and Assyrian used clay as bonding materal, the Egyptians used lime and gypsum cement. The first modern concrete (hydraulic cement) was made in 1756 by a British Engineer John Smeaton by adding pebbles as coarse aggregate and mixing powder brick into the cement. In 1824 an English inventor Joseph Aspdin invented Portland cement which as remain the dominant cement used in concrete production (Bellis, 2015)

The reactivity of blast furnace slag was first discovered in Germany in 1862 and it has been used as a cementitous material for over 100years. (Alexander et al, 2003) The famous concrete structures include the Hoover dam, the Panomal canal and the Roman pantheon.

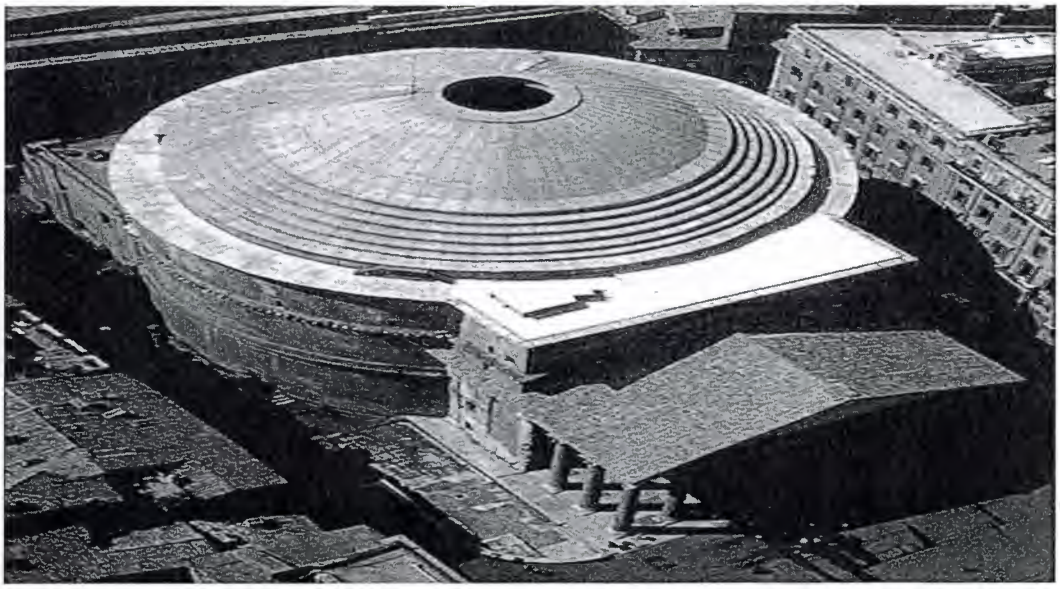

Figure 2.2: The Pantheon (Gromicko and Shepard, 2015)

2.1.2 CONCRETE CONSTITUENTS

Concrete generally composes of three main ingredients which are water, cement and aggregates. The properties of the final product vary as the ratio of the ingredients changes, which allows the engineer to design concrete in a way to meet their specific need.

2.1.2.1 WATER

ASTM C1602 standard specification for mixing used in the production of hydraulic concrete, defines source of mixing water in different categories:

I. Batch water: Batch water is the water discharged into the mixer from a source, which serves as a main source of mixing the concrete

II. Ice: This may be used as part of mixing during hot weather .The ice should be melted completely by the end of the mixing.

III. Water added by the truck operator: ASTM C94 (AASHTO M157) allows the addition of water on site if the slump is less than specified, provided the allowable water cement ratio is not exceeded and also meeting several conditions.

IV. Free moist can have substantial portion of the total mixing water, therefore it is recommended to ensure the water from aggregates should be free from harmful materials

V. Water in the admixture: The water content of admixture should be taken into consideration especially when the admixture water content is sufficient to affect water cement material ratio by 0.01 or more

1. Recycled water: Non portable or water recycled from concrete operation can also be used as mixing water in concrete provided they meet the acceptable criteria given in ASTM1602. The maximum permitted solid content allowed to be present in water to be used in concrete is 50000 part per million, or 5% of the total mixing water and should be tested in accordance with ASTMC1603

2.1.2.2 CEMENT

Cement is a binder, a substance that sets, hardens and can bind other materials together. The word "cement" is traced to the Roman, who used the term" opus caementicium" to describe masonry similar to modern concrete that was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick additives that were added to the burnt lime to obtain hydraulic binder were later referred to as cementum, cimentium and cement.

According to European standard (BS EN 197-1); cements are defined in format which indicates the cement type, main constituents, strength class and its rate of early strength.

All the cement types aside CEMI have a symbolic letter immediately after the Roman numeral indicating the cement type, this indicates the range of Portland cement clinker proportions.

The symbolic letter after the CEM notation indicates the level of Portland cement present within the cement

A = high level clinker (PC clinker content 80-90%) – CEMII/A

B = medium level clinker (PC clinker content 65-79%) – CEMII/B

A = PC clinker content 35-64% - . CEMIII/A

B = PC clinker content 20 -34% - . CEMIII/B

C = PC clinker content 5-19% - . CEMIII/C

CEMII also have an additional letter after the letter indicating level of Portland cement clinker, this letter indicates the second main constituent present in the cement.

S = blast furnace slag V = siliceous fly ash

P = natural pozzolana L = lime stone

T = burnt shale D = silica fume

M = composite cement W = high lime pfa

The figure 42.5 present in the expression indicates the standard strength class and the letter after the figure shows "R" which indicates rapid early strength.

CEMII/B-S 42.5R, CEMIII A42.5R and CEMI 42.5R cements were used.

Table 2.1: European Standards EN197-1 Cement Compositions

Cement Type	Designation	Notation	Clinker K	G.G.B.S. S	Silica fume D	Pozzolana Natural P	Pozzolana Industrial Q	Fly ashes Silic. V	Fly ashes Calcar W	Burnt Shale T	Limestone L	Limestone LL	Minor Additional constit.
I	Portland Cement	I	95-100	-	-	-	-	-	-	-	-		0-5
II	Portland Slag Cement	II / A-S	80-94	6-20	-	-	-	-	-	-	-		0-5
		II / B-S	65-79	21-35	-	-	-						0-5
	Portland Silica Fume Cement	II / A-D	90-94	-	6-10	-	-	-	-	-	-		0-5
	Portland Pozzolana Cement	II / A-P	80-94	-	-	6-20	-	-	-	-	-		0-5
		II / B-P	65-79	-	-	21-35	-	-	-	-	-		0-5
		II / A-Q	80-94	-	-	-	6-20	-	-	-	-		0-5
		II / B-Q	65-79	-	-	-	21-35	-	-	-	-		0-5
	Portland Fly Ash Cement	II / A-V	80-94	-	-	-	-	6-20	-	-	-		0-5
		II / B-V	65-79	-	-	-	-	21-35	-	-	-		0-5
		II / A-W	80-94	-	-	-	-	-	6-20	-	-		0-5
		II / B-W	65-79	-	-	-	-	-	21-35	-	-		0-5
	Portland Burnt Shale Cement	II / A-T	80-94	-	-	-	-	-	-	6-20	-		0-5
		II / B-T	65-79	-	-	-	-	-	-	21-35	-		0-5
	Portland Limestone Cement	II / A-L	80-94	-	-	-	-	-	-	-			
		II / B-L	65-79	-	-	-	-	-	-	-	6-20		0-5
		II / A-LL	80-94	-	-	-	-	-	-	-	21-35	6-20	0-5
		II / B-LL	65-79	-	-	-	-	-	-	-		21-35	
	Portland Composite Cement	II / A-M	80-94	<------6-20------>									
		II / B-M	65-79	<------21-35------>									
III	Blastfurnace Cement	III / A	35-64	35-65	-	-	-	-	-	-	-		0-5
		III / B	20-34	66-80	-	-	-	-	-	-	-		0-5
		III / C	5-19	81-95	-	-	-	-	-	-	-		0-5
IV	Pozzolanic Cement	IV / A	65-89	-	<------11-35------>				-	-	-		0-5
		IV / B	45-64	-	<------36-55------>				-	-	-		0-5
V	Composite Cement	V / A	40-64	18-30		<------18-30------>			-	-	-		0-5
		V / B	20-39	31-50		<------31-50------>			-	-	-		0-5

COMMON CEMENTS USED IN THE REUBLIC OF NORTH CYPRUS

I. PORTLAND COMPOSITE CEMENT:

It is obtained by grinding 80-88 and 65-79 unit mass of Portland cement with silica fume, blast furnace slag, pozzolan, fly ash, limestone, baked schist and certain amount of setting regulation as gypsum.

II. PORTLAND SLAG CEMENT:

This is obtained by grinding certain amount of Portland clicker and 21 -35 or 6 -20 unit mass of slag with little amount of setting regulator as a gypsum. Portland slag cement is preferred in north Cyprus due to its climate condition and island structure, to protect concrete against sulphate, acid attack, and other aggressive chemicals where cement will be used in coastal, port and dock construction, dams and in all concrete structures that may come into contact with sea water.

III. PORTLAND LIME STONE CEMENT:

This is classified into four kinds, depending on contains of 6-20 or 21-35 unit of mass lime stone amount and the content of calcium carbonate amount in the lime stone structure

IV. PORTLAND CEMENT

It is obtained by grinding 95 -100 mass of Portland clinker and some certain amount of setting regulator as gypsum. It is mostly used in multi story concrete structure, bridges also in precast concrete.

2.1.2.3 AGGREGATES

Aggregates are considered to be more impermeable than the hydrated cement paste and it is obvious that the permeability of concrete depends majorly on the inherent permeability of its constituents than on the interface. A recent study by Tsunkamoto shows that, for a given crack opening displacement, the presence of lager mean aggregate size leads to drop in fluid permeability (Hoseini, 2009).

Majorly, concrete mixture consists of both fine and coarse aggregate. Fine aggregate generally consist of natural sand or crushed stones with most particles passing through 0.38 inch sieve, and coarse aggregates are any particle greater than 0.19 inch, but generally ranges between 0.38 and 1.5 inches as in diameter. The aggregates helps to increase the strength of the concrete more than the strength cement can provide on its own.

Sand, gravel, crushed stones, slag, recycled concrete and geo synthetic aggregates are used as aggregate. Aggregates are the most mined material in the world. In order to achieve a good concrete mix, aggregate should be clean, hard, free of absorbed chemical or coating of clay and other fine materials that could cause concrete deterioration. It account for the largest percent of concrete.

Gravel and sand are mostly dug naturally from pit, river, lake or sea bed. Crushed aggregate is produced by crushing quarry rocks, boulders, cobbles or large size gravel. Properties expected of a good concrete include

a. Durability
b. Grading
c. Particle shape and surface texture
d. Abrasion and skid resistance
e. Unit weight and void
f. Absorption and surface moisture

Particle sizes distribution by sieve analysis of particles greater than 0.075 and hydrometer analysis for particles size lesser than 0.075 is shown in the table below.

Table 2.2: Grain size classification of soil (Agarwal)

S/N	Soil type	Particle sizes(mm)
1	Clay	Less than 0.002
2	Silt	0.002 -0.075
3	Fine sand	0.075 -0.425
4	Medium sand	0.425 -2.000
5	Coarse sand	2.000 - 4.756
6	Fine gravel	4.756 -20.000
7	Coarse gravel	20.000 – 80.000

2.1.2.4 ADMIXTURES

In present days, concrete is used for wide variety of purposes. In ordinary condition, concrete may fail to exhibit the required performance of quality and durability. In such cases, modification of ordinary concrete properties can be made by addition of admixture so as to make the concrete more suitable for any situation (Giridhar et al, 2013).

The addition of water-reducing admixture due to water content decrease at a given consistency can enhance both the early and ultimate strength of concrete. However the ultimate strength of concrete may not be seriously affected. Nowadays, for ecological reasons and cost control, the use of pozzolanic and cementitious by- products as mineral admixture in concrete is now on the increase. When admixture is used as partial replacement for Portland cement, it usually has retarding effect on the concrete strength at the early ages. However, the ability of mineral admixture to react with calcium hydroxide (constituent of hydrated Portland cement paste) at normal temperature to form additional calcium silicate can lead to significant reduction in porosity of both matrix and interfacial transition zone (Jankovic et al ,2011). Admixtures are ingredient present in the concrete other than water, cement, and aggregates that are added to the mix immediately before or during mixing. It is added to modify some of the properties of the mix. They are usually classified according to the specific function they are intended to perform, below are some of the common designated groups of admixture

I. Water reducing admixture

II. Set modifier (retarding, accelerator)

III. Air entraining agent

IV. Anti bleeding /segregating admixture

V. Corrosion inhibitor

VI. Curing and shrinkage (drying) reducing admixture

VII. Water-proofing admixture

VIII. Anti – freezing admixture

IX. Admixture controlling alkalis aggregate reaction (AAR) (Jolicocur et al, 2015)

Concrete should be workable, strong, and durable, finish able, water tight, and wear resistance. The main reasons for using admixtures are:

I. To achieve certain properties in concrete more effectively.

II. To maintain the quality of concrete during the stage of mixing, transportation, placing, and curing in adverse weather condition

III. To overcome certain emergencies during concrete operation

IV. To reduce the cost of concrete

2.2 CONCRETE PERMEABILITY

Permeability is defined as the transportation fluid through a porous medium under applied pressure. This is the most important property of concrete governing its long term durability. (Kameche, et al, 2014)

Permeability in concrete is the movement of water through concrete under pressure, and also to the ability of concrete to resist penetration of any substance like liquid, gas or chloride ion. When water infiltrates into concrete, the calcium hydroxide in hydrated cement paste (the binder phase in concrete) will be leached out. Leaching of calcium hydroxide reduces the PH value of the pore solution, which may eventually lead to the decomposition and even leaching of the main hydrates in concrete i.e calcium silicate hydrates (C-S-H). This will undoubtedly increase the porosity, and reduces the strength and impermeability of the concrete (Liu et al, 2014).

One of the main reasons behind concrete deterioration is due to the penetration of fluid carrying aggressive ions through the concrete. Therefore, fluid penetration resistance of concrete is a critical parameter in determining the long term performance of structures in a marine environment. (Hamilton et al, 2007)

The parameter that has the most significant influence on durability of concrete is the water cement (w/c) ratio or water cementious (w/cm) ratio. Low w/c ratio reduces the permeability, therefore reducing the voids in concrete. This implies that it will be more difficult for water and other corrosives to infiltrate the concrete. Permeability in concrete influences durability because it controls the rate of at which moisture containing aggressive chemicals penetrates into the concrete. Decreasing the w/c ratio also has great impact on concrete strength which further improves its resistance to cracking (Rohne, 2009)

The necessity for information on the permeability of concrete dates from the early 1930's when it became necessarily for designers of dams, and other large hydraulic structures to know the rate at which water rise through concrete that was subjected to relatively high hydraulic pressure. Recently, there is a renewed interest in the permeability of concrete which does not only centre on the flow of water through concrete in water works structures but also deals with permeability to aggressive substances such as chloride ion from sea water, and deicing salts, Sulphate ions and other deteriorating chemicals. (Abualamal, 2014)

The increasing awareness of the role that permeability plays in the long term concrete durability has led to the need for ways to quickly asses the permeability of concrete. The use of admixtures such as silica fumes, latex emulsions and high range water reducer allows placement of lower permeable concrete. It became more necessary to know more information on the effect of these admixtures, concrete mix and curing so that low permeability concrete can be uniformly specified and manufactured.

A common way to measure concrete permeability is the standard test method ASTM C1202 "Electrical Indication of Concrete's Ability to Resist Chloride ion penetration" also known as raid chloride impermeability test. This method is the most accepted test method to determine the relative permeability of concrete. A 60V electrical potential is set across a sawed four inches diameter concrete cylinder section and the total current passing through the section over time is read and measured in coulomb. Lower coulomb values indicate lower permeability.

In 1986, Construction Technology Laboratories researchers studied the effect of mix design, material and curing on permeability of selected concretes. The concrete studied had w/c ratio ranging from 0.26 to 0.75. Compressive strength varied from 3580psi to 15250psi at 90 days. Silica fumes and high range reducers were used to produce the lower w/c ratio concrete.

Moist curing for 7 days minimum recommended in ACI 308, standard practice for curing concrete results in much more impermeable concrete, this is especially important at higher w/c ratios. (Abualama, 2014)

There are several rapid test procedures available for estimating permeability instead of more complex flow testing. The rapid chloride permeability test (AASHTO T277) is reliable and quickly accesses the relative permeability of variety of concretes. Another alternative is the simple absorption based test procedure that test for the volume of permeable voids (ASTM C 642) is used. However, total test time is greater and predictability is less than for the AASHTO test. (Hamilton et al, 2007)

2.2.1 FACTORS CONTROLLING PERMEABILITY OTHER THAN CONCRETE MATERIALS

There are three major factors which determine concrete permeability

I. WATER - CEMENT RATIO:

The American standard (ACI 318) building code addresses an exposure condition of concrete aimed to have low water permeability by requiring a maximum w/c ratio of 0.5 and a minimum specified strength of 4000 psi (Obla et al, 2005).

Also, According to European standard EN206, the first criterion to be considered in other to improve concrete durability is to limit the maximum w/c ratio in the concrete mix. (Sanjuan and Martialay, 1996). The porosity of cement paste ranges from 30-40 vol% in the form of gel or capillary pores which are about 2×10^{-9} m and 1×10^{-6} m diameter respectively. Capillary pores are formed due to excess w/c ratio. This essential micro structure difference results in a major difference in the mechanical and durability behaviour of both the cement paste and the transition zone between the paste and the aggregates. (Aitcin, 2003)

II. CURING CONDITIONS

Curing is the technical process that involves a combination that promotes cement hydration; time, temperature and humidity condition immediately after the placement of concrete mixture into formwork. The constituent compounds of Portland cement begin its hydration as soon as water is added which determines the porosity of hydrated cement at specified water cement ratio. The hydration almost stops when the vapour pressure of water capillary falls below 80 percent of the saturation humidity. Time and humidity are important factors in hydration process controlled by diffusion of water. It is noted that the time-strength relation in concrete technology generally assume moist-curing condition and normal temperature. Concrete increases in strength with age after setting, suitable curing of the concrete after whilst it is maturing further increases the strength of the concrete.

At a specific cement- water ratio, the longer moist curing applied, the higher the strength obtained assuming that the hydration of anhydrous cement particle is still in progress (Jankovic et al, 20011).

Curing can be affected by the application of heat or/and the preservation of moisture within the concrete. Majorly curing prevents or helps to preserve the water used in the mixing from escaping and it is usually done by

a) Covering the concrete with damp sand which are kept damp by watering periodically

b) Flooding or submerging the concrete in water which is mostly used

c) Treating the surface of the concrete to prevent it from drying out (Arum and Olotuah)

I. COMPACTION:

Perfect compaction and placement of fresh concrete are one of the most important part of the whole process of concrete operations. The mixing process of concrete operation entraps air within the mix and for each 1% of void left in the concrete mix ,the strength is reduced by approximately 5-6 %. The air entrapped will be typical when the percentage ranges from 5-20%.

Compaction is important in other to achieve

a) Maximum strength of the placed concrete

b) Maximum durability.

c) Avoidance of visual blemishes such as honeycomb, and blow holes on the surface of the form cast concrete.

d) Adequate bond and protection for reinforcement in the concrete

II. ADMIXTURES

Incorporation of minerals admixtures such as ground granulated blast furnace slag (GGBFS), fly ash (FA), silica fume (SF) and lime stone crystalline water proofing admixture has been of great interest and gradually applied to practical projects because these mineral admixtures can improve resistance to the deterioration by aggressive chemical and permeation. GGBFS is a by product from manufacture of pig iron while FA is a by product of coal power generation. A number of benefits in incorporating these materials have been in publications such as improving fresh properties of concrete, reduce hydration evolution heat and decrease chloride ion penetration, reduce sulphate attack and alkalis silica reaction. (Hiu- Sheng et al, 2009)

2.2.2 EFFECTS OF GROUND GRANULATED BLAST FURNACE SLAG IN CONCRETE PERMEABILITY

Slag is an industrial waste material resulting from steel refining process in a conversion furnace. GGBS results from the fast cooling of molten slag and is a pozzolanic as well as latent hydraulic material (Kourounis et al, 2007).

Granulated slag is the hydrated blast furnace slag, dried and ground in fine powder form. It is a by product of iron-steel industry and obtained from the blast furnace. Iron ore, lime stone, and coal are charged into the blast furnace and heated to about 1500°C. The raw materials are converted to molten iron and blast furnace slag. The two products are separated in natural forms, the iron sinks down the bottom of the blast, while the slag floats and dispersed over the iron. (EN 197-1)

A pozzolana is a material which has characteristics of reacting with lime $C_a(OH)_2$ in the presence of water at ordinary temperature to form compound with cementious properties (C-S-H gel). Recently, different types of material admixtures including pozzolanic (natural pozzolana, low calcium fly ash, silica fume), autopozzolanic (high calcium fly ash, and blast furnace slag) and crystalline materials as water proofing admixtures are added to Portland cement during the milling processes or directly to the cement in which some interact physically and/or chemically with the cement or its hydraulic product to improve the properties and reduce the factors related to declining concrete durability. Also, mineral addition has improved the strength by filling off the pores, changing its diameter and orientation. (Saraya, 2014)

Ground granulated blast furnace slag (GGBS) is a material that has beneficial effect on concrete (Ogawa et. al, 2012). Portland blast furnace slag cement is a mixture of OPC not more than 65% weight of granulated slag. It is generally known that the rate of hardening of slag cement is slower compared with that of OPC at early age but thereafter increases so that, the strength becomes close to or even exceeds that of OPC.(Abdel Rahman et al, 2011) In Japan, Portland blast furnace cement (BFS cement) is classified into categories, these are

A,B and C which contain varying percent of GGBS, BFS from 5% - 30%, from 30% -60% and from 60% -70% respectively according to Japan Industrial Standard (JIS R 5211). (S. Miyazawa, 2014). GGBS blended with Portland cement gives higher fluidity, reduce heat of hydration decreases water permeability and improves chemical resistance as a result densification due to secondary hydration reaction, together with reduced environmental impact of CO_2 discharge. However, blended GGBS with Portland cement has low strength development at the early age, may decrease carbonation resistance, and increase heat of hydration if the GGBS content in blended cement is low or activated at high temperature (Ogawa et al, 2012)

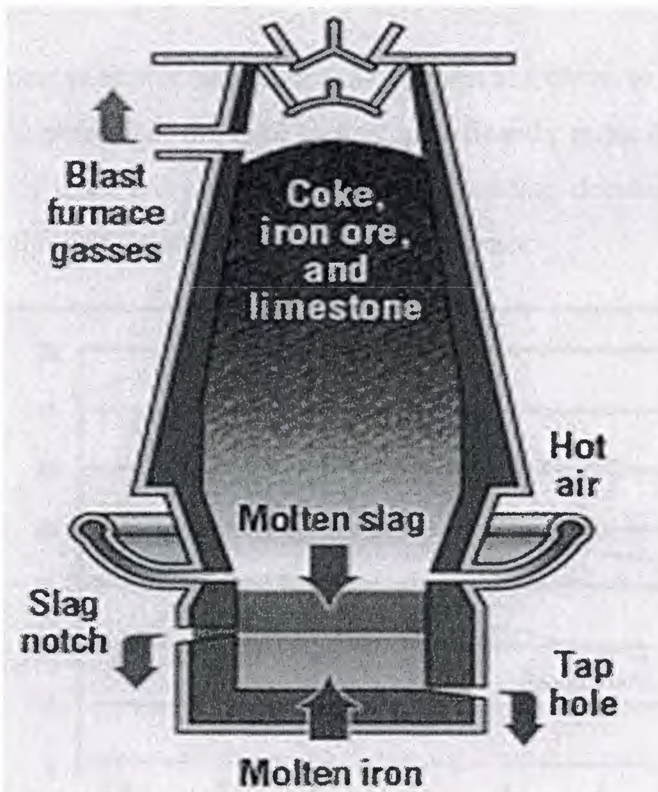

Figure 2.4: Blast furnace slag (National Slag Association)

2.2.2.1 CHARACTERISTICS OF SLAG CEMENT

Portland blast furnace cement is a mixture of ordinary Portland cement and not more than 65%wtn percent of granulated slag. It is generally known that the rate of hardening of slag cement is slower than that of ordinary Portland cement during the early ages but there after increases such that, in about a year the strength becomes close to or even greater than those of Portland cement. GGBS is hydraulically very weak itself due to its glassy structure, therefore a highly alkaline medium is required in order to disintegrate the silicate-aluminates network of the slag glass (Abdul Rahman et. al, 2011)

I. HYDRATION REACTION IN BLAST FURNACE SLAG

The hydration reaction in blast furnace slag involves the activation of the slag with alkalis and sulphates in order to form hydration product. Slag is combined with Portland cement in order to form extra hydrate with the effect of pore inhibition. As a result, the concrete is produces with a less open hydrate containing only Portland cement. Such low permeability greatly increases the resistance of concrete to sulphate and acid attacks. (EN197-1)

II. THERMAL CRACK

Hydration of slag cement is slower and releases lower heat compared to Portland cement. The use of GBBS up to 70 percent of the total cement significantly reduces the heat in concrete especially in casting of thick cross section. The corresponding decrease in the critical heat difference minimises the risk for early thermal structural cracks

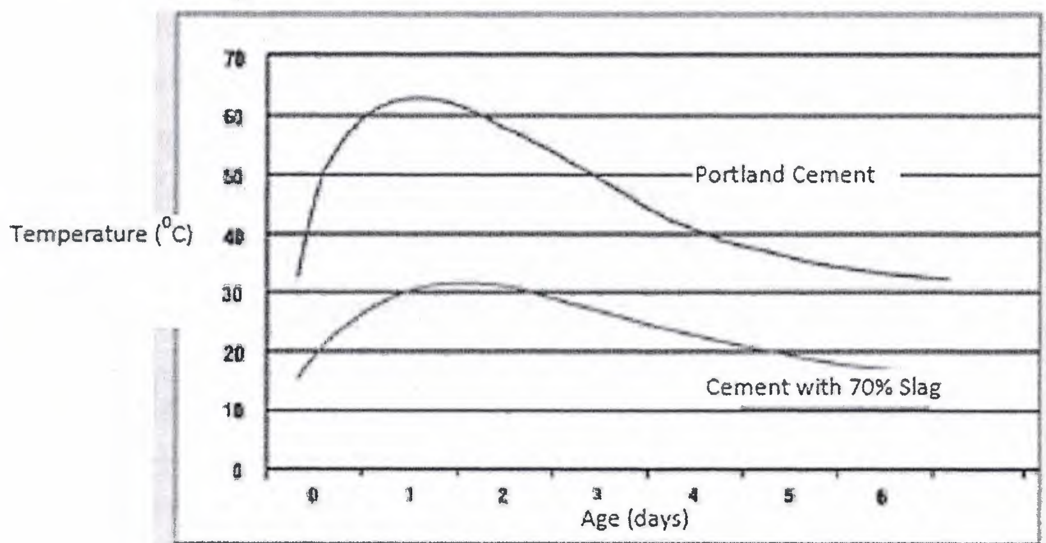

Figure 2.5: Thermal cracks (EN197-1)

I. CHLORINE PERMEABILITY

The GGBS is significantly more resistant to chlorine ingress than Portland cement of the same grade. Steel reinforcement in concrete is protected by the alkalinity of the hardened cement adhesion. The ingress of chlorine reduces the protection and corrosion takes place due to presence of oxygen and moisture. Thus, the structures exposed to chloride threat, benefit from the improved strength and longer useful service life from slag cement.

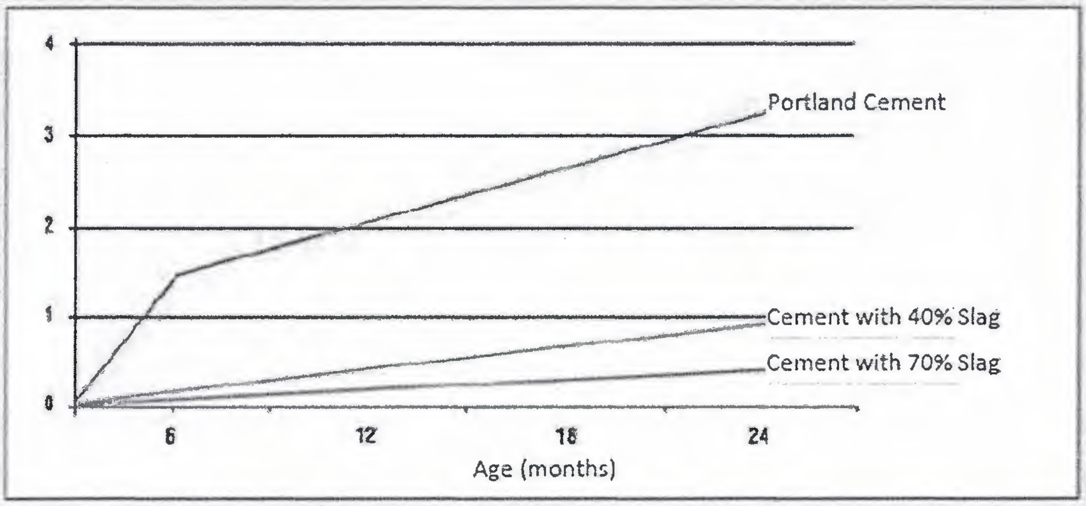

Figure 2.6: Chlorine permeability (EN 197-1)

I. STRENGTH DEVELOPMENT

In a properly cured slag cement concrete, the strength increase continues even at the end of 28th day. It is shown in the graph below, the relation between the strength increase at early and late ages. In general, the concrete produced with about 70%or more GGBS cement, at 1 day after the casting, adequate strength to mechanical impact likely to result from the removal of the formwork.

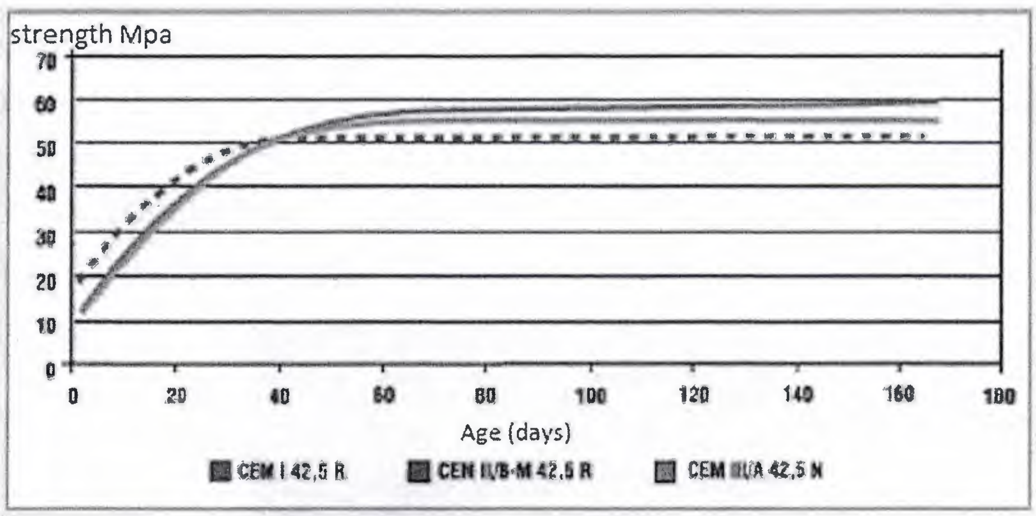

Figure 2.7: Strength developments (EN197-1)

II. SULPHATE AND ACID ATTACK

Sulphate attack is one of the most important factors that affect concrete durability. Sulphate ions naturally exist in soil, sea water, ground water and also in the water output from waste water treatment plant.

Water-based sulphate undergo reaction formed by way of expansion with C_3A component in Portland cement and a different form of $Ca(OH)_2$.The formation of ettringite in the concrete leads to expansion. If the expansion capacity of the concrete is exceeded, it may lead to severe cracks in the concrete.

III. ALKALI – SILICA REACTION

Gel is formed as a result of the reaction between alkalis such as potassium and sodium within Portland cement and the reactive silica within aggregate. In a moist environment, gel absorbs the water and begins to expand. When the expansion has reached an internal pressure at a level sufficient to crack the concrete, the concrete undergoes crack. The use of GGBS in concrete minimises the alkalis-silica reaction, no crack forms in the concrete as result of volumetric expansion.

APPLICATION OF SLAG CEMENT CONCRETE

I. Construction of bridges, domes and geothermal plants

II. Port, wharf construction and under water concrete

III. Marine structures, sea walls, road crossing at the river mouth (estuaries)

IV. Mass concrete

V. Reinforcing concrete

VI. Structures exposed to acid rain or chloride attack

VII. Concrete desired to minimize the alkalis silica reaction resulting from thr reaction aggregate

VIII. Large scale civil engineering projects, roads, tunnel, bridges

IX. Construction of channels and sewer system

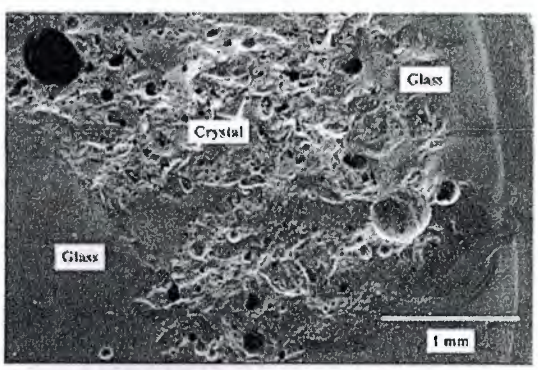

Figure 2.8: Appearance of glassy and crystalline phases of blast furnace slag (Gan et al, 2012)

2.2.2.2 REDUCING PERMEABILITY WITH SLAG

When Portland cement hydrates, it forms calcium silicate hydrate gel (CSH) and calcium hydroxide (Ca $(OH)_2$). CSH provides strength and holds the concrete together .Permeability of concrete is related to the proportion of CSH to Ca $(OH)_2$ in the cement paste. The higher the proportion of CSH to $Ca(OH)_2$ the lower the permeability of the concrete .When the slag cement is used as part of the cementious material in a concrete mixture , it react with $(Ca(OH)_2$ to form additional CSH , which in turn lower the permeability of the concrete.

Concrete with lower permeability can be achieved by substituting 25 to 65 percent slag for Portland cement (SCA)

$$C_3A + 2C_a^{2+} + 2SO_4^{2-} + 26H_2O \longrightarrow C_6AS_3H_{32} \quad (1)$$

$$2C_3A + C_6AS_3H_{32} + 4H_2O \longrightarrow C_4ASH_{12} \quad (2)$$

$$C_4A + 0.5Ca^{2+} + 2SO_4^{2-} + 20H_2O \longrightarrow C_6AS_3H_{32} \quad (3)$$

$$C_3A + 0.5CaCO_3 + 0.5Ca(OH)_2 + 12H_2O \longrightarrow C_4AC_{0.5}H_{12} \quad (4)$$

Ettringite ($C_6AS_3H_{32}$) forms in the cement matrix from the result of the reaction between C_3A in Portland cement and the internal sulphate ions from gypsum shown in equations above. Shown in equation (2) is the reaction of the remaining C_3A with ettringite to form monosulfate (C_4ACH_{12}). Ettringite formed in equation (3) is as result of sulphate ions supplied from external sources outside the cement matrix, the reaction between the monosulphate and external sulphate ions results to cement expansion.(S. Ogawa, et.al , 2012). Shown below is an example of an early structure in the United Kingdom made from GGBS (Osborne, 1999)

2.2.3 EFFECTS OF PLASTICIZER IN CONCRETE PERMEABILITY

In recent times, various polymers are being incorporated in modern concrete in order to achieve desired properties. Addition of plasticiser into fresh cementitious materials can improve their rheological properties and also, in the premise of satisfying construction requirements, lower w/c ratio could be achieved. It is well known that w/c ratio is required to produce concrete with higher strength, lower permeability, and higher durability (Malhotra, 1999) and (Gagne et al, 1996). Plasticisers are beneficial to the refinement of pore structures at a constant w/c ratio (Khatib and Mangat, 1999). The influence of various types of plasticisers on pores was examined, and was found that the size of cluster of aggregate cement particles became smaller when plasticiser with higher dispersing ability was added

(Sakai et al, 2006). Much research on cement mortar with plasticisers have been carried out, few studies dwell on their impact on the pore structure and the impermeability from the microstructure point of view in the fresh state of cement paste. It is supposed that these plasticiser may affect the pore structure and the impermeability from three perspectives

I. Changing the flocculation microstructure of the cement grains
II. Altering the cement hydration process
III. Filling the pores and the cracks in the transition zones and forms films in many cases (Zhang, 2014)

2.2.4 EFFECTS OF CRYSTALLINE WATER PROOFING ADMIXTURES (CWA) IN CONCRETE PERMEABILITY

Water is an important compound in concrete production, placement, and curing. But once its role is fulfilled especially at the end of hydration process, water is no longer friendly with concrete. (Hooker, 2012)

Crystalline water proofing admixture (CWA) is a special cementitious mix of chemical that readily reacts with moisture present in concrete to form crystalline structure within the pores and capillary tracts of the concrete. It is used to ensure water proofing for the concrete against ground water infiltration, protecting against water borne salts.

The crystals accelerate the autogenous healing capabilities of concrete to fill and block static cracks u to 0.4mm. The silicate reacts with calcium hydroxide (from the cement hydration process) to form a calcium silicate hydrate (C-H-S) which is similar to that formed by cement hydration but with variable hydrate concentration (CSH_n) (Ken, 2013)

The materials used in producing permeability reducing admixtures are generally classified into three categories:

a. The major category consists of hydrophobic or water- repellent chemicals obtained from fatty acid, vegetable oil and petroleum. These materials form a water- repellent layer along pores in the concrete.
b. The second category is fine divided solids, either inert or chemically active fillers such as talc, siliceous powder, clay and coal-tar itches. These materials densify the concrete and physically minimise the water infiltration through the pores.
c. The third category which will be used in this study consists of crystalline products, proprietary active chemicals in a carrier of cement and sand. These are hydrophilic materials

that increase the density of calcium silicate hydrate or generate crystalline deposits that block concrete pores to resist water infiltration.(Hooker, 2012) and (Ken, 2013)

Advantages of Crystalline Water Proofing Admixtures

The use of crystalline water proofing admixture (CWA) is along integral water proofing system which aide in resisting extreme hydroscopic pressure. It has no detrimental effect on the performance of the concrete provided that the recommended conditions are met.

Besides reducing permeability, the admixture also acts as a mild retarder, so it helps to minimise the heat of hydration and consequently reduces shrinkage cracking, below are other advantages of CWA

Other advantages of CWA is its non toxic nature, cost effect and process friendly system (Penetron, 2015)

Areas of its application

Crystalline water proofing admixture is considered for projects and applications that need waterproof concrete. It is mostly used in areas where there is threat of water infiltration though concrete structures like foundations (e.g pile foundation), sewage treatment plant, tunnels and subway systems, underground structures, swimming pool and reservoirs (Penetron, 2015)

2.2.5 PREVIOUS RESERCHES ON CONCRETE PERMEABILTY

Several researches have been carried out on the control of concrete permeability using different approaches and materials such as silica fume, rise husk, metakaoline, and fillers to improve the quality characteristics of concrete in both the fresh and hardened states and also making the concrete more economical and ecological friendly.

In King Fahd University of Petroleum and Minerals, studies on the use of fly ash, silica fume, or a highly reactive finely pulverised fly ash as supplementary cement material in concrete were carried out. The concrete mixtures were designed for constant workability of 75-100mm slump. The performance of ordinary Portland cement (OPC) and silica fume (SF), fly ash (FA) and very fine fly ash (VFFA) cement concrete was tested for. Concrete specimen, 75mm in diameter and height 150mm were cast for each of the concrete mixtures. The concretes were tested after 3, 7, 14, 28, 90, 270, and 450 days of water curing. In other to assess the performance of these supplements in concrete, the specimen were evaluated by placing them in 15.7% Cl^- and 0.55% SO_4^- solution after being cured for 28days. These specimens were exposed to sulphate – chloride solution for 6 hours and then allowed to dry.

This wet – dry period constituted only a cycle. The concrete specimens were retrieved and tested after 90, 270, and 450 cycle exposure. It was noted from the experiment that the water requirement of FA cement concrete was less than OPC and SF cements concrete. Consequently, the mechanical properties and durability characteristics of the former cement was better than those of the latter cements. Also, from the characteristics of the chloride permeability classification, it was observed that the highest reduction in the chloride permeability was noted in the FA cement concrete, followed by SF and VFFA cement concretes. The decrease in the permeability of the blended cement was explained as the conversion of $Ca(OH)_2$ to secondary calcium –silicate-hydrate. (Al-Amoudi et al, 2011)

In International Journal of Civil Engineering and Technology (IJCIET), an article with the title "Experimental study on water permeability and chloride permeability of concrete with GGBS as a replacement material for cement" provides valuable information on this thesis study. In this article, both steady flow and depth of penetration methods of water permeability testing were used for the evaluation of permeability of concrete. GGBS was used as partial replacement for cement from 0-100% at increment of 5% interval, and the samples arranged in permeability testing machine and test was carried out for 100hours. The experimental results showed that, with partial replacement of cement by GGBS till 60%, the permeability of concrete is decreased and the resistance to chemical attack is increased. However, the permeability increases from 65% replacement of cement by GGBS. (Tamilarasan et al, 2012)

Also, according to CRD-C 163-92 standard in an experimental study titled "Test method for water permeability of concrete using triaxial cell" describes other alternative of testing water permeability. This test method involves the establishment of a steady flow condition in cylindrical concrete sample housed in a triaxial permeability cell. A pressure gradient is maintained across the specimen with one end exposed to ambient pressure and the opposite end at the end drive pressure. The radial confining pressure is maintained around the specimen. The effluent is collected, and volume flow rate is determined. Once the steady-state flow conditions are known, the intrinsic permeability is calculated (wbdg.org)

$$K = \frac{\gamma}{\mu} * k$$

Where K = hydraulic conductivity, μ = dynamic viscosity, γ = specific gravity of the fluid

In another research, effectiveness of silica fume in reducing permeability of normal and high performance concrete was carried out. The aim of this research was to investigate the effect of various level of cement replacement with silica fume at 0%, 5%, 10% and 15%, on strength, elastic modulus and permeability. The result showed the significance effect of replacement of silica fume in reducing permeability and at 15% replacement level of cement with silica fume, the coefficient of permeability was reduced 80 times, it also increased the strength and elastic modulus of the concrete.(Bagheri et al, 2008)

Another study titled “Absorption and permeation performance of selangore rice husk ash blended grade 30 concrete” was carried out. This study was carried out using rice husk ash as a supplementary cementing material. Its reports the results of durability performance conducted on the normal strength concrete specimens of $30N/mm^2$ containing 20% or 30% RHA by cement weight, with or without adding plasticizer. The results obtained show that replacement of cement with RHA lowers the concrete initial surface absorption, lowers permeability and increases resistance of concrete to chloride ion penetration in comparison with the OPC control concrete. (Kartini et al, 2010)

In a publication by Virginia Transportation Research Council, the research on the permeability of concretes containing Portland cement alone or Portland cement with a pozzolan (fly ash, silica fume) or a slag was experimented by either rapid permeability or ponding test. From the results of the experiment, it was observed the rapid permeability test is more convenient and relatively faster compared with ponding test as the standard ponding duration is 90 days. However, for low - permeability concrete, 90 days is not sufficient, the specimen were put as long as 30 month. It was also observed that permeability decreases with time, and the addition of pozzolans or slag is very significant in decreasing water permeability. (Ozyildirim, 1998)

2.2.6 LIMITATIONS IN PERMEABILITY STUDIES

Due to difficulty in generating suitable crack pattern in concrete specimen and availability of appropriate methods for concrete permeability measurement, a limited number of studies have been made on the permeability of cracked concrete. Some research has been made on measuring permeability of concrete subjected to compressive loading. It was reported that the application of compressive load have minimal effect on both water and chloride permeability of concrete while some evidence support the significant micro cracking occurred in the concrete (Wang and Jansen, 2013)

Concrete basically has two types of pores , which determines the permeability , these pores are capillary pores (with diameter varying between 0.01 to 10 micron)in the cement paste which the coat the aggregate and larger micro voids , between 1mm to 10mm, which are caused by faulty compaction of fresh concrete.

2.3 RELATIONSHIP BETWEEN COMPRESSIVE STRENGHT OF CONCRETE AND ITS DURABILITY

The engineering properties of concrete such as strength, durability, permeability and shrinkage have direct influence and controlled by the number, type, size and distribution of pores present in the cement paste, the aggregate components and the interface between the cement paste and the aggregate. (Basheer et al, 2001)

When stress is applied on concrete, it response depend on the stress type, and the influence that the influence that the combination of various factors perform on the porosity of the different structural component of concrete. These factor include properties and proportion of material that are used for concrete mixture design, degree of compaction, and condition of curing (Jarkovic and Nikolic, 2011). Strength is obtained due to the hydration products of cement which are the concrete compounds and continuous hydration increases the compressive strength of the concrete. The process of strength growth is called hardening which is often confused with setting. Regarding the strength of concrete, the water cement ratio and the porosity is the most important factor; the water cement ratio affects the porosity of both the cement mortal matrix and the interfacial transition zone between the matrix and the coarse aggregate.

a) SETTING:

This is the stiffening of the concrete after it has been placed. A concrete can “set” in as much as that there is no longer fluid in it, but may still be weak, have low workability. Setting is due to early stage calcium hydrate formation and to enttrigite formation.

b) HARDENING :

Hardening is the process of strength growth that may continue for weeks or months after the concrete has been placed. This is largely due to formation of calcium silicate hydrate (CSH)

2.4 DURABILITY OF CONCRETE

The early and premature deterioration of concrete structures is a serious issue in most part of the world, as it could put the public safety in jeopardy and escalating repair cost which may directly affect or burden the future economy.(Tayeh et al, 2012)

Durability of concrete is the resistance of concrete against weathering, chemical and physical attacks that gives rise to deterioration of concrete during its designed service life (Bilir, 2012). According to ACI committee 201, durability of cement concrete is defined as it ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. (Nagesh, 2012) It varies in concrete, depending on the exposure environment and properties desired. For example concrete exposed to tida sea water will have different requirement than an indoor concrete floor. These properties may vary in concrete ingredients, mixing proportion, placing, curing practices and ultimate durability and life of concrete is determined by it environment.

Durability of concrete depends on its ability to resist the infiltration of noxious chemical substances. Transport properties of concrete, especially permeability play an important role in assessing and predicting the durability of concrete structure. The hydric state greatly has influence on the transport parameters like permeability which influence the penetration of aggressive species and so on concrete durability. (Kameche, et al, 2014)

For several years, from1983, the problem of the durability of concrete structure was majorly topic of interest in Japan (Ouch and Hibino). Infiltration of noxious substances can speed up the degradation process of matrix which substantially reduce the durability and the life of concrete. Therefore permeability control is an important consideration in the design of concrete and engineering structures for long time durability.

2.4.1 FACTORS AFFECTING THE DURABILITY OF CONCRETE

Disintegration of concrete and corrosion of reinforcement is one of the major signs of deterioration of concrete structures. After laboratory investigation and extensive studies in existing structures, researchers have identified a number of factors affecting the durability of concrete were observed, some of these parameters are discussed below.

I. AGGREGATE TYPE:

As the aggregates occupy up to 80% by volume of concrete, the resistance surface properties of aggregate is very important parameter considering durability of concrete structure. For adequate durability of concrete especially in marine structures, the aggregate material should be dense, none shrinking and alkalis resistance.

II. WATER –CEMENT (W/C) RATIO:

This factor influences both the strength and the durability of concrete. According Abraham's law, the strength of concrete at a given age and normal temperature decreases with increasing the water-cement ratio assuming full compaction of the concrete have been done. Permeability of concrete depends mainly on the water cement ratio, which determines the size, volume, and continuity of the capillary voids. Permeability is known to be the most important characteristics determining the long term durability of reinforced concrete exposed to sea water as it helps in preventing the diffusion of noxious substances like salt ions into the concrete .ACI 318-83 required that normal weight concrete subjected to freezing and thawing in most condition should a maximum water ratio of;

a. 0.45 in case of curbs, gutter, guardrails, or their section and

b. 0.50 for other element

I. CEMENT:

The resistance of concrete against the action of destructive agencies greatly depends on the type and proportion of cement. The main chemical factor that influence the chemical resistance of cements are the C_3A in Portland cement and the alumina level of slag, if present. Chemical attack seems greater when both the level of C_3A and the alumina level of slag are higher. (Osborne, 1999)

Cement content in concrete has significant effect on the durability of concrete. Mix should be designed in a way to ensure proper cohesion and prevent segregation and bleeding. Researchers assessed the performance of cement individually by either exposing the mortar and concrete specimen in seawater or in its constituent salt solution, to study their strength and solution.

II. AIR ENTRAINMENT

Normally, harden concrete contained air is more uniform, as less absorption and permeability and more resistance to freezing and thawing. Normally 4-6% of air volume of concrete is entrained which is dispersed throughout the concrete. However, if the air entrained is greater than 10% by volume of the concrete, the compressive strength will be reduced to about one-half of the strength without air entrainment.

III. QUALITY OF WATER

Sea water contains a total 3.5% salinity of which

78% is NaCl

15% is $MgCl_2$ and $MgSo_4$

According to ACI 318-83 the mixing water should be portable and free from salts.

2.4.2 PROBLEMS OF DURABILITY

Durability problem of ordinary concrete can be linked with the severity of the environment and the use of inappropriate high water/cement ratio. High performance concrete with lower water/cement ratio are usually more durable than ordinary concrete not only because less porosity, but also because the capillary and pore network are disconnected due to development of self desiccation (Aiticin, 2003). For the best performance concrete, the mixture proportion must be appropriate to the specific application and preparation, placing, compaction and curing should be carried out under proper supervision.(Osborne, 1999) Problem of durability of concrete may be due to environment that concrete is exposed to or by internal causes within the concrete itself. Concrete will remain durable if;

I. The cement paste structure is dense and of low permeability

II. It is made with graded aggregate that are strong and inhert.

III. The ingredients in the mix contain minimum impurity such as alkalis, chloride, sulphate and silts.

Problems of durability in concrete could be any of the following action

a) PHYSICAL DURABILITY PROBLEMS

Physical durability problem can be any of the following actions

i. Permeability or percolation of water

ii. Freezing and thawing action

iii. Temperature stressed i.e high heat of hydration

b) CHEMICAL DURABILITY PROBLEMS

Chemical factors affecting durability is related to the presence of various ions dissolved in sea water or transported in the wet air. (Aitcin, 2003)

Chemical durability problem can be any of the following

I. Chloride ingress

II. Corrosion of reinforcement

III. Delay enttrigite formation

IV. Sulphate attack

V. Alkali aggregate reaction

2.4.3 RELATIONSHIP BETWEEN PERMEATION OF CONCRETE AND CONCRETE DURABILITY

Research evidences have illustrated the correlation between the relevant transport properties and either the penetration of different aggression substances or the mechanism of deterioration

I. SULPHATE ATTACK

Sulphate attack occurs when sulphate ions from the environment (e.g water or soil) penetrates into the concrete pores and within the internal system. According to (Spark, 1998) for sulphate attack to occur, concrete must be highly permeable, a source of water and sulphate must be present. The prominent form of sulphate attack on the internal cement matrix is when sulphate source reacts with calcium aluminates hydrate and monosulphate hydrate, resulting in the formation of ettringite. This reaction process is the reaction responsible for the crack generation and spalling of concrete members (Alam et al, 2012)

II. CHLORIDE INGRESS

There are interactions between the chloride ions and hydration product of cement, which may trigger the development of frost damage. However, the fundamental destructive effect of chloride is their influence upon the reinforcement corrosion process which is primarily due to their capacity to displace the corrosion inhibits properties of the alkaline cement paste pore solution. This risk is higher as the threshold of the chloride expected in corrosion is reached. (Basheer et al, 2001)

I. ALKALIS – SILICA REACTION

Alkalis- silica reaction in concrete (ASR) is one of the major chemical reactions causing gradual but severe deterioration of hardened concrete (Ichikawa, 2009). Concrete failure is due to certain unfavourable phenomena that occur during the reaction between alkalis and aggregates (Owsiak, 2004). This reaction between the silica in concrete aggregates and alkaline solution in the micro pores of concrete results in the formation of bulky hydrated alkalis silicate gel. The expansive pressure generated by this hydrated alkali silicate is generally believed to induce the cracking and deterioration of concrete (Ichikawa, 2009)

II. CARBONATION

When carbon dioxide diffuses into concrete, in the presence of water, it reacts with calcium hydroxide to form calcium carbonate. As a result of this, the PH of the pore solution is diminished below 10.the corrosion of the reinforcement will start if the carbonation progresses until the surface of the reinforcement is reached, as the passive layer of the steel surface will be dissolved (Basheer et al, 2001).

The pore structure, the permeability of concrete and the chemical reactivity are altered by product of carbonation. The interaction between carbonation and chloride contamination of concrete is the likely cause of the most severe corrosion problem encountered in practise (Basheer et al, 2001).

III. FREEZE – THAW DETERIORATION

The ease of movement of water into and within concrete depends on the pore structure characteristics of concrete. The pore distribution in concrete mainly determines the extent of damage to concrete during freeze –thaw cycle, the amount of freeze able water present in the capillary pores is also important and depends on the degree of saturation, the minimum temperature reached by the water and composition of the pore solution. The internal tensile stress developed due to freezing is observed to be in the range of 1- 4 N/mm^2. Therefore, internal cracks may develop initially and repeated cycles of freeze and thaw may result in critical damage of the concrete (Basheer et al, 2011)

IV. CORROSION

This type of deterioration is a serious problem in all climates. It may occur due to presence of water that penetrates throuhg concrete cover. The steel rusts as result of long exposure to water in the presence of air and makes it expand up to four times its original volume. This process create tensile stresses in concrete and eventually leads to cracking and spalling of the concrete cover zone (Afroze, 2002).

2.4.4 CAUSES OF PROBLEMS IN DURABILITY

In many cases, deterioration of concrete is caused by infiltration of various ions, liquids and gases from the environment. For instance, the ingress of chloride or carbon dioxide would depassivate steel in concrete, and the presence of oxygen and water may cause the steel to corrode. Like wisely, the ingress of chemicals, such as acids, alkalis and sulphates are responsible for the chemical degradation of concrete. Also, moisture movement during freezing and thawing action also causes deterioration of concrete (Basheer et al, 2001).

The problems in durability are caused by many categories but can majorly be classified into two categories which are

a. EXTERNAL CAUSES

External causes are:

I. External weathering condition

II. External temperature

III. Abrasion

I. Electrolyte action

II. External humidity

III. Attack by natural or industrial liquid gas

b. INTERNAL CAUSES

Internal causes can further be categories into

i. Physical causes

Typical examples of problem attribute to physical causes are :

a) Frost action

b) Volume change due to different in thermal properties of aggregates and cement paste.

ii. Chemical causes

This can be categories into

a. Alkali aggregate reaction

b. Corrosion of steel

CHAPTER THREE

MATERIALS AND METHODOLOGY

The scope of this study is to provide more insight on the level of permeability of concrete mixes, with varying parameters in addition to determine the most efficient mix amongst the standard mixes that will be used in the in problematic areas of North Cyprus. For these purpose, an ***experimental methodology*** will be selected and carried out. The "principle" concrete mix combination to be tested will be CEMII with superplasticizer and with crystalline water proofing admixture, which is preferred with one of the leading companies in North Cyprus (Tufecki group). A detailed experimental campaign is designed to check the effect of each parameter in this "key" concrete mix combination. CEMI and CEMIII will be used to check varying amount of slag replacement compared to CEMII. In addition to three different slag contents, concrete mixes will be prepared: 1) with both superplasticizer and crystalline water proofing admixture, 2) with only superplasticizer, 3) with only crystalline water proofing admixture, and 4) without any crystalline water proofing admixture or superplasticizer addition for all the types of cements suggested.

Main focus of this study is to check the impermeability performance of concrete with varying parameters; and since it is known that the impermeability of these mixes will be evolving with continuous hydration of cement, compressive strength development of each mix will also be observed simultaneously, so that the effect of ongoing hydration can be verified. Table 3.1 summarises the parameters controlled in different concrete mixes to be tested in this experiment campaign.

3.1 METHODOLOGY

Impermeability of concrete is of great significance in any engineering structure which comes in contact with water (e.g. concrete foundation) or which is intended to retain water (e.g water reservoir). In this experiment procedure, different trails of mixes were made as shown in table 3.1 below. Concrete of different percentage of replacements and admixtures were produced, maintaining specific interval of slump to investigate their permeability characteristics.

Table 3.1: Organization and distribution of test samples

Cement type	Test types	Without admixture		With only plasticizer		With only CWA		With plasticizer and CWA		Total cube
		7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	
CEMI	Impermeability	3	3	3	3	3	3	3	3	24
	Compressive strength test	3	3	3	3	3	3	3	3	24
CEMII	Impermeability	3	3	3	3	3	3	3	3	24
	Compressive strength test	3	3	3	3	3	3	3	3	24
CEMIII	Impermeability	3	3	3	3	3	3	3	3	24
	Compressive strength test	3	3	3	3	3	3	3	3	24
		Total cube samples								144

0 - 65% of cement was replaced by GGBS and the mix grade C30 was used with varying admixture. For each kind of mix or level of replacement, 12cube samples were casted by thoroughly mixing cement, fine aggregates (0-5 mm), coarse aggregates (5-12mm) and (12-19mm), admixture(s) (depending on the mix design) and water in the in the mixer machine. For every kind of mix, the slump was taken to check the effect of additives on the concrete workability. All the cubes were subjected to 100% humidity curing for specified period, then compressive test was carried out on 3 samples of each mix on the due dates with a compressive test machine, but as for the impermeability test the sample were removed a day before the test to dry the sample from existing water of curing.

Also for impermeable 3 samples were tested from every mix, for 7 and 28 days, these samples were arranged in permeability testing machine, setting the water and air pressure to 5 and 8 bars respectively for 72 hours. After wards, the samples were broken with the aid of a machine, and the water rise through the sample was measured.

3.2 MARTERIALS USED

In this section various materials available in North Cyprus that were used in this study will be discussed in details. The cost of materials used is given in the appendix.

3.2.1 CEMENTS

Three different types of BEM cimento, which is the most widely used cement brand in North Cyprus, were selected.

1. CEMII/B-S 42.5R; Ordinary Portland cement is replaced with 33.5% by mass. Is the most widely used cement in North Cyprus because of its slow hydrating due to slag's nature and it is beneficial for its lower rate of heat hydration in North Cyprus where the temperature is generally high.
2. CEMIII A42.5R 55.5% by mass of OPC is replaced by slag to check the effect of increased slag compared to CEMII/B-S 42.5R
3. CEMI 42.5R is Portland cement containing pure clinker compounds without any slag replacement which serves as the control set in this experiment.

Table 3.1 shows the Properties of cements used in this experiment

Table 3.2: Properties of cements used

Properties	CEMI 42.5R	CEMII/B-S 42.5R	CEMIII A42.5R
Insoluble residue	0.24	0.50	0.38
SO_3 (%)	0.56	2.47	1.83
MgO	1.68	3.48	4.22
Ignition loss (%)	2.85	2.00	2.25
Specific gravity(g/m^3)	3.10	3.00	2.97
Specific surface(cm^2/g)	3230	4660	4690

3.2.2 PLASTICISER

DRACO LEVELCON X50 conforming with EN934-2 ,ASTM C-494 type G is used in North Cyprus by one of the leading ready mix concrete company (Tüfekçi group), was the superplasticizer admixture selected. It has a high water-reducing characteristics, it was added into the mixing water at ratio 1.03% based on cement weight and thoroughly mixed with the concrete.

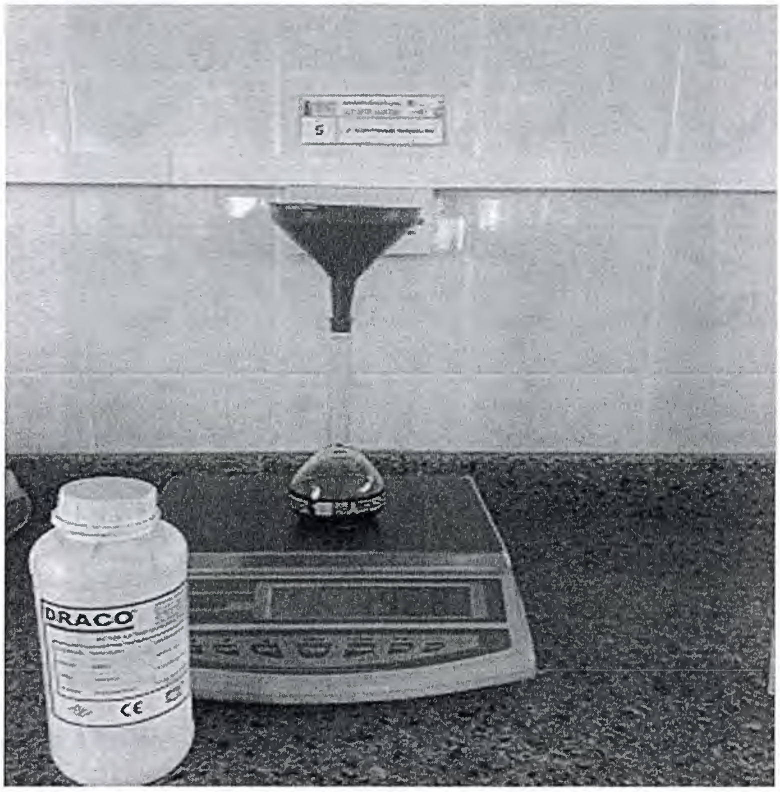

Figure 3.1: Weighing procedure of the superplasticizer admixture (DRACO LEVELCON DX 50 SR)

3.2.3 CRYSTALLINE WATER PROOFING ADMIXTURE

DAWCO K11 CWA was the water proofing material used as crystalline water proofing admixture; it forms a high crystalline structure within the pores and capillary of the concrete. This product is used by the Tüfekçi group in potentially problematic areas where water infiltration to concrete is highly expected. Beside slag replacement in cement, addition of DAWCO K11 CWA crystalline water proofing admixture and its performance on the level of impermeability of concrete mixtures will also be studied in this thesis.

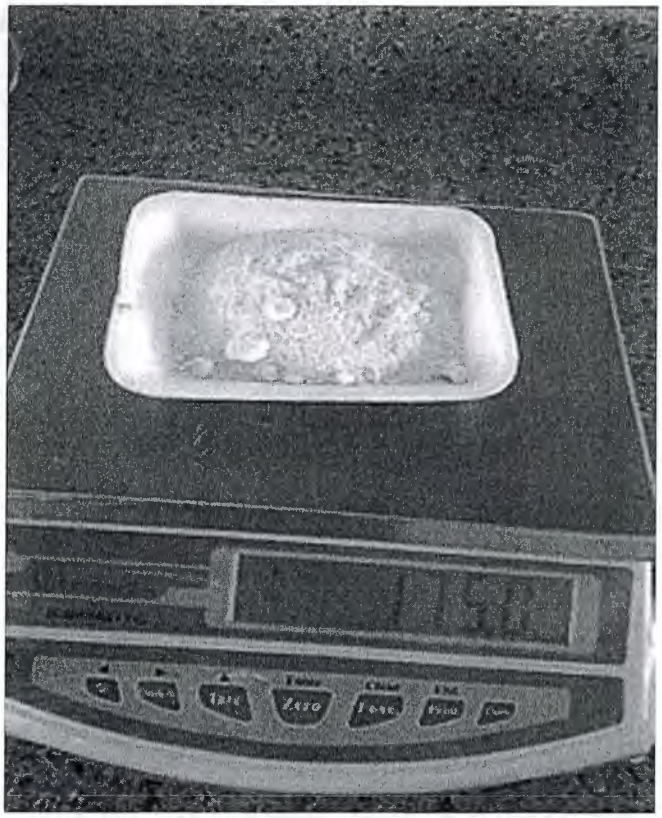

Figure 3.2: Weighing procedure of CWA (DAWCO K11 CWA)

3.2.4 WATER

Potable water was used without testing or qualification as mentioned in ASTM C1602 standard.

3.2.5 AGGREGATES

Crushed aggregates of three different size categories, ranging from 0-19mm, were used. These sizes were selected because self compacting concrete (SCC) is being considered, as in the case study. The specific gravity and water absorption values of the aggregates are provided in appendix table3

For the concrete mixes, the aggregates distribution were selected to be 0-5mm crushed by 54%, 5-12mm fine aggregate to be 19% and 12-19mm coarse aggregate 27%. Aggregate of lower gradation were selected for the self compacting concrete because it provides a better flow and a higher workability.

3.2.5.1 PRELEMINARY TESTS ON THE AGGREGATES

Several tests were conducted during material selection for appropriate batching, these tests include:

a. SIEVE ANALYSIS

Aggregate gradation is an important design parameter affecting the workability and strength properties of concrete (Ozen and Guler, 2014)

The grain size analysis test helps to determine the relative properties of different grain sizes, distributed among certain size range (gradation) in order to determine its compliance with design and production standard.

APPARATUS

All the apparatus were carefully selected

I. A scale for weighing samples

II. Sieves of different sizes

III. Oven for drying

SAMPLE PREPARATION [AGGREGATE]

Aggregate samples of different sizes 0-5mm, 5-12mm and 12-19mm were obtained from rocks available in north Cyprus, reduced to test size in according to standards. These samples were dried to a constant weight in an oven set.

PROCEDURE

I. The samples were weighed to the nearest 0.1g by total weight sample. This was to check for any loss of material after the sample has been graded and suitable sieve sizes were selected in accordance with specification.

II. The sieves were nested in order of decreasing size from top to bottom and began agitation and shaking the sample for sufficient amount time.

III. COARSE AGGREGATES

After the materials have been sieved, each tray was removed; each size was weighed independently and was recorded to nearest 0.1g. The happed aggregate within the sieve were carefully removed.

IV. FINE AGGREGATES

The materials retained on each sieve were weighed as well, to the nearest 0.1g, and the material entrapped within the sieve were cleaned out with the aid of soft brush.

Figure 3.3: Aggregates of different gradation

a. LOS ANGELES ABRASION TEST

This is the most common method for assessing the abrasion resistance of aggregates which determines the relative competence or resistance to abrasion of aggregate.

In this study, aggregate 5-12mm, and 12-19mm sizes were tested to evaluate their mechanical property.

Graded aggregate samples were placed into a steel drum containing eleven steel spheres and were rotated for 500 revolutions. The interior of the cylindrical drum has shelf that picks up the sample and charge during each rotation and drops them on the opposite side of the cylinder, thereby subjecting the aggregates sample to attrition. The cylinder rotates at 30 to 33 rpm and after the 500th revolution, the machine automatically stopped by a counter switch. After completion of revolution, the resulting sample was sieved over 1.7mm sieve to determine the amount of degradation that occurred during the test. The abrasion loss as percentage of the original mass of the test sample after 500 revolutions was calculated.

$$K_{500} = \frac{G0 - G500}{G0} \times 100$$

Where k_{500} = abrasion loss after 500 revolution [%]

G_0 = Original sample mass[g]

G_{500} = sample loss after 500 revolution [g]

The result was calculated according to TS699 for 500 revolutions.

CALCULATION FOR LOS ANGELES ABRASION TEST

$G_O = 5000$

$G_{500} = 3377$

$K_{500} = \frac{5000-3377}{5000} * 100$

$K_{500} = 32.46\ \%$

According to American standard which specifies the abrasion test value to a range between 25- 55 percent, that is, the 32.46 percent obtained from out test confirms that the aggregate is suitable construction.

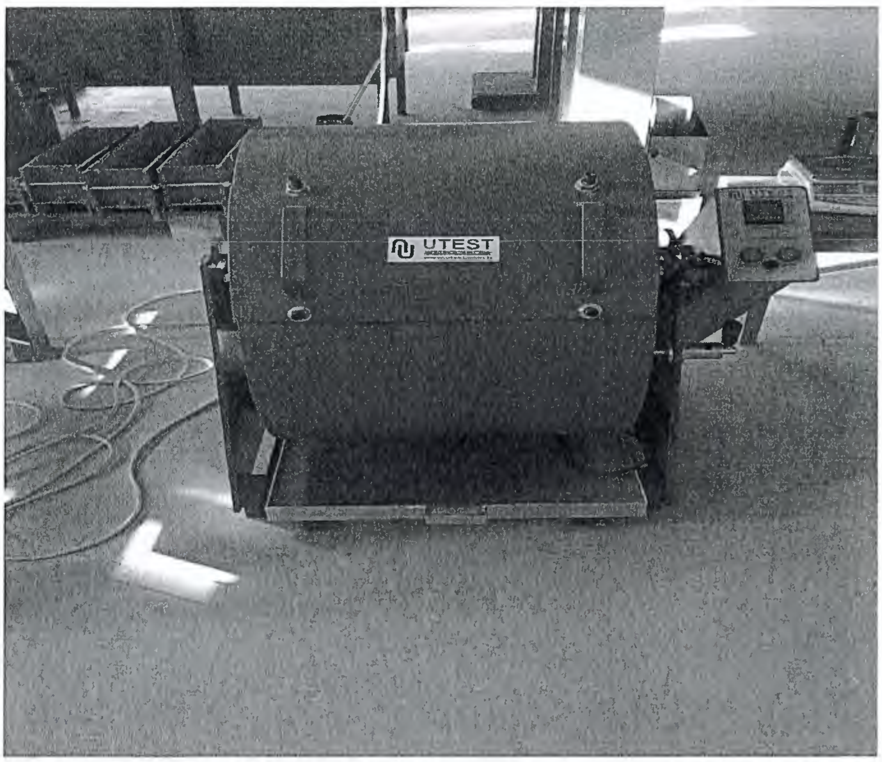

Figure 3.4: Los Angeles test machine

b. METHYLENE BLUE TEST FOR FINE AGGREGATES

Clay mineral is naturally found in small fraction of naturally crushed aggregates. Generally, presence of clay in high quantity is considered harmful in concrete and mortar by increasing the required mix water to provide a concrete or a mortar of a specific workability which substantially reduces the strength, durability and volume stability of the hardened concrete or mixture. Clay mineral absorbs methylene blue [a cationic dye] from aqueous solution because of its ability to exchange cations. This is the basis of this test method: measuring cation exchange capacity and surface area, also for detecting the presence of clay minerals.

The Methylene blue value [MBV] resulting from the test depends on the characteristics such as mineralogy, particles sizes and porosity. If the MBV is below 12, the aggregate is accepted according to standard. Though high MBV value a times does not necessarily mean that the material is not suitable due to presence of clay, it can be an indication of problems such as high water demand, so further investigation especially in case of high fined aggregates should be carried out.

The apparatus used for this experiment were weighing balance [AASHTO M23], Methylene blue test set, 2mm sieve and quantitative filter paper.

Materials used were 200g sample of dies fine aggregates, methylene blue, and 500ml of clean water.

The sample of aggregates were obtained from a concrete mix company in North Cyprus [Tüfekçi group], and was heated to about 105□ to ensure a well dried sample, then sieves with a 2mm sieve.

500ml of water was added to 200g of the sample that passes through the 2mm sieve. The methylene blue test apparatus was set up and a stirrer designed for 600rpm helps in proper mixing of the sample. For every 3min 1ml of methylene was added to the sample and the readings were taken by making a drop for the mixture on a quantitative filter paper at every mixing interval until the required indication was noticed (clear spark like indication by the drop edges)

Readings from methylene blue test are:

Number of reading (drops on filter paper) = 9

Mass of aggregate = 200g

Amount of methylene blue used = 9ml

Percentage presence of clay material in the aggregate % = $\left(\frac{\text{Amount of methylene blue used}}{\text{Mass of aggregate}}\right)$ Amount of methylene blue used

Percentage presence of clay material in the aggregate % = $\left(\frac{9}{200}\right) \times 9 = 0.405\%$

Since the result is less than 1%, which conforms with AASHTO TP 57-06 and the number of drops on the quantitative filter paper before indication is less than 12, it indicates that the aggregate is suitable for use in construction.

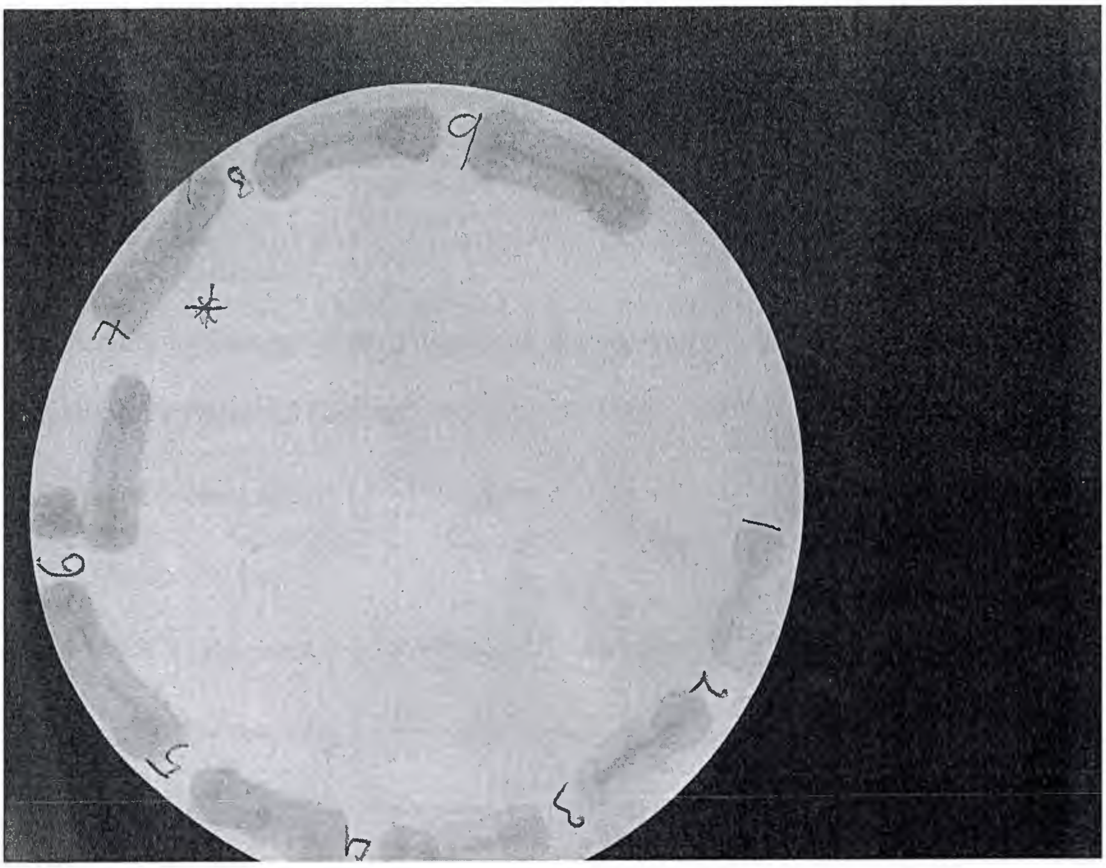

Figure 3.5: Quantitative litmus paper showing methylene drops

3.3 MIX DESIGN PARAMETERS AND CALCULATIONS

Specified proportion of materials including water and admixtures according to the concrete mix design shown in appendix table 5 was used for determining the suitability of the local materials available in North Cyprus. Twelve batches were prepared as described in the table, cement or cementious material content was 340 kg/m^3 for all the mixes to obtain comparable water permeability and compressive strength test at both 7 and 28 days. CEMI, CEMII and CEMIII were the cements used in all the mixture. The chemical and physical analysis of cement and slag are given in the appendix. All the categories of aggregates used were crushed aggregates and the nominal maximum size was 19mm, because self compacting concrete (SCC) is a target as in the case study.

The concrete mixes were prepared at two w/c ratios; 0.5% and 0.65%. All batches that includes superplasticizer were prepared at 0.5% w/c ratio while other mixtures where prepared at 0.65%. The concrete were mixed in accordance to ASTM 192.

An example mix design calculation

Cement = 340kg/m^3

Percentage of Water used = 0.5- 0.65%

Aggregates = {(0-5) = 54%, (5-12) =19%, (12-19) = 27%}

Admixture = 1.2%

Density = $\left(\frac{mass\ (g)}{volume(cm3)}\right)$

The density for compositions are given in the appendix

Density for CEMII = 3.03g/cm^3

Volume of cement used = $\left(\frac{340}{3.03}\right)$ = 112dm^3

Note; 1000dm^3 = 1m^3

For 0.5% w/c ratio used = 0.5×340kg/m^3 = 170 kg/m^3

Volume of 0.5% w/c ratio = $\left(\frac{221}{1}\right)$ = 221 dm^3

CRYSTALLINE WATER PROOFING ADMIXTURE

1.4% crystalline water proofing admixture was used = $\left(\frac{1.47}{100}\right)$ × 340 = 4.99 kg/m^3

Density of crystalline water proofing admixture used = 2.745 g/m^3

Volume of crystalline water proofing admixture used = $\left(\frac{4.99}{2.745}\right)$ = 1.82dm^3

1m^3 of concrete = 1000dm^3 (cement + water + admixture + aggregate), there for 1000dm^3 – cement –water – admixture = aggregate

1000- 112-221 – 1.82 = 665.18dm^3

54% of (0-5) aggregate was used; 0.54 × 665.18 = 359.19 dm^3

19% of (5-9) aggregate was used; 0.19 × 665.18 = 126.38 dm^3

27% of (9-12) aggregate was used; 0.27 × 665.18 = 179.60 dm^3

Mass of (0-5) aggregate = volume × density = 359.19 × 2.69 = 966.22kg/m^3

Mass of (9-12) aggregate = 126.38× 2.7 = 341.23 kg/m^3

Mass of (12-19) aggregate = 179.60 × 2.74 = 492.10 kg/m^3

The mixes varies with percentage of the w/c ratio and admixture used as shown in appendix

3.4 MATERIAL WEIGHING

For each batch, the quantities of the materials were weighed according to mix design of the total weight of the batch. The weighing balance used has an accuracy of 0.1%

3.5 SAMPLE PREPARATIONS

The representative samples of concrete materials available in North Cyprus were obtained from one of the major leading concrete mixing company (Tüfekçi group) and properly kept under room temperature before commencing the experiment.

Series of experiments were carried out on the materials as discussed above to verify its conformity with recognized standards.

Three cubes are taken from each sample, but it can vary depending on specification, and the moulds are 150mm ×150mm ×150mm (BS EN 12390-1:2000)

3.5.1 MIXING

After proper measurement as specified in the mix design, the materials were properly mixed in the laboratory batch mixer, in a manner that avoids loss of water and other materials.

The period of mixing was an average of 5 minutes after all the materials were put in the drum to ensure proper mix of concrete of uniform appearance.

3.5.2 COMPACTION

In order to ensure symmetrical distribution of concrete within the mould; used in making sample cubes, an approximate half of its depth in the mould was compacted using tamping bar on the average of 25strokes on each layer. The sides of the mould were also randomly tapped to close the voids possibly left by tamping bar.

3.5.3 CURING

The test specimens were stored in a place free from vibration at room temperature for couple of hours from the time of addition of water to the dry materials in order to allow the concrete to set. After this period, the specimen were marked and removed from the moulds, then immediately submerged into water and kept there until they were taken out on the 7th and 28th day for compressive strength test and 6 th and 27 th day for impermeability test i.e a day before the testing date, according to European standard (EN 1239-8). The water was also maintained at room temperature.

3.5.4 SLUMP TEST

Slump test was the test used in determining the workability of the fresh concrete. The apparatus used are slump cone and tampering rod. It is important that the slump test meets the range limit dictated by the British standard, the sample should be repeated if it fails to meet the required slump (EN 206-1:2000)

PROCEDURE

i. The internal surface of the mould was thoroughly cleaned and places in smooth, horizontal, rigid and non-absorbent surface.

ii. The mould was filled in about four layers with the freshly mixed concrete, each approximately to one-fourth of the mould height

iii. Each layer was tampered randomly, tampered 25 times with tampering rod.

iv. After filling the mould and tampering the last layer, the concrete at the top surface of the mould was levelled with trowel

v. The mould was removed from the concrete immediately by raising it slowly in the vertical direction

vi. The difference in the level between the height of the mould and the highest point of the subsided concrete was measured and recorded in millimetres.

Figure 3.6: Slump test procedure

Table 3.3: Slump test results

Cement type	Without super plasticizer or crystalline water	Only super-plasticizer (mm)	Only Crystalline water proofing admixture (mm)	With super-plasticiser & crystalline water
CEMI	200	190	220	210
CEMII	220	240	220	210
CEMIII	180	200	200	180

Table 3.4: Classes of slump according to EN 206-1:2000

Slump class	Slump in (mm)
S_1	10-40
S_2	50-90
S_3	100-150
S_4	160-210
S_5	≥ 220

The slumped concrete can take different shapes, and according to the profile of concrete, the slump is termed as true slump, shear slump or collapse slump. A very dry mix having 0-25mm is suitable for road making, low workability mix of slump 10- 40 mm is suitable for foundations with light reinforcement; medium workability slump 50-90mm is good for normal reinforced concrete placed with vibration, high workability concrete $\geq$ 10 mm. According to the case study used in this investigation, the selected slump range is S_4 - S_5; self compacting concrete (SCC) is considered for the deep raft foundation with heavy reinforcement shown in figure3.7 below. The high workability characteristics of the SCC is to allow easy flow of the concrete during casting, form strong bond with the reinforcing bars and requires no vibration or compaction

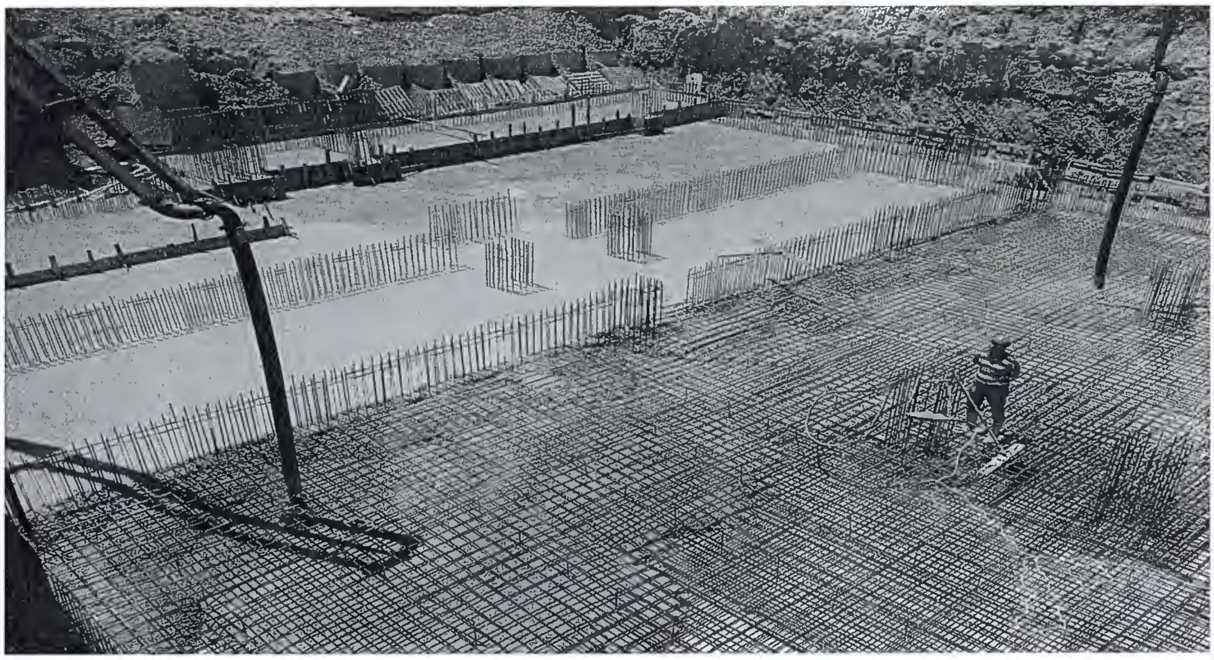

Figure 3.7: Deep raft foundation near a sea shore at Kyrenia, TRNC

3.6 TEST FOR WATER PERMEABILITY

The main reference standard is European standard (EN12390-8); specifies a method of determining the depth of penetration of water under pressure in hardened concrete. The model of the equipment used in this study is UTC 180 which can accommodate only three samples at a time, although there are other models that accommodates up to six samples.

3.6.1 DESCRIPTION OF EQUIPMENT

The equipment has an adjustable locking height for stabilizing the samples while applying pressurized water the water pressure was set on 5 bars and air pressure on 8 bars. It was connected to the water mains and no electrical connection is required except for the compressor. The water was connected to water inlet connector and compressor connected through air inlet connector. The numbering of the sample was made from left to right; the tubes were also numbered to indicate which burette corresponds to each sample.

The samples were simultaneously subjected to pressured water penetration on their cover surface for 72 hours.

The other faces were free for visual inspection except of the upper face that was covered by the locking plate. At the end of the 72th hour as defined in the reference standard, the samples were split into two using an indirect tensile device. By carefully examining the broken face of the sample, the level of maximum water penetration was measured and recorded.

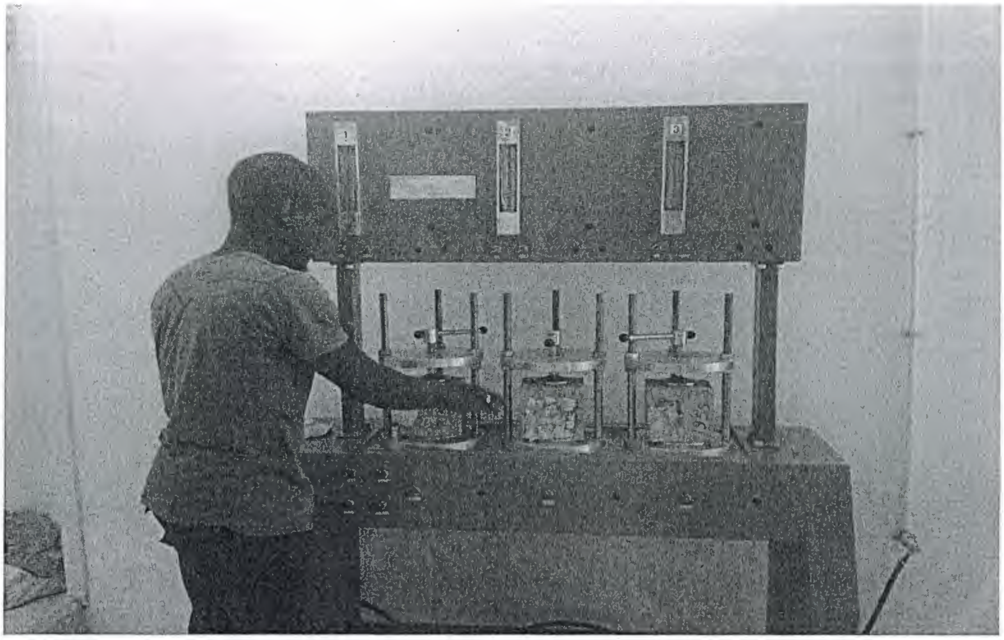

Figure 3.8: Setting of cube samples in the Permeability testing machine (UTC-0180)

3.6.2 OPERATION OF THE PERMEABILITY TESTING EQUIPMENT

The machine was connected to water mains using a Ø10mm diametre hose and air supply with a Ø10 mm diameter hose. Also the two drainage points of the machine (overflow of water tank / and over flow tray) to a drain using Ø10mm diameter hose.

The air pressure was set at 8 bars

The water tap was turned open

The water tank was filled to1000ml water

The water inlet of the sample was closed

The air tap was turned to evacuate bleed of air present in the tank and allows water to enter

The tap was immediately closed when water was noticed from over flow tank

3.6.3 PERMEABILITY MEASUREMENT

The weight of samples were measured and recorded before they were placed in the permeability testing machine. They were then subjected to pressurized water for period of 72 hours before they were then taken out and weighed again to check their mass difference before setting them up for splitting as shown in figure 3.6 below. Finally, the level of water rise in each sample was measured and recorded.

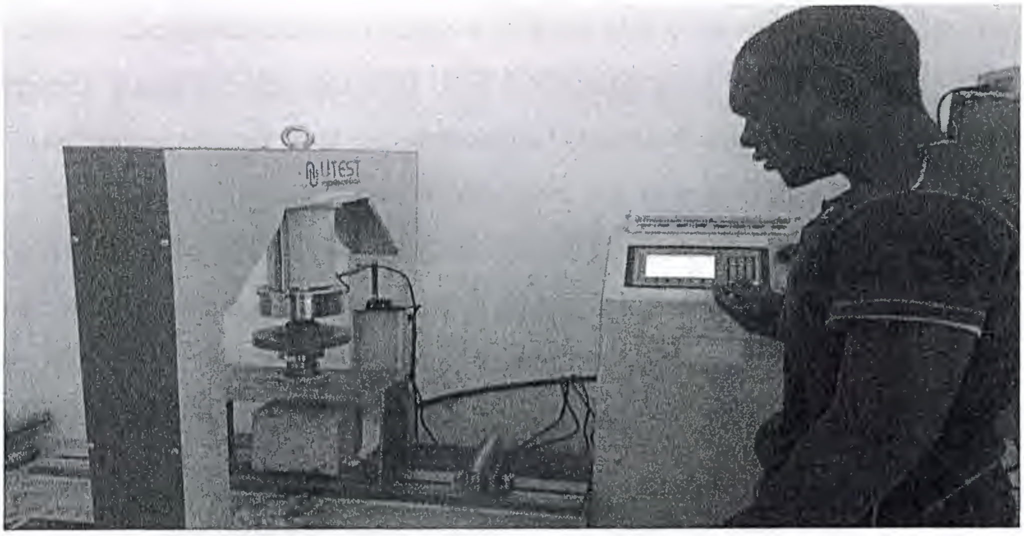

Figure 3.9: Sample splitting for permeability measurement

Figure 3.10: Level of water rise in a sample

3.7 COMPRESSIVE STRENGTH TESTING

Compressive strength is the ability of material to resist load tending towards reducing its size. This is the most important test in concrete which gives an idea about all the characteristics properties of concrete. Similar to permeability measurement, the strength development of each type of sample is tested in two ages; 28 days as a standard and 7 days for checking the performance in early age as well.

In this study cube specimens of $150mm * 150mm * 150mm$ were used. After the sample were properly cured for the specified time for compressive test, they were removed and excess water was wiped out from the surface the beaming surface of the testing machine was cleaned of particles and the specimens were placed one after the other in such a way that the load would be applied to the opposite sides of the cube cast. It was aligned centrally on the base plate of the machine and the load was applied gradually and continuously till the specimen fails. Finally the maximum load was recorded for each sample and the average was calculated.(BS EN 12390-2:2009, BS EN 12390-3:2000)

Figure 3.11: Testing a cube sample for its compressive strength

CHAPTER FOUR

RESULTS AND DISCUSSION

As described earlier, the permeability characteristics of self compacting concrete mixes with varying parameters has been investigated in this thesis study. The compressive strength of these mixes was also evaluated to check the effect of ongoing hydration. The level of permeability was obtained by measuring the highest rise of water in each splitted sample, and the compressive strength characteristic was also obtained with the aid of compressive strength testing machine showing the maximum stress the samples can withstand before failure.

A total of 144 cube samples were used in this experimental campaign for both the permeability and compressive strength characteristics investigations. Impermeability performance of 12 different mixes was investigated for both 28 and 7 days, 3 cube samples were tested for each mix at each age. Similarly, 72 cube samples were tested under compressive strength and 3 samples were also tested for each mix at each age. Two different w/c ratio values were employed in the manufacture of mixes providing the targeted slump test.

a). 0.5% w/c ratio was used for all mixes that contains plasticizer

b). 0.65% w/c ratio was used for other mixtures without plasticizer

Table 4.1: Permeability and compressive strength test results obtained from different concrete mixes for 7 and 28 days

Cement type	Test type	Without superplasticizer		With only superplasticizer		With only CWA		With superplasticizer and CWA	
		7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
CEM I	Permeability (cm)	11.5	6.5	1.73	1.10	5.00	2.30	4.8	1.00
	Compressive strength test (MPa)	24.90	35.40	32.50	38.80	23.30	29.00	28.70	41.40
CEMII	Permeability (cm)	4.40	2.20	1.53	0.90	2.87	1.80	1.80	1.30
	Compressive strength test (MPa)	27.20	29.20	34.20	42.50	24.00	32.20	33.20	40.10
CEMIII	Permeability(cm)	4.90	0.6	1.4	1.00	8.6	0.70	1.9	1.00
	Compressive strength test (MPa)	21.40	37.22	28.20	39.10	20.98	35.7	45.40	60.00

4.1 PERMEABILITY CHARACTERISTIC OF THE CONCRETE MIXES

It can be clearly observed from the results obtained that level of permeability is less than the value obtained in 7 days irrespective of the type of mixture. This shows that the age of hydration generally affects the level of permeability in all the concrete mixes. In this experimental procedure, water reducing plasticiser, "levelcon DX50" was used as the plasticiser which reduces water requirement by certain percentage (10% -15%) and gives the concrete mix high strength and good workability at low w/c ratio. Davco K11 CWA, a crystallization based powder system that protects and water proofs concrete structures by crystallization. Graphs of permeability characteristics of the concrete mixes are provided below. The plotted points in the graph are the average values obtained for 3 samples of the same batch tested at same age, where the error bars explain that; the value less than one standard deviation away from the mean accounts for 68.27% of the set, while two and three standard deviation away from the mean account for 95.45% and 99.73% respectively.

Table 4.2: Permeability results of CEM I mix for 7 and 28 days showing the mean and standard deviation

Table 4.2: Permeability results of CEM I mix for 7 and 28 days showing the mean and standard deviation

CEM I	7 Days mean	StandardDeviation	28 Daysmean (cm)	Standard Deviation
No Admixture	11.5	1.3	6.5	1.3
Plasticizer	1.73	0.4	1.1	0.2
CWA	5	0.1	2.3	0.1
Plasticizer& CWA	4.8	1.1	1	0.1

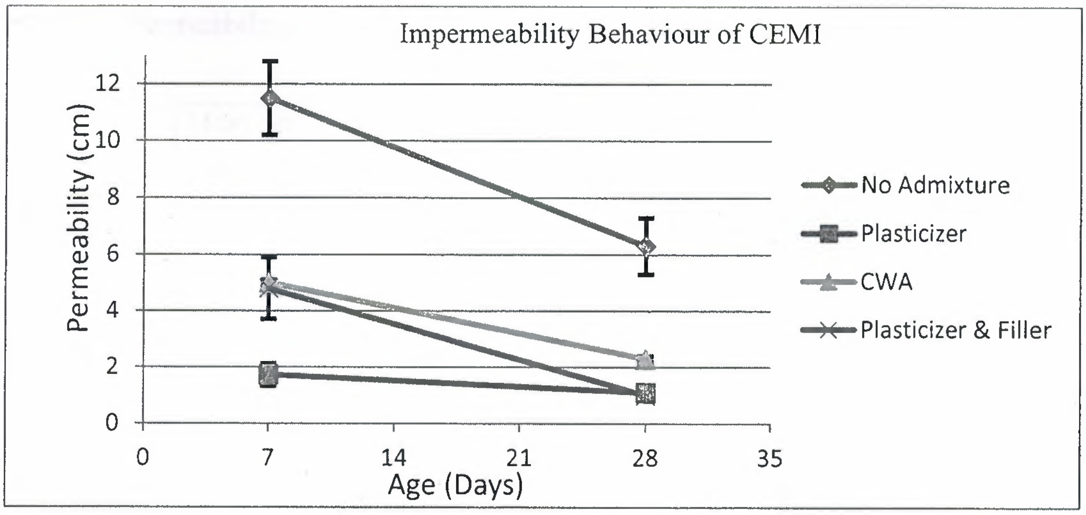

Figure 4.1: Permeability behaviour of CEMI mixes

The permeability characteristic of concrete mixtures with CEMI is given in the figure 4.1 above, where the level of permeability against ages is represented. It can be observed that all the mixes decrease in permeability level as the age increases. This tendency is expected to occur due to ongoing hydration and microstructure being developed with the increasing hydration products within the samples, causing denser and more impermeable concrete. Mixture with no admixture is observed to have the highest level of water permeability, followed by the mixture with only crystalline water proofing admixture while mixture with only super plasticiser has the least permeability. This sequence of permeability is almost the same for both 28 and 7 days, however at 28th day mixtures with only plasticiser and with both plasticizer and crystalline water proofing admixture are observed to have almost the same permeability value. This shows that reduced w/c ratio being compensated with the addition of plasticizer, has the most significant effect on improving the impermeability of CEMI both in early and late ages. On the other hand, the use of crystalline water proofing admixture is observed to have much lesser effect on the concrete impermeability since the combination of both superplasticizer and crystalline water proofing admixture shows almost the same performance compared to the concrete mix with only plasticizer. The mixture with only CWA and with both admixture seem to exhibit the same performance in the 7days age, however later on, mixture with the both admixture shows an increase in impermeability performance, which is one of the highest impermeability performances exhibited together with mixture with only plasticizer.

Table 4.3: Permeability results of CEM II mix for 7 and 28 days showing the mean and standard deviation

CEM II	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
No Admixture	4.4	1.7	2.2	0.7
Plasticizer	1.5	0.5	0.9	0.5
CWA	2.9	0.6	1.8	0.2
Plasticizer & CWA	1.8	0.4	1.3	0.3

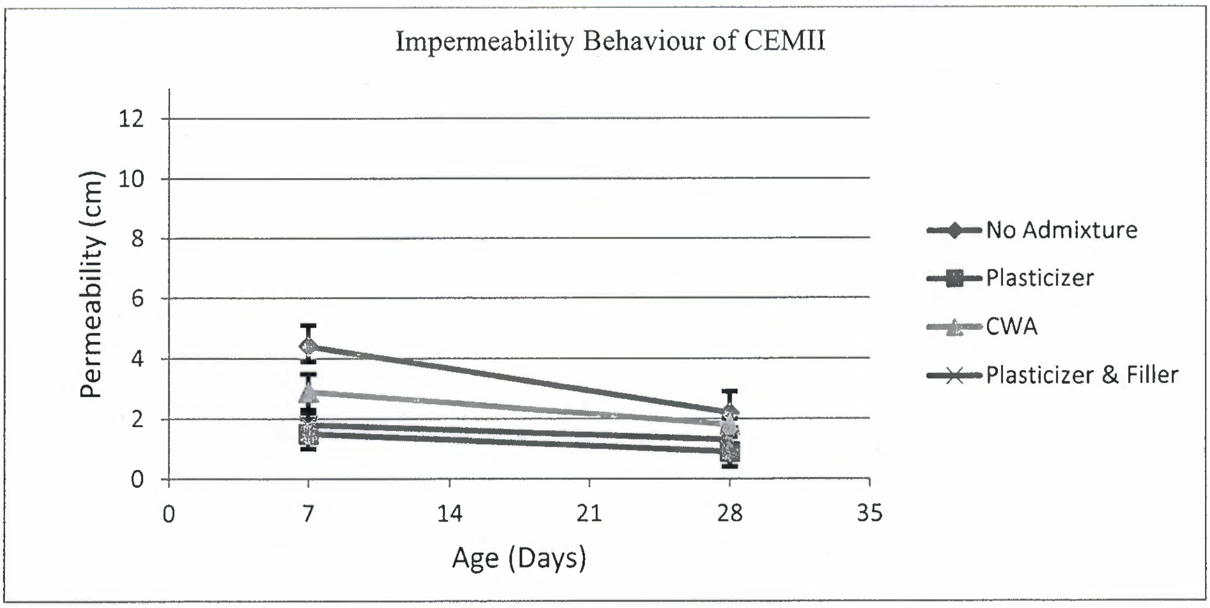

Figure 4.2: Permeability behaviour of CEM II mixes

Figure 4.2 above shows the permeability characteristics of CEMII against ages. In this graph, the level of permeability is observed to also decrease with ages; with progressing hydration process. The sequence of the level of permeability is same as in CEMI. However, there is clear distinction in the levels of permeability of each type of mix compared with CEMI. In addition to this, unlike in CEMI where mixture with only plasticizer and with both superplasticizer and crystalline water proofing admixture were observed to have same level of permeability, in CEMII the permeability level is different as the mixture with only plasticizer having the lowest value of permeability.

Table4.4: Permeability results of CEMIII mix for 7 and 28 days showing the mean and standard deviation

CEM III	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
No Admixture	4.9	1.9	0.6	0.2
Plasticizer	1.4	0.1	1	0.4
CWA	8.6	1	0.7	0.2
Plasticizer & CWA	1.9	0.3	1	0.2

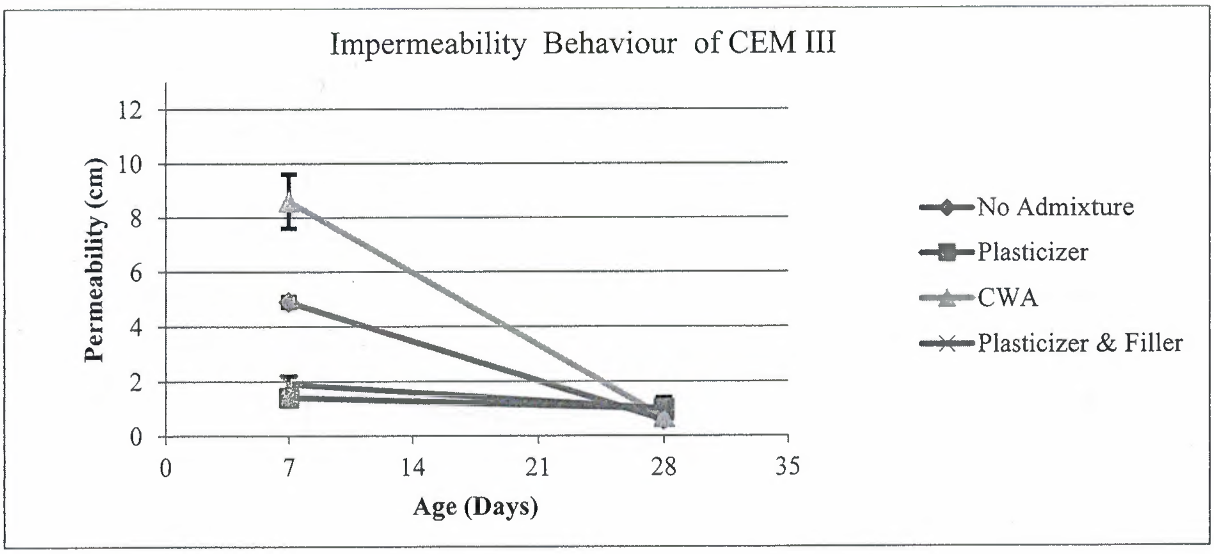

Figure 4.3: Permeability behaviour of CEMIII mixes

In figure 4.3 given above, the permeability characteristics of CEM III against ages are observed to be similar to the characteristics exhibited by CEM I and CEM II, the level of permeability decreases with increase in time. However, the sequence in 7 days permeability level is different; in CEM III mixture with only CWA has the highest permeability level with a wide range from the second most permeable mixture which is with no admixture and the mixture with only plasticizer still maintains the least permeability. Another different feature observed is that at the age 28days, CEM III shows the least permeability in all same mix types compared with CEMI and CEM II. Also, there is a great permeability difference for all CEMIII mixes, between the ages of 7 and 28 days. However the permeability difference is not significant in all the mixes in 28 days. Therefore, for economical reasons, if CEMIII is to be used for water resisting structures, no need to use any admixture provided that its compressive strength is satisfied. This shows that increased slag cement (CEM III) yields a highly water resisting concrete independent of added plasticizer or CWA. The same finding is also reported in many references (Al- Amoudi et al, 2011), (Tamilarasan et al, 2012)

Table 4.5: Permeability results of the three cement mixes without admixture for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	11.5	1.3	6.5	1.3
CEM II	4.4	1.7	2.2	0.7
CEM III	4.9	1.9	0.6	0.2

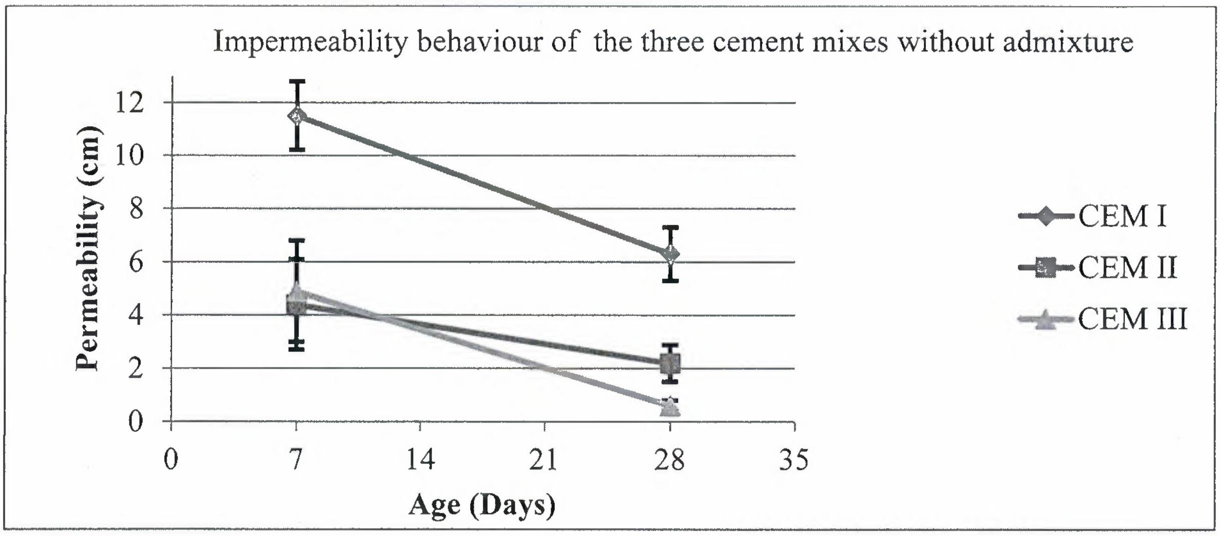

Figure 4.4: Permeability behaviour of the three cement mixes without admixture

It is observed in graph 4.4 describing the graph of permeability of the three cement mixes without any admixture that the permeability decreases with ages and CEM III has the least permeability while CEMI has the highest permeability in both early and late ages. This behaviour clearly shows the positive effect of slag content on the impermeability characteristics of the samples. The high permeability level of CEMIII at early age is due to slow hydrating characteristic of slag cement.

Table 4.6: Permeability results of the three cement mixes with only superplasticizer for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	1.73	0.4	1.1	0.2
CEM II	1.5	0.5	0.9	0.5
CEM III	1.4	0.1	1	0.4

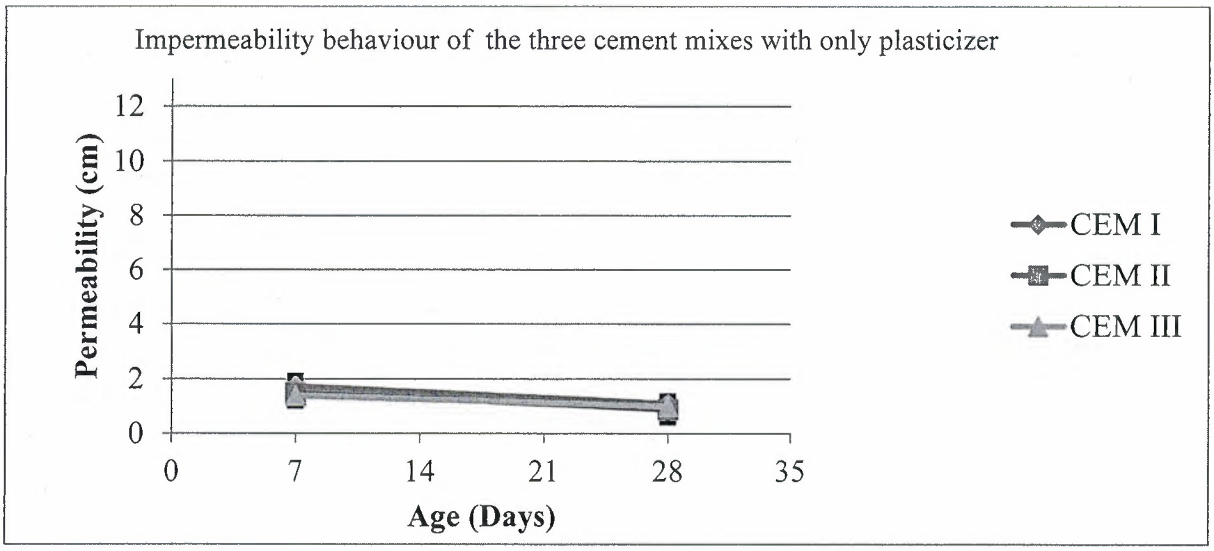

Figure 4.5: Permeability behaviour of the three cement mixes with only superplasticizer

Figure 4.5 is the graph for permeability of the three cement mixes with only plasticizer for both 28 and 7 days. It is observed that the permeability reduces with ages with significantly low permeability in both ages and the concrete mixes show very little differences from themselves in both 28 and 7 days. Compared to figure 4.4,it can be observed that addition of only plasticizer yields similar impermeability performance of concrete mix, even though cements with varying slag contents were used. This implies that if plasticizer is decided to be used in concrete manufacture where impermeability is an issue, any of the three types of cements will yield similar impermeability behaviour. This explains that the w/c ratio is an important factor in controlling water permeability in concrete structures.

Table 4.7: Permeability results of the three cement mixes with only CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	5	0.1	2.3	0.1
CEM II	2.9	0.6	1.8	0.2
CEM III	8.6	1.3	0.7	0.2

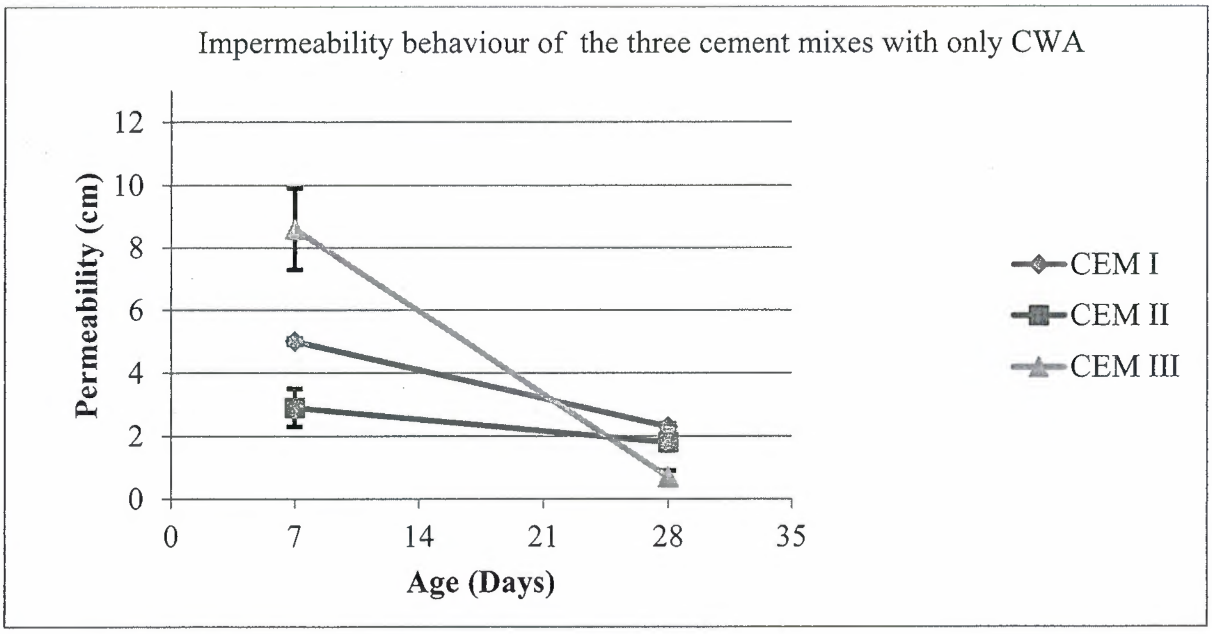

Figure 4.6: Permeability behaviour of the three cement mixes with only CWA

The graph of permeability of the three cements mixes with only CWA for 28 and 7 days is described in figure 4.6. CEM III is observed to have the highest permeability level at early age, but lowest permeability at the late age. This can be due to the slow hydration characteristic of CEM III which is also inhibited with the addition of the CWA. Another observation made in figure 4.6when compared with figure 4.4 is that; CEMIII without admixture and CEMIII with only CWA have very close impermeability values. This finding implies that with the availability of increased slag content, CWA remains redundant. However, when behaviour of CEMI without any admixture and with only CWA is compared in figure 4.6 and figure 4.4, effect of CWA on improving impermeability becomes more significant. It is also observed that CEMII and CEMI have very similar impermeability behaviour at 28days, even though their early age (i.e7days) was distinct.

Table 4.8: Permeability results of the three cement mixes with superplasticizer and CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	4.8	1.1	1	0.1
CEM II	1.8	0.4	1.3	0.3
CEM III	1.9	0.3	1	0.2

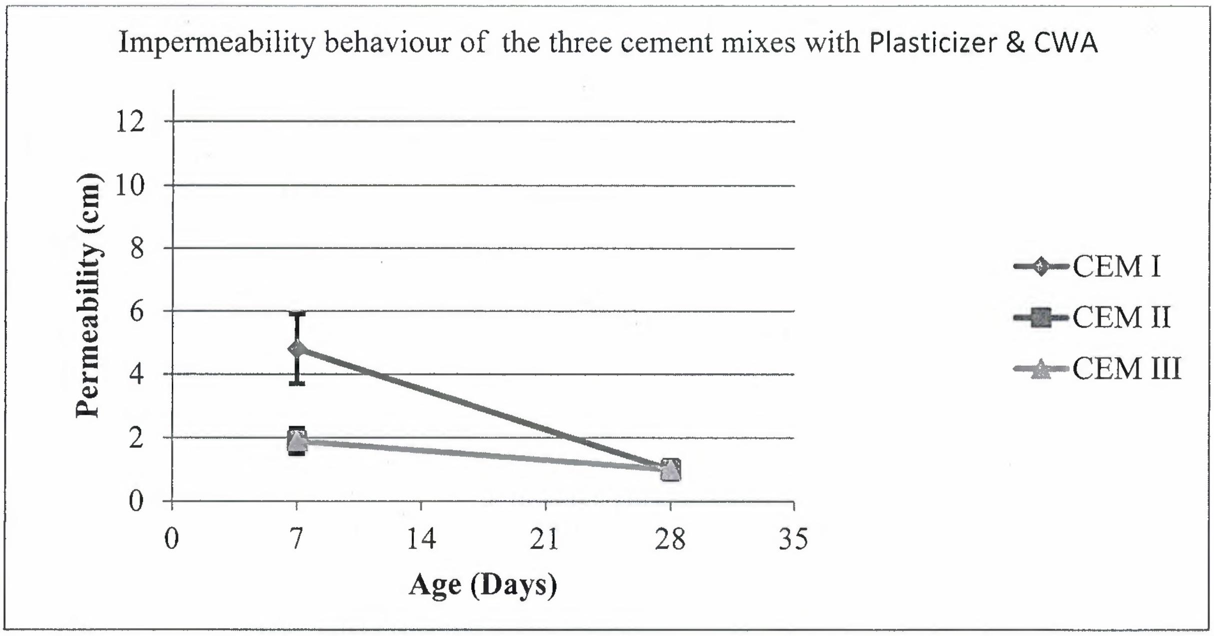

Figure 4.7: Permeability behaviour of the three cement mixes with both superplasticizer and crystalline water proofing admixture

Figure 4.7 also describes the graph of permeability of the three cements mixes with both admixtures for 28 and 7days. CEMI has the highest permeability at early age but there is no significant difference in the mixes at 28 days. CEMI and CEMIII exhibit similar permeability characteristics in both early and late ages. However, in the late age all the mixes have almost the same values of permeability, which is lower for CEMI and CEMII but not lower for CEMIII mixtures prepared with only plasticizer shown in figure 4.5.

Generally it is observed that w/c ratio has the most significant impact on permeability of concrete and the permeability generally decreases with ages.

4.2 COMPRESSIVE STRENGTH TEST

The compressive strength test was carried out on the same sample types as mentioned earlier to check and verify the effect of progressing hydration of cement and development of microstructure formation. The compressive strength results obtained from this experiment for both 7 and 28 days is given in table 4.1 above. The result shows that compressive strength in concrete is greatly affected by different factors such as w/c ratio, admixtures, and cement types. Same as in permeability test, the plotted points in the graph are the average values obtained for 3 samples of the same batch tested at same age, where the error bars explain that; the value less than one standard deviation away from the mean accounts for 68.27% of the set, while two and three standard deviation away from the mean account for 95.45% and 99.73% respectively.

Table 4.9: Compressive strength results of CEM l mix for 7 and 28 days showing the mean and standard deviation

CEM I	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
No Admixture	24.9	2.2	35.4	0.9
Plasticizer	32.5	2.5	38.8	2.2
CWA	23.3	1.5	28.9	0.5
Plasticizer & CWA	38.7	1.6	45.4	0.3

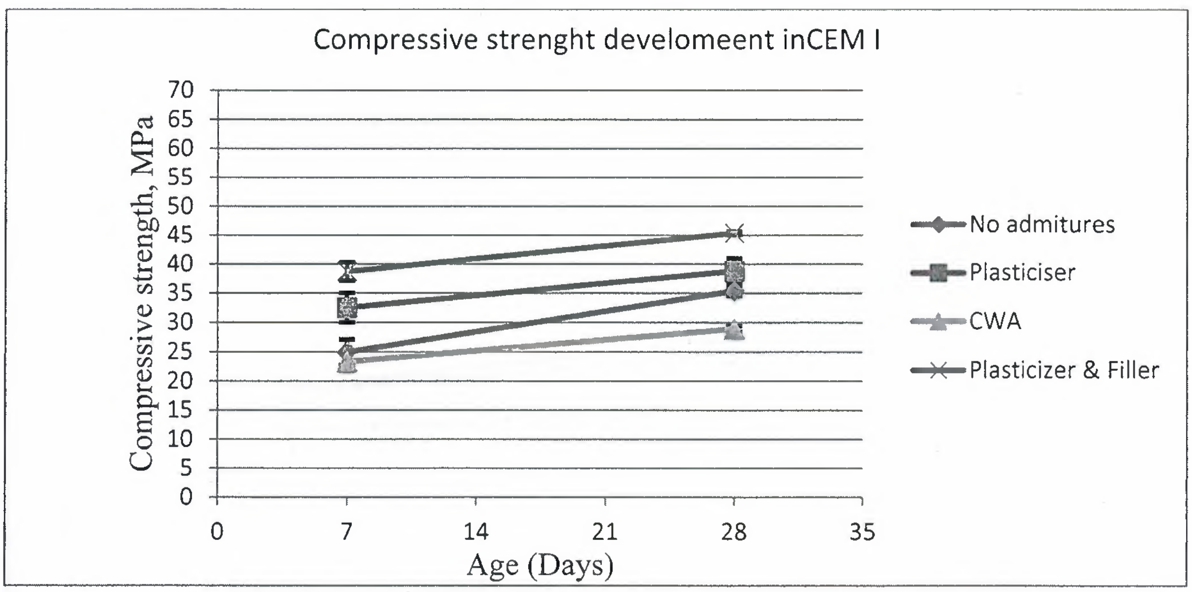

Figure 4.8: The compressive strength development of CEMI mixes

Figure 4.8 shows the compressive strength of CEM I with and without admixture at 7 days and 28 days. Similarly to what is observed in permeability behaviour, this finding also implies the effects of ongoing hydration and developing microstructures, in this case yielding an increased compressive strength. It can be observed that the strength generally increases as the age increases. The samples with both admixtures is observed to have the highest compressive strength value in 28 days, followed by the sample with only plasticizer and lastly sample with CWA having the least value. This can be explained that, the reduced w/c ratio has significant effects on the compressive strength and the plasticizer used as a reagent, compensate for the reduced w/c ratio in other for the sample to fulfil the designed workability standard. Whereas the CWA absorbs the water from the concrete mix without any compensation for w/c ratio required. However, it helps in the densification of the particle structures of the concrete. But in the sample with both admixtures, microstructure development and w/c ratio of the sample are justified giving the concrete higher strength.

Table 4.10: Compressive strength results of CEMII mix for 7 and 28 days showing the mean and standard deviation

CEM II	Mean for 7days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
No Admixture	27.5	0.2	29.2	0.6
Plasticizer	34.2	1.5	42.5	2
CWA	24	3.1	32.2	0.9
Plasticizer and CWA	33.2	1	40.1	1.9

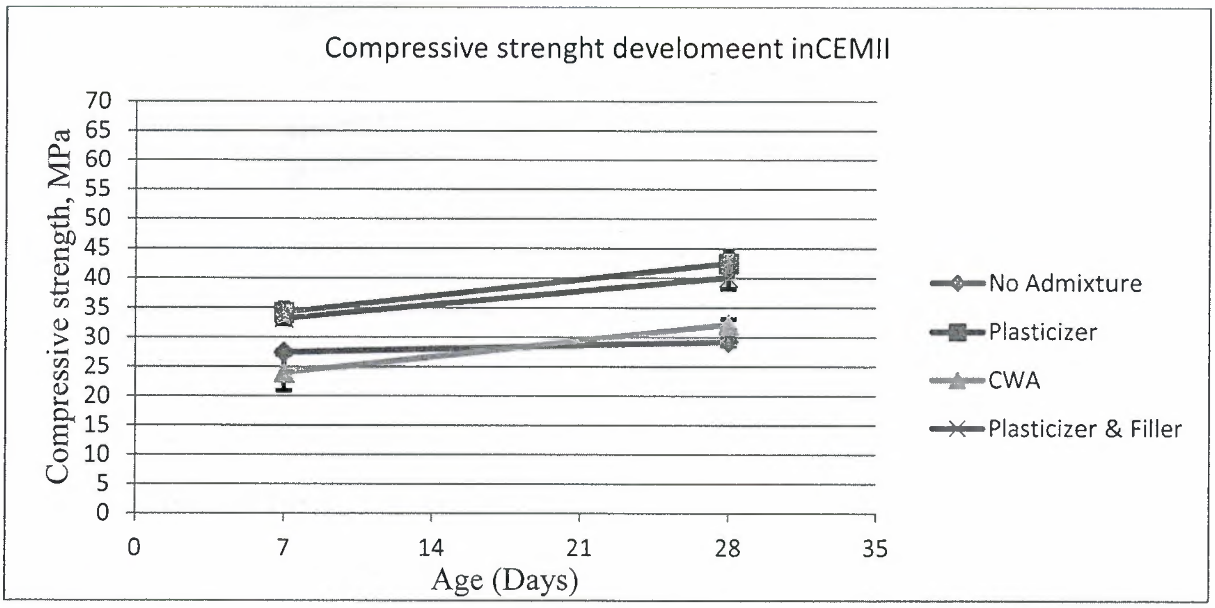

Figure 4.9: The compressive strength development of CEMII mixes

Figure 4.9 shows the compressive strength of CEMII of different mixes for both 7 and 28 days. The compressive strength is observed to increase as the age increases, with sample with both admixtures having the highest value of compressive strength at 28 days, followed by the sample with only plasticizer having same trend as in CEMI. But in CEMII, sample with only

CWA has higher compressive strength value than sample without admixtures. This can be due to the replacement of cement with slag which is less dense than cement (given in appendix)

Table 4.11: Compressive strength results of CEMIII mix for 7 and 28 days showing the mean and standard deviation

CEM III	Mean for 7 days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
No Admixture	21.4	1.8	37.2	0.6
Plasticizer	28.2	1	39.1	0.2
CWA	21	1.4	35.7	1.4
Plasticizer and CWA	45.4	0.6	60	7.1

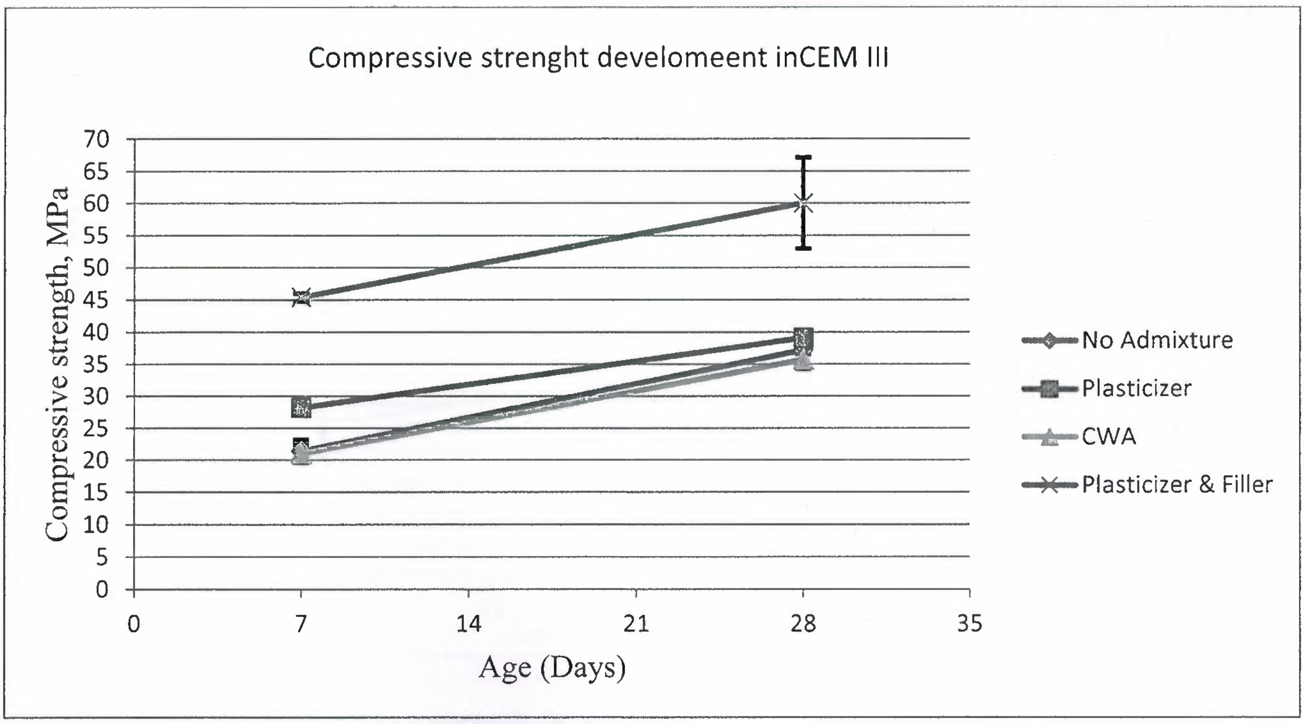

Figure 4.10: The compressive strength development of CEMIII mixes

In figure 4.10 above is the compressive strength of CEMIII with different mixes as in other samples for both 7 and 28 days. The compressive strength is also observed to increase with age but with wider variation between the ages compared with CEMI and CEMII. This can be due to the fact that CEMIII undergoes much slower hydration at early age. The sequence of the compressive strength hierarchy with CEM II but with much higher values in CEMIII when both admixtures were used, and also shows the highest compressive strength value of all the mixes.

These findings indicate that only CWA or only plasticizer addition to CEMIII does not yield a significant effect on compressive strength performance. However, addition of both admixtures is observed to have a significant effect.

Table 4.12: Compressive strength results of the three cement mixes without admixtures for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
CEM I	24.9	2.2	35.4	0.9
CEM II	27.5	0.2	29.2	0.6
CEM III	21.4	1.8	37.2	0.6

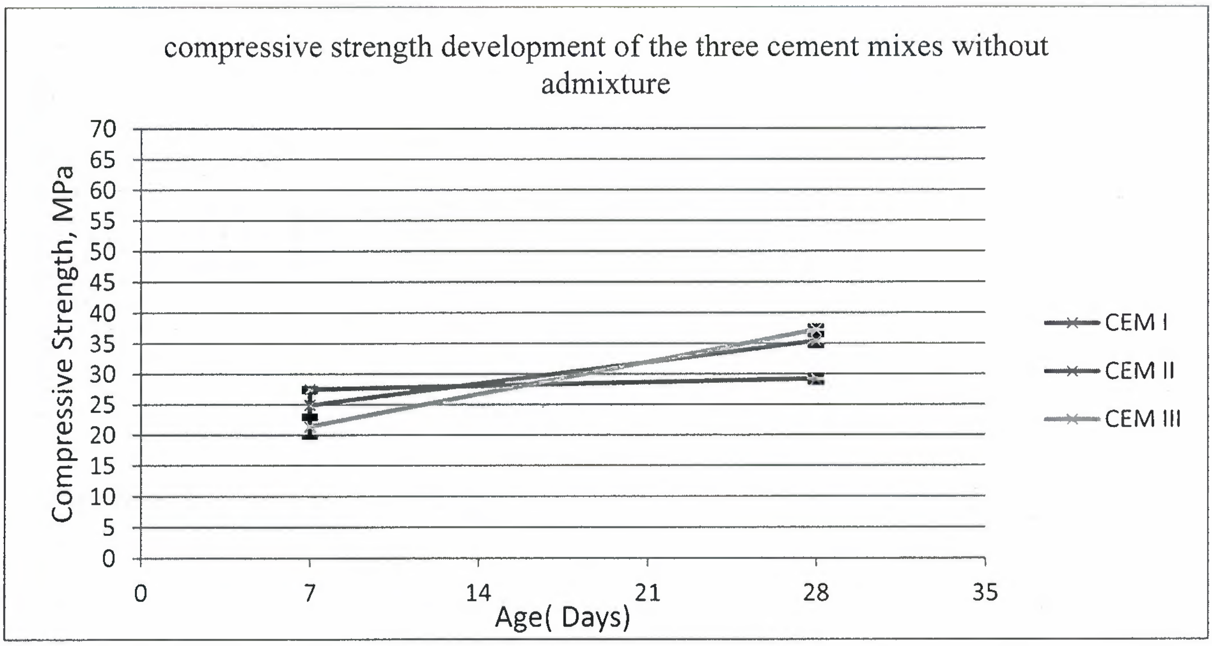

Figure 4.11: Compressive strength development of the three cement mixes without admixture

Figure 4.11 is the graph of compressive strength test of the three cements mixes without admixtures for both 28 and 7 days. It can be observed that the compressive strength increases as the age increases in all the mixes with CEM III having both the lowest and the highest strength value in both 7 and 28 days respectively. This is due to its low hydrating characteristics of slag cement, especially at early age. However, partial replacement of Portland cement (PC) with slag is observed to yield relatively lower value. This is similar to the study carried out by Tamilarasan et al, 2012, where replacement of Portland cement with

Table 4.14: Compressive strength results of the three cement mixes with only CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
CEM I	23.3	1.5	28.9	0.5
CEM II	24	3.1	32.2	0.9
CEM III	21	1.4	35.7	1.4

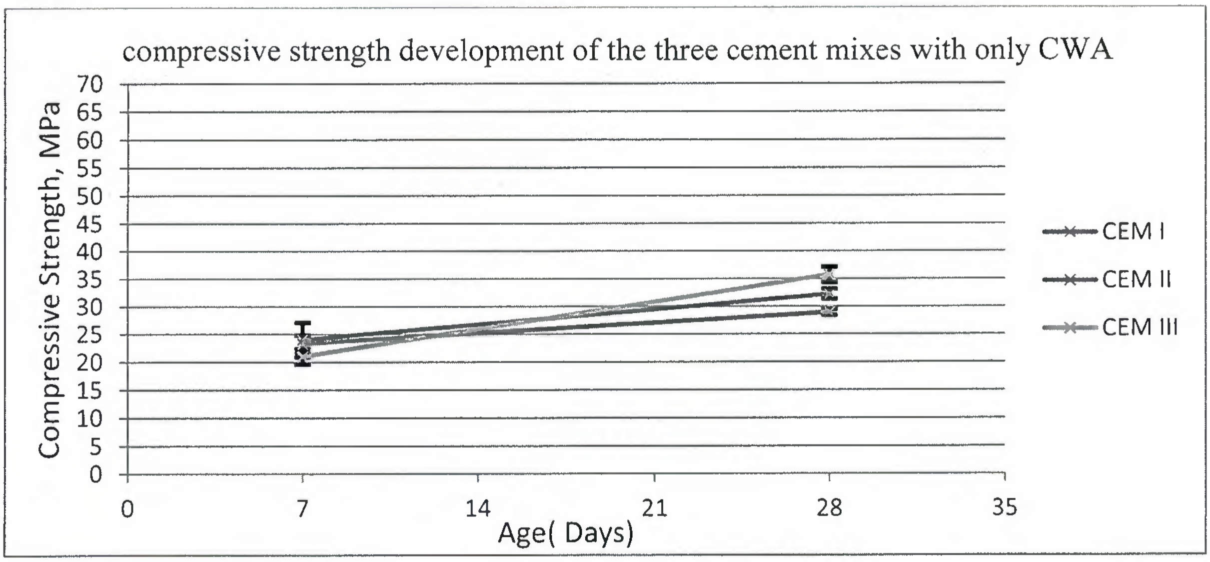

Figure 4.13: Compressive strength development of the three cement mixes with only CWA

Described in figure 4.13 is the graph of compressive strength development of the three cement mixes with only CWA for 28 and 7 days. It is observed that the cement mixes have low strength at early age and at the late age compared with other mixing parameters. This can be due to the low rate of hydration hindered by the CWA as it absorbs the water content in the concrete mix. CEMIII gives the lowest and the highest strength development at both early and late ages respectively. This supports the findings observed in figure 4.6; where CEMIII had the highest and lowest permeability values of 7 and 28 days respectively.

Table 4.15: Compressive strength results of the three cement mixes with superplasticizer and CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
CEM I	38.7	1.6	45.4	0.3
CEM II	33.2	1	40.1	1.9
CEM III	45.4	0.6	60	7.1

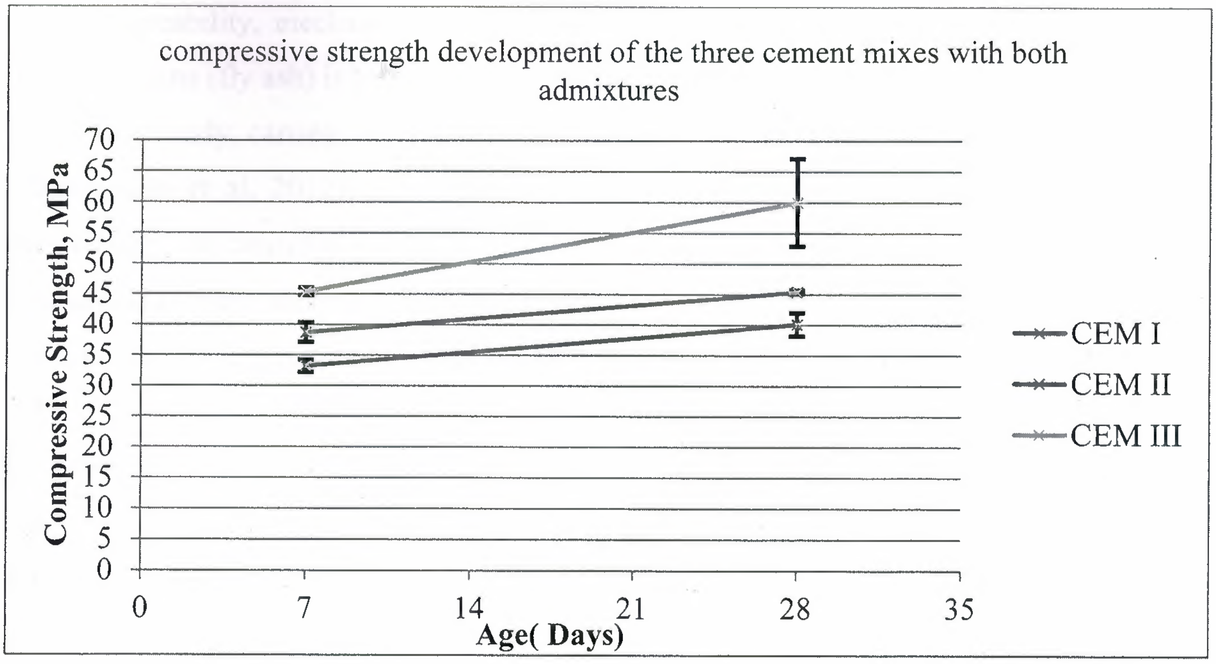

Figure 4.14: Graph of compressive strength development of the three cement mixes with both Plasticizer and CWA

It is observed in figure 4.14 representing the graph of compressive strength development of the three cement mixes with both Plasticizer and CWA for 28 and 7 days that the compressive strength increases with ages. All the mixes have high compressive strength at both early and late age. CEMIII shows the highest compressive strength value in both early and late ages. And its 28th day compressive value is observed to be the highest value of all the mixes tested for compressive strength in this thesis study.

Generally, it can be observed that the compressive strength increases with age and also slag cement has lower hydration characteristic in early age but with higher compressive strength at 28 days. Combination of both admixtures shows the highest compressive strength in 28 days for all mixes with CEM III having the highest compressive strength values. Similarly, in CEMI and CEMII, their highest compressive strength development is observed in their mixes using both admixtures with slight difference from their mixes with only plasticizer at 28th day test. However, the compressive strength test development in both CEMI and CEMII mixes with only plasticizer in the early age is higher than their mixes with both admixtures.

Comparing the results obtained from this experimental study with the previous work studies as discussed in the literature review, explained in an experiment carried out in King Fahd University of Petroleum and Minerals (Al-Amoudi et al, 2011), both experiments prove that the impermeability, mechanical properties and durability characteristic of cement replaced with pozzolana (fly ash) is better compared to ordinary Portland cement.

In another study carried out on the partial replacement of cement by GGBS till 60% (Tamilarasan et al, 2012), the results agrees with the outcome of this experiment as the permeability of concrete was decreased, resistance to chemical was increased and the mechanical property (strength) was also increased.

Also, in another experiment in which the cement was replaced with silica fume (Bagheri et al, 2008), the result shows the significance effect of replacement of silica fume in reducing the permeability correlating with the permeability reducing characteristic GGBS used in this study.

Figure 4.15 below gives the percentage increment of CEMI in both the compressive strength developments and the impermeability behaviour for 28days. It is observed that mixture with plasticizer has low increment in both tests. This explains that the rate of hydration is speed up when plasticizer was added to the mix

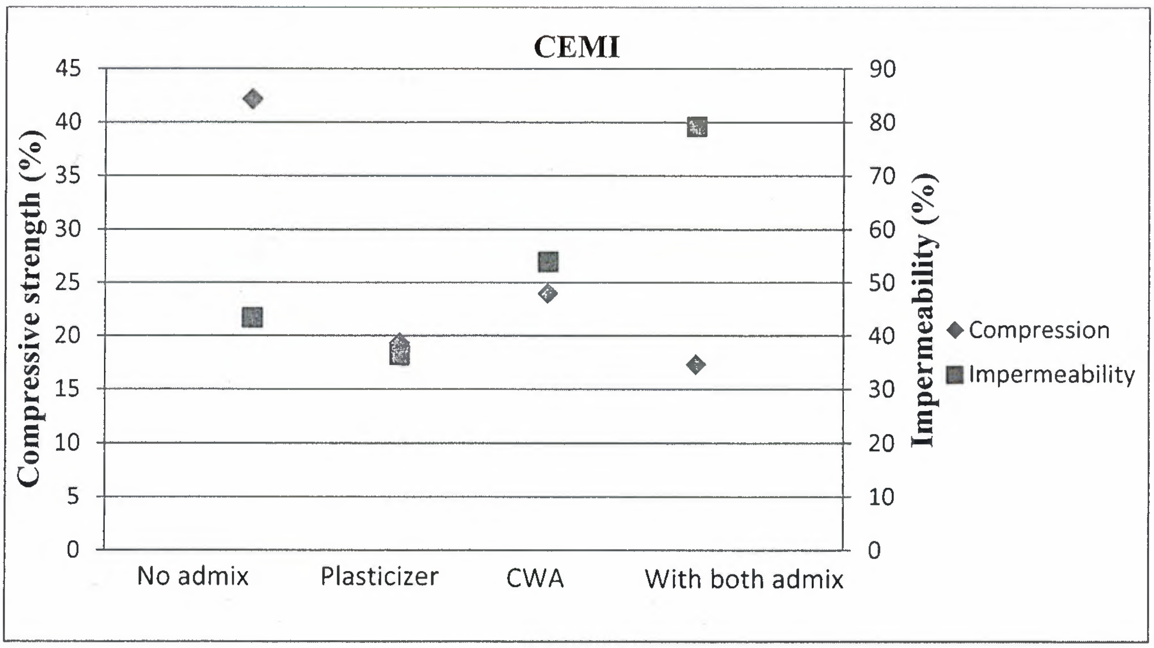

Figure 4.15: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for CEMI

Figure 4.16 below gives the percentage increment of CEMII in both the compressive strength developments and the impermeability behaviour for 28days. The compressive strength is observed to give little variation but with high percentage of impermeability in mix with no admixture.

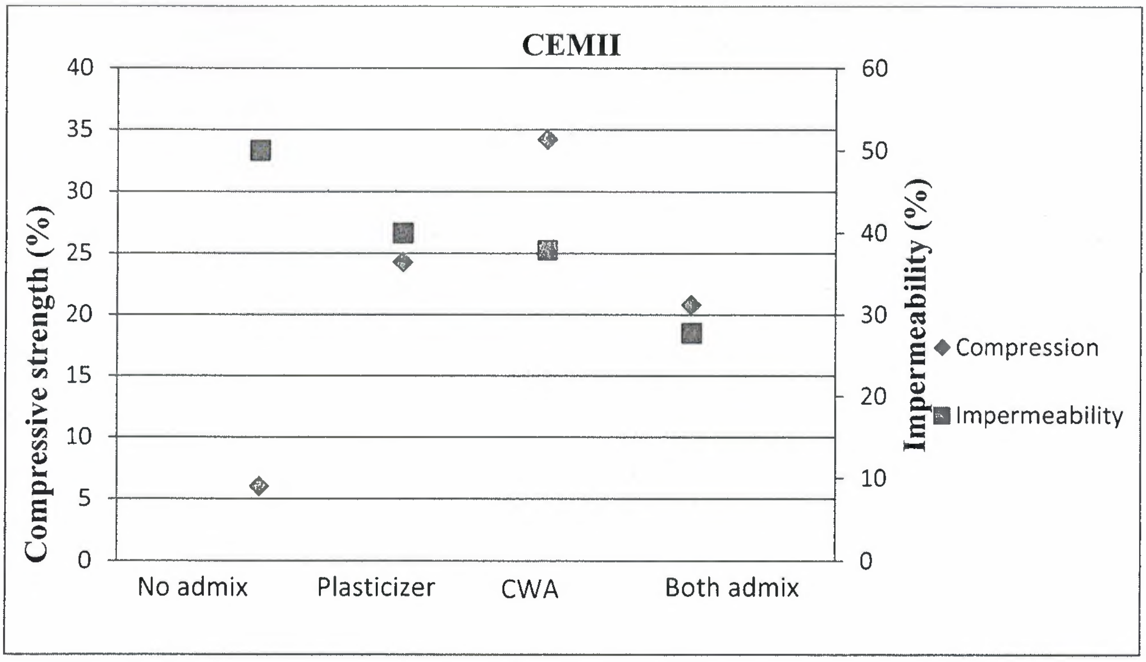

Figure 4.16: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for CEMII

It is observed in figure 4.17 below that the rate of hydration in CEMIII is slow which explains the high variations in mixes without superplaticizer.

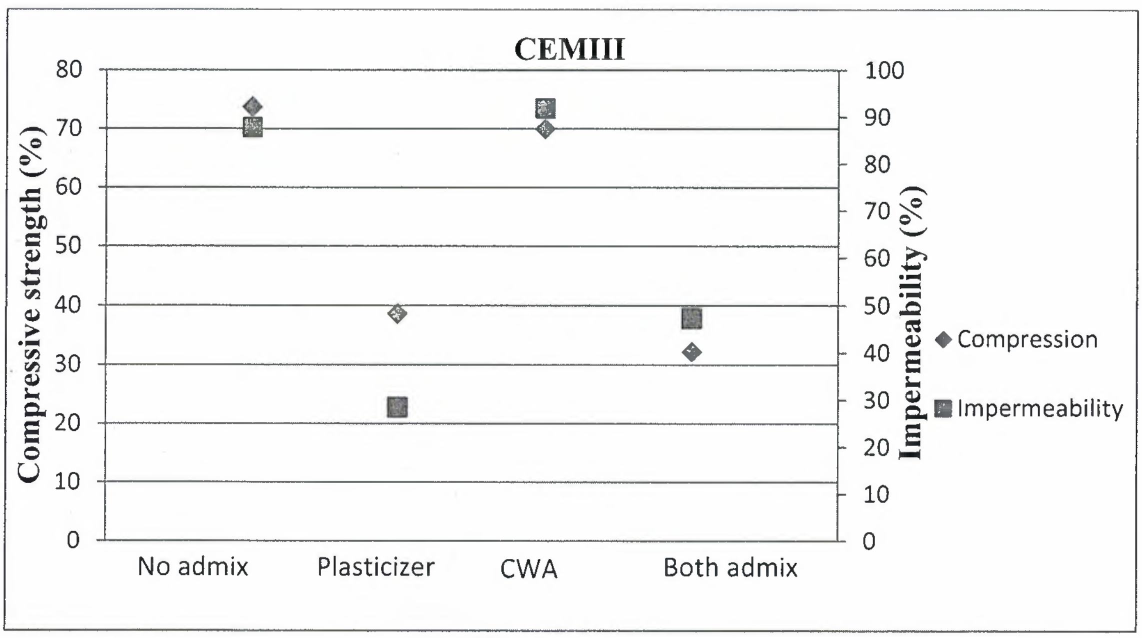

Figure 4.17: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for CEMIII

Comparing the three cements without admixture, it is observed that CEMIII has the slowest rate of hydration in both tests. This is due to the slow hydrating process of the increased slag content

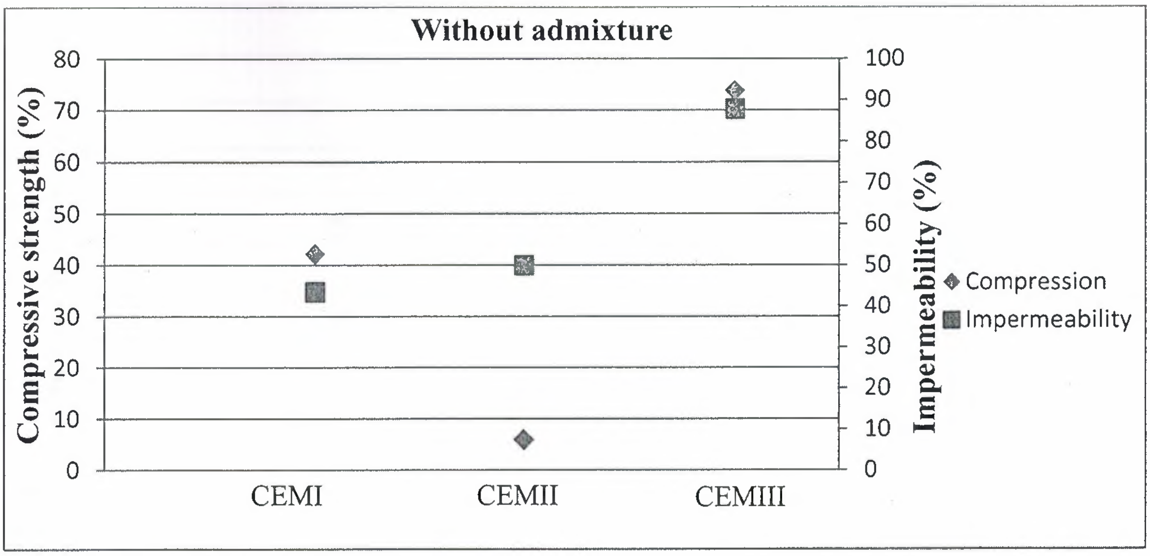

Figure 4.18: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for the three cement mixes without admixture

When the three cements are compared with only plasticizer, it is observed that the percentage increment of the compressive strength increases as the slag increases. This also explains the effect of slow hydrating slag content.

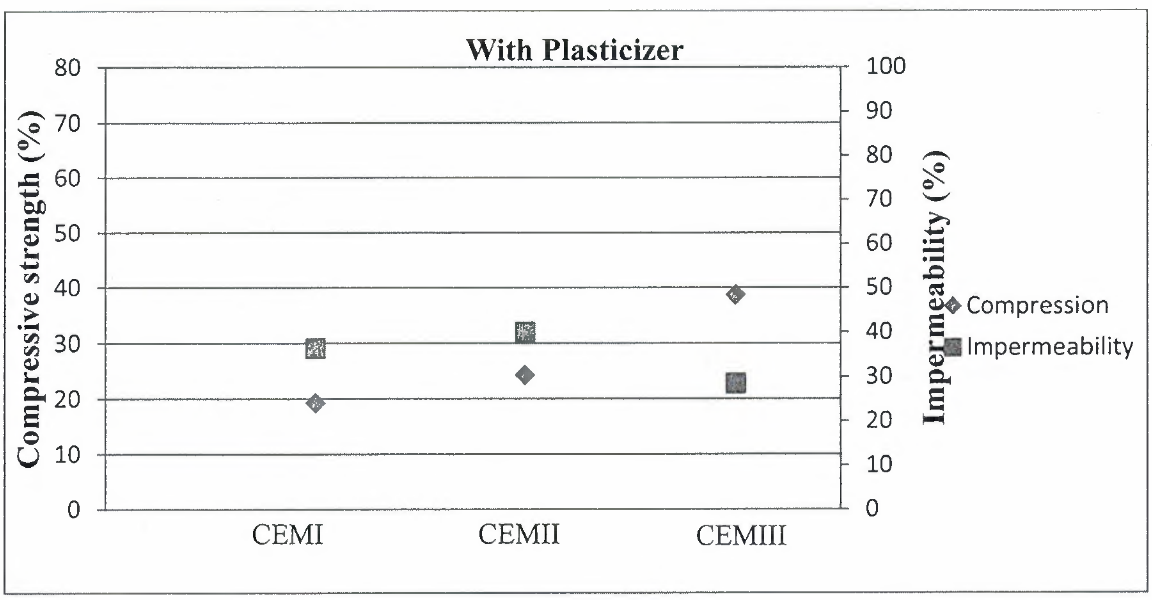

Figure4.19: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for three cements without only Plasticizer

The percentage increment in both tests is observed to be highest in CEMIII in the mixes with only CWA. This can be explained that the microstructure formation and rate of hydration is hindered by the addition of CWA which absorbs water from the mix.

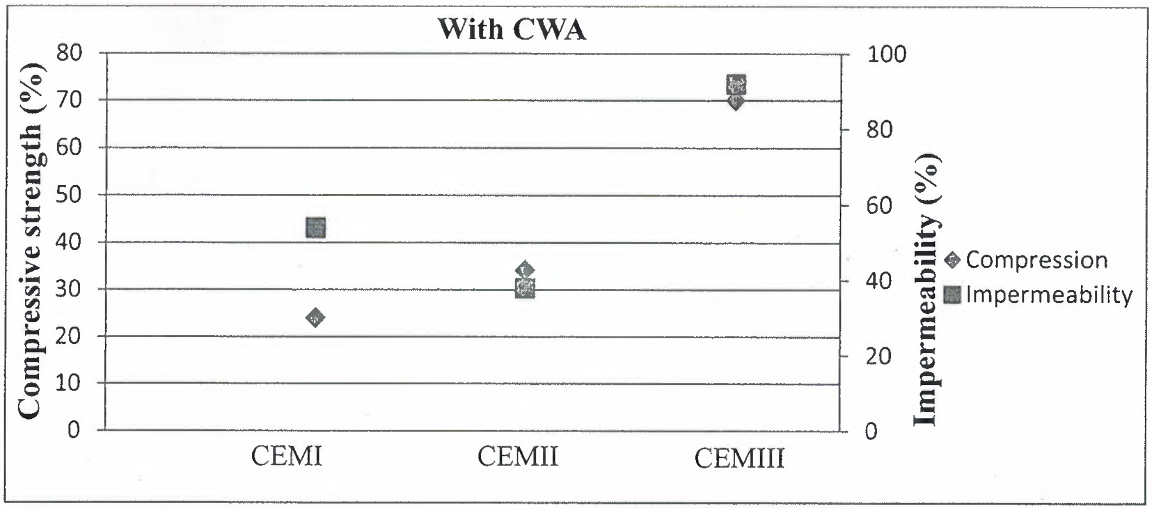

Figure 4.20: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for three cements without only CWA

Figure 4.16 shows the percentage increment of the three cements in both the compressive strength developments and impermeability behaviour. It is observed that compressive strength development increases as the slag content increases. However, CEMI shows the highest percentage for impermeability which explains its high porosity at the early age.

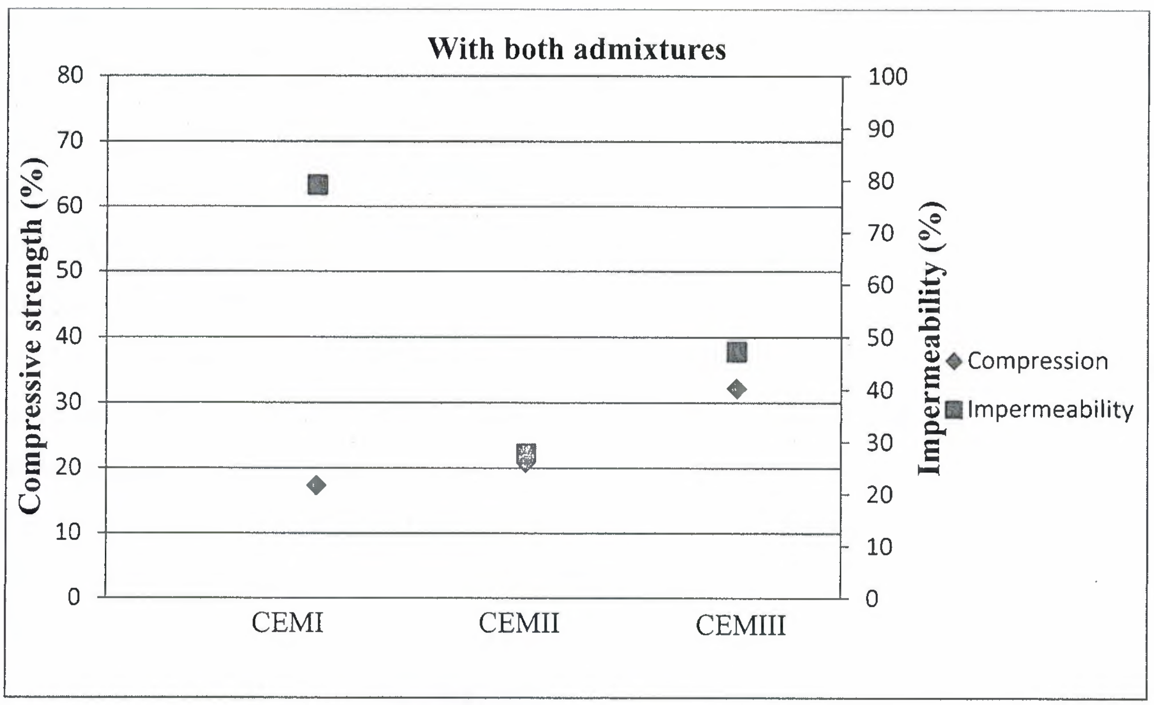

Figure 4.21: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for three cements with both admixtures

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this study, a detailed experimental investigation on mainly the permeability characteristics of self compacting concretes made with varying components; such as slag, superplasticizer, CWA was carried out. The compressive strength performance of the concretes was also evaluated.

Water permeability in concrete is a critical problem in North Cyprus, and researches showed that there is no existing statistical data that shows the permeability characteristics of concretes produce in the island. This study provides insight on the permeability characteristics of concrete produce in North Cyprus showing the statistical data of both the level of permeability and compressive strength of the mixes. Some of ythe conclusions from this study are given below.

I. The use of CWA was observed to have less effect on the permeability characteristic of CEMI. It is suggested to use only superplasticizer as it is observed in the permeability results that both mixtures (with only superplasticizer and with both admixtures) give the least permeability result with almost same value. More also, mixture with only superplasticizer gives the least permeability result in early age as well

II. Similar to the findings in CEMI, comparing the parameters used in CEMII, it will be suggested use only superplasticizer as water reducing admixture in concrete made with CEMII to minimise its water permeation. This is because mixture with only superplasticizer gives the highest impermeability characteristics in both early and late ages compared with other parameters.

III. In a situation where CEMIII is to be used for water resisting structure, addition of any admixture will not be essential because the permeability value at 28th day is at the least in the mixture without any admixture, increased slag content governs the impermeability performance without reading any effect on admixtures. However, in a case where impermeability is necessary at early age, CEMIII with only superplasticizer may the best alternative because of its high impermeability behaviour at early age as shown in the results.

IV. The permeability characteristic of the three cement types was also compared without any admixture; CEMIII gives the least permeability value in 28 days test. But due to its slow hydration process, it has higher permeability value at early age compared with CEMII

V. Water /cement ratio is observed to be a very significant factor that affects the permeability behaviour of the concretes for the three cement types. When only superplasticizer was used in the concrete mixes, their permeability values are at close range and significantly low with CEMIII having the least value at both early and late ages.

VI. Comparing the addition of only CWA to the three cement types, permeability values are relatively higher compared to addition of only superplasticizer especially at the early age. CEMIII is also observed to have the least permeability at the late age.

VII. Addition of both superplasticizer and CWA to the concrete mixes gives low permeability values of almost same range at late age. CEMIII is observed to have the least permeability value at late age.

VIII. In concrete mixes with CEMI, addition of both superplasticizer and CWA gives the highest compressive strength test value. This can be justified by the crystallization of the sample with addition of CWA and reducing its w/c ratio with addition of superplasticizer. CEMI with both admixtures is also observed to have high impermeability characteristic.

IX. Observing the compressive strength development in CEMII, CEMII with only superplasticizer gives the highest value. It gives both the highest impermeability characteristics and compressive strength development compared with other parameters or conditions used in CEMII concrete mix. Observing these characteristics in CEMII, addition of CWA will be redundant as it shows now significant advantage over the mix with only superplasticizer in both tests carried out.

X. From the whole set of results obtained from the compressive strength test carried out in this study, CEMIII with both superplasticizer and CWA gives the highest compressive strength value in both early and late ages. However, CEMIII without any admixture shows higher impermeability characteristic compares with CEMIII mix with both superplasticizer and CWA. In a situation where highly impermeable concrete is necessary, CEMIII without any admixture may be suggested as the most efficient choice for economical reason, provided its compressive strength is satisfied.

XI. Comparing the compressive strength development of concretes made from the three cement types without any admixture, CEMIII gives the lowest and highest value at early and late age respectively. The low strength at the early age is due to the slow hydration characteristics of slag cement. Also, comparing the permeability behaviour of the mixes, CEMIII is again observed to be highly resistant to water permeability.

XII. Also, comparing the concrete mixes with addition of only superplasticizer, CEMII gives the highest compressive strength value and the lowest permeability value in both early and late ages.

XIII. When the effect of only CWA was tested on the compressive strength development of the concrete types, the compressive strength value of CEMIII is observed to be lowest at early age and higher at late age. The early age low compressive strength is due to the slow hydration process in slag cement which is more hindered with the addition of CWA.

XIV. In the compressive test where plasticizer and CWA were added to the mixes, CEMIII shows the highest compressive strength value in both early and late ages. Its compressive strength value at 28th day is observed to have the highest value of all the concrete mixes tested for strength in this study.

XV. The effects of plasticiser is more effective than the CWA in both the permeability and compressive strength test but the combination of the admixtures gives the best result for strength

XVI. The permeability of concrete decreases with age and with reduction in w/c ratio

XVII. The strength of concrete increases with age and also with reduction in w/c ratio

XVIII. Concretes with slag have higher resistance to water permeability than the ordinary Portland cement.

XIX. CEMIII shows the best results for both permeability and compressive strength. However the permeability difference in CEMIII is not apparent in mix with or without admixture, indicating that slag content governs the impermeability characteristics over other components added.

5.2 RECOMMENDATIONS

From the observations and conclusions made from this study, following recommendations are made on investigating the permeability characteristics of concrete for concrete durability.

5.2.1 RECOMMENDATIONS FOR MORE EFFICIENT CONCRETE MIX

I. If CEMI is to be used for water resisting structure, CEMI with only superplasticizer is recommended to be considered especially where early age impermeability is highly required.

II. In a case where CEMII is to be considered for water impermeable structure, CEMII with only superplasticizer may also be recommended as it gives the lowest permeability in both early and late ages with the highest compressive strength development values in both ages of the mix trials carried out with CEMII

III. CEMIII is generally recommended for providing the mixes with highest impermeability.

IV. Observations from this study showed that the particular CWA used in this experiment has little or no significant effect on the permeability behaviour of the tested specimens especially in CEMIII. However, varying its percentage in mixes is recommended to be considered, or observing its effects in other cement types or even considering other water proofing admixtures

V. In a case where only CWA or only superplasticizer exhibits same property with both admixtures, selecting the mix with either of the admixtures should be the best alternative for economical reasons.

5.2.2 RECOMMENDATIONS FOR FUTURE STUDIES

I. Further experimental study on the effects of CWA used in this study should be investigated by varying its percentage replacement in cement or using it with other types of cement.

II. Other categories of water proofing admixtures mentioned in chapter two of this study should be experimented to compare their effects with the CWA used in this study.

III. Further investigations on slag effect on water permeability should be carried out by varying its percentage replacement in cement.

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EXPERIMENTAL INVESTIGATIONS OF THE PERMEABILITY CHARACTERISTICS OF SELF COMPACTING CONCRETE MIXES MADE WITH VARYING CONSTITUENTS

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

By

SHIRU, SHOLA QASIM

In Partial Fulfilment of the Requirements for

The Degree of Master of Science

In

Civil Engineering

NICOSIA, 2015

Shiru Shola Qasem : "Experimental Investigations on the Permeability Characteristics of Self Compacting Concrete Mixes Made with Varying Constituents"

Approval of the Graduate School of Applied Sciences

Prof. Dr. İlkay Salihoğlu
Director

We certify this thesis is satisfactory for the award of the Degree of Master of Science in Civil Engineering

Examining Committee in charge:

Prof. Dr. Ali Ünal Şorman (Chairman of the Jury) (NEU)

Assist. Prof. Dr. Ayşe Pekrioğlu Balkıs (CIU) (Member of the Jury)

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I declared that I carried out the work reported in this thesis in the Department of Civil Engineering, Near East University, Cyprus, under the supervision of Asst. Prof. Dr. Pinar Akpinar and all sources of knowledge used have been duly acknowledged in accordance with the academic rules and ethical conducts.

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ABSTRACT

Observing some cases in North Cyprus where structures close to sea water are threatened with high tendency of water permeability, which may later cause severe durability problems; there is need to manufacture concrete with high impermeability to ensure its high quality. In addition, providing a systematic experimental data showing the level of impermeability of concrete mixes that are currently in use in North Cyprus. This is expected to make a beneficial contribution to the ready mix concrete sector in the country , as well as to the related literatures.

The influence of varying percentages of blast furnace slag cement and two admixtures (superplasticizer and crystalline water proof admixture) on the level of permeability of concrete mixes was studied to determine the most efficient mix. The study of the permeability self compacting mixes under varying criteria was carried out according to EN12390-8 and also their compressive strength developments were evaluated with ongoing hydration, especially with slow hydrated slag cement that yields the development of concrete microstructure. Both the impermeability and compressive strength characteristics of the samples were been tested for 28 days as standard age of concrete and 7 days to check their early age performances.

The observations obtained from this study showed that with increased slag cement (CEMIII) in a concrete, addition of admixture(s) has little or no significant effect on the impermeability behaviour of the concrete especially at the late age. Contrarily, the addition of admixture(s) to Ordinary Portland cement (OPC)(CEMI) and the partially replaced slag cement (CEMII) gives their best impermeability results with CEMI having its best impermeability behaviour when both admixtures (crystalline waterproofing admixture and superplasticizer) were used and CEMII was at its best impermeability with only superlasticizer. It was observed from the results that the water permeability into the concrete was less in concrete made of slag (CEMII) and was lesser when the percentage of slag was increased (CEMIII). However, the addition of admixture(s) generally improves the compressive strength developments of all the specimens in both their early and late ages especially in slag cements, with CEMIII having the highest compressive strength of all the samples when it was mixed with both admixtures.

Keywords: Self compacting concrete, Water permeability, Granulated Ground Blast Furnace Cement, Compressive strength, Plasticizer, CWA, Concrete Durability.

ÖZET

Kuzey Kıbrıs'ta özellikle denize yakın bölgelerde inşaa edilen binalarda, daha sonra tehlike arz edebilecek dürabilite problemlerine neden olabilecek, beton elemanlarda su geçirimliliği eğilimi tespit edilmiştir. Bu yapılan tespit ile hem geçirimlilik niteliği az, yüksek kaliteli beton üretiminin önemi, hem de Kuzey Kıbrıs'ta üretilmekte olan hazır beton karışımlarını geçirimlilik eğilimleri açısından inceleyen sistematik deneysel veri eksikliğinin önemi ortaya çıkmıştır. Bu çalışmadan elde edilecek sonuçların hem ülkedeki hazır beton sanayisine, hem de ilgili literatüre olumlu yönde katkı koyması beklenmektedir.

Değişen yüzdeliklerle cüruf içeriği ve iki farklı katkı maddesi (süper akışkanlaştırıcı ve kristalize su-geçirmezlik sağlayıcı katkı maddeleri) ile hazırlanmış kendiliğinden yerleşen beton karışımlarındaki geçirimsizlik eğilimi incelenerek en verimli karışımın belirlenmesi için çalışmalar yürütülmüştür. Bu çalışmalar esnasında EN 12390-8 referans olarak alınmıştır. Geçirimsizlik çalışmalarına ilaveten, yine beton mikro-strüktürünün çimento hidratasyon reaksiyonunun devami ile gelişmesine paralel olarak gelişmesi beklenen numunelerin basınç mukavemeti performansıları da gözlemlenmiştir. Hem geçirimsizlik, hem de basınç mukavemeti ölçümleri , standar numune yaşı olan 28 güne ilaveten, erken yaş niteliklerinin de gözlemlenmesi amacıyla 7. günde de yapılmıştır.

Yürütülen bu deneysel tez çalışması sonucunda elde edilen veriler ışığında; arttırılmış cüruf içerikli çimento (CEM III) kullanıldığında diğer katkı maddelerinin geçirimsizlik niteliği açısından karışımın performansına önemli ölçüde etki etmediği tespit edilmiştir. Öte yandan, CEM III yrine daha az cüruf içeren CEM II kullanıldığında sadece süper akışkanlaştırıcı katkı maddesi içeren karışımın, curuf içeriği olmayan CEM I çimentoları kullanıldığında ise her iki katkı maddesinin beraber kullanımı ile en geçirimsiz karışımın elde edildiği gözlemlenmiştir. Genel anlamda geçirimsizlik niteliğinin cüruf içeriği ile arttığının da gözlemlenmesi yanında, numunelerin basınç mukavemeti performansı için cüruf içeriğine ilaveten iki katkı maddesininde kullanılmasının hem erken (7 gün) hem de standart (28 gün) süresinde olumlu etkileri gözlemlenmiştir.

Anahtar Kelimeler: Kendiliğinden Yerleşen Beton, Su geçirimliliği, Cürufflü çimento, akışkanlaştırıcı, Beton dürabilitesi.

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LIST OF ABBREVIATIONS

BMV: Blue Methylene Value

CEM: Cement

CWA: Crystalline Water Admixture

FA: Fly Ash

GGBFS: Granulated Ground Blast Furnace Slag

OPC: Ordinary Portland cement

SCC: Self Compacting Concrete

TRNC: Turkish Republic Of Northern Cyprus

W/C Ratio: Water Cement Ratio

CHAPTER ONE

INTRODUCTION

1.1 GENERAL CONCEPTS

Concrete is known to be the most widely used construction material in the world because of its low cost, high compressive strength, excellent performance when used together with steel reinforced concrete (Wang, 2013). It is a heterogeneous material obtained by the mixture of cement paste (binder) and aggregates (filler) which constitute around 80% of the concrete. These combine together to form a synthetic conglomerate. Sometimes materials other than aggregates, water and hydraulic cement are added to concrete batch before or during mixing to provide a more economical solution and enhanced concrete properties. These materials are known as additives or admixtures depending on the stage of mix. (Arum and Olotuah, 2006)

Several researches on concrete structures have proven the great importance of water molecules on concrete structures especially in the first ages, helps in cement hydration and consequently hardness of concrete. However, it presence after the end of concrete hydration reaction may be detrimental by transporting noxious substances that can speed up degradation process of matrix which substantially reduces the durability and the useful life of the concrete. Therefore, permeability control is an important consideration in the design of concrete and engineering construction (Magalhaes and Costa, 2013).

Permeability controls the speed of aggressive water penetration into the concrete besides regulating the movement of water during the occurrence of several concrete durability problems. The importance of permeability cannot be under estimated as it is the most important factor to esteem durability under the most diverse conditions of service life of engineering structures. Therefore, concrete must be manufactured considering the environment in which it will be used. (Magalhaes and Costa, 2013)

1.2 DEFINITION OF THE PROBLEM

It is known that permeability is a significant factor affecting the durability of concrete and the duration of the service life.

One of the leading ready mix concrete companies of Turkish Republic of Northern Cyprus (Tüfekçi group) reported a vital problem that is being faced especially in coastal areas of North Cyprus, that reinforced concrete structures are experiencing the problem of water infiltration mainly through the foundations especially during the early stage of manufacture.

It was also observed that different cements, with or without additives are being currently used in combination with certain admixture, however there is no existing experimental data showing the level of permeability of concrete mixes currently being manufactured in North Cyprus. Considering these problems, studies should be carried out to manufacture high quality concrete with high impermeability characteristics ensuring its durability, especially the ones exposed to the danger of water infiltration. Moreover, studies with these defined purposes will provide statistical data that will be used in tackling the problem of water penetration in North Cyprus and other parts of the world facing similar problems as well.

1.3 OBJECTIVES AND THE SIGNIFICANCE OF THE STUDY

The objective of this study is to investigate the impermeability performance of concrete mixes made in North Cyprus with various cement types, crystalline water proofing admixture and plasticizer, by carrying out detailed and systematic experimental investigations. In addition, aiming to suggest an efficient (e.g. most impermeable amongst the tried mixtures) concrete mix that will meet the needs required in North Cyprus, a significant contribution is expected to be made to the related literature in the world on the issue of concrete impermeability with the data to be obtained from these experimental studies.

1.4 STRUCTURE OF THE STUDY

This study is mainly focused on the investigation of the permeability and compressive strength of concrete manufactured with available materials in North Cyprus. This study consists of five chapters. In chapter one, the general concept of the study, definition of problem, objectives of the research and the significance of study are discussed. Chapter two focuses on general concrete overview, concrete permeability, effects of slag on concrete, concrete durability and inter-relationship between permeation of concrete and concrete durability. Chapter three discusses the details on the materials and methodology used throughout this experimental study. Chapter four is dedicated for the results obtained and discussions. Finally, in chapter five, conclusions are made from the results obtained in this study and some future recommendations are suggested for future studies.

CHAPTER TWO

LITERATURE REVIEW

This chapter will be focused on the literature review on concrete, concrete permeability and its potential to cause durability problems, as well as previous studies on concrete permeability, factors affecting concrete permeability and related tests procedures. It will further discuss on other properties of concrete which include compressive strength and workability.

2.1 OVERVIEW ON CONCRETE

American Concrete Institute (ACI) defines concrete as a composite material that consists essentially of binding medium within which are embedded particles or fragments of aggregates usually combine of fine and coarse aggregates (Dolen, 2011).

Concrete is an important element in construction materials, widely used in various aspect of engineering construction. So it is very necessary to consider its durability as it directly has significant effect on economy, serviceability and maintenance. In other word, it is very important to lay more emphasis on the permeability characteristics of concrete, as it has much bearing on its durability. Aggressive chemicals are well known to attack concrete only in solution form. The penetration of this aggressive fluid is dependent on the degree of permeability of concrete (Seshadri et al, 2013).

In engineering, a well designed and manufactured concrete is expected to be water resistant, containing discontinuous pores and micro cracks. When it is subjected to extreme loading or weathering, it deteriorates through a variety of physical and chemical process substantially reducing the concrete durability (Wang et al, 2013). Pores in concrete include air voids, capillary pores and gel pores. This is one of the most important attributes of concrete materials, pore structures in concrete possesses a definite proportion and has serious implication on transmission of aggressive substances within the concrete. Researchers have shown that pore structures in concrete affects permeability, frost resistance and physical mechanical performance of concrete (Duan et al, 2013). It is generally recognised that the foremost prerequisites for durability of concrete is that , it should be dense and impermeable to liquid and gasses with high resistance to the infiltration of ion species such as chloride and sulphate (Obsorne, 1998)

In 1930, air entraining agent was developed which greatly contributes to concrete resistance to permeability and improves its workability. This was an important contribution in which the durability of modern concrete is improved. Air entrainment is an agent when added to concrete mix, creates many air bubbles that are extremely small and closely packed, of which most of them remain in the hardened concrete (Gromicko and Shepard, 2015).

2.1.1 BRIEF HISTORY OF CONCRETE

The early concrete structures were built by the Nabataea traders or Bedouins who occupied and controlled a series of oasis and developed a small empire in the region of south Syria and north Jordan in around 6500BC. They later discover the advantages of hydraulic lime i.e cement that hardens underwater and by 700BC, they were building kiln to supply mortar for the construction of rubble wall houses, concrete floors and underground cistern (Gromicko and shepard, 2015).

Figure 2.1: An ancient Nabataea building in North Jordan (Gromicko and shepard,2015)

The Babylonians and Assyrian used clay as bonding materal, the Egyptians used lime and gypsum cement. The first modern concrete (hydraulic cement) was made in 1756 by a British Engineer John Smeaton by adding pebbles as coarse aggregate and mixing powder brick into the cement. In 1824 an English inventor Joseph Aspdin invented Portland cement which as remain the dominant cement used in concrete production (Bellis, 2015)

The reactivity of blast furnace slag was first discovered in Germany in 1862 and it has been used as a cementitous material for over 100years. (Alexander et al, 2003) The famous concrete structures include the Hoover dam, the Panomal canal and the Roman pantheon.

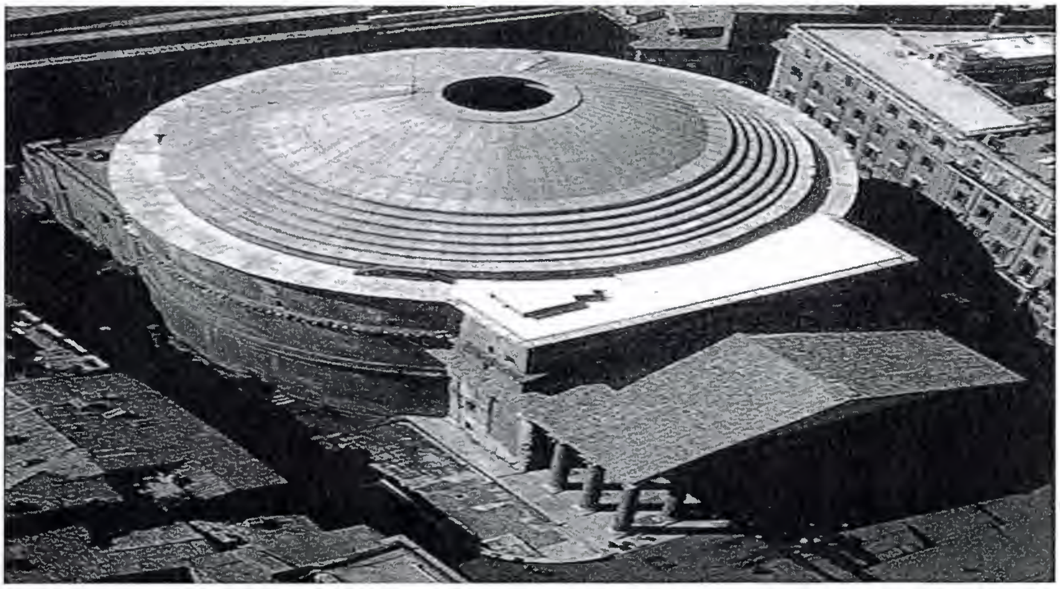

Figure 2.2: The Pantheon (Gromicko and Shepard, 2015)

2.1.2 CONCRETE CONSTITUENTS

Concrete generally composes of three main ingredients which are water, cement and aggregates. The properties of the final product vary as the ratio of the ingredients changes, which allows the engineer to design concrete in a way to meet their specific need.

2.1.2.1 WATER

ASTM C1602 standard specification for mixing used in the production of hydraulic concrete, defines source of mixing water in different categories:

I. Batch water: Batch water is the water discharged into the mixer from a source, which serves as a main source of mixing the concrete

II. Ice: This may be used as part of mixing during hot weather .The ice should be melted completely by the end of the mixing.

III. Water added by the truck operator: ASTM C94 (AASHTO M157) allows the addition of water on site if the slump is less than specified, provided the allowable water cement ratio is not exceeded and also meeting several conditions.

IV. Free moist can have substantial portion of the total mixing water, therefore it is recommended to ensure the water from aggregates should be free from harmful materials

V. Water in the admixture: The water content of admixture should be taken into consideration especially when the admixture water content is sufficient to affect water cement material ratio by 0.01 or more

1. Recycled water: Non portable or water recycled from concrete operation can also be used as mixing water in concrete provided they meet the acceptable criteria given in ASTM1602. The maximum permitted solid content allowed to be present in water to be used in concrete is 50000 part per million, or 5% of the total mixing water and should be tested in accordance with ASTMC1603

2.1.2.2 CEMENT

Cement is a binder, a substance that sets, hardens and can bind other materials together. The word "cement" is traced to the Roman, who used the term" opus caementicium" to describe masonry similar to modern concrete that was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick additives that were added to the burnt lime to obtain hydraulic binder were later referred to as cementum, cimentium and cement.

According to European standard (BS EN 197-1); cements are defined in format which indicates the cement type, main constituents, strength class and its rate of early strength.

All the cement types aside CEMI have a symbolic letter immediately after the Roman numeral indicating the cement type, this indicates the range of Portland cement clinker proportions.

The symbolic letter after the CEM notation indicates the level of Portland cement present within the cement

A = high level clinker (PC clinker content 80-90%) – CEMII/A

B = medium level clinker (PC clinker content 65-79%) – CEMII/B

A = PC clinker content 35-64% - . CEMIII/A

B = PC clinker content 20 -34% - . CEMIII/B

C = PC clinker content 5-19% - . CEMIII/C

CEMII also have an additional letter after the letter indicating level of Portland cement clinker, this letter indicates the second main constituent present in the cement.

S = blast furnace slag V = siliceous fly ash

P = natural pozzolana L = lime stone

T = burnt shale D = silica fume

M = composite cement W = high lime pfa

The figure 42.5 present in the expression indicates the standard strength class and the letter after the figure shows "R" which indicates rapid early strength.

CEMII/B-S 42.5R, CEMIII A42.5R and CEMI 42.5R cements were used.

Table 2.1: European Standards EN197-1 Cement Compositions

Cement Type	Designation	Notation	Clinker K	G.G.B.S. S	Silica fume D	Pozzolana Natural P	Pozzolana Industrial Q	Fly ashes Silic. V	Fly ashes Calcar W	Burnt Shale T	Limestone L	Limestone LL	Minor Additional constit.
I	Portland Cement	I	95-100	-	-	-	-	-	-	-	-		0-5
II	Portland Slag Cement	II / A-S	80-94	6-20	-	-	-	-	-	-	-		0-5
		II / B-S	65-79	21-35	-	-	-						0-5
	Portland Silica Fume Cement	II / A-D	90-94	-	6-10	-	-	-	-	-	-		0-5
	Portland Pozzolana Cement	II / A-P	80-94	-	-	6-20	-	-	-	-	-		0-5
		II / B-P	65-79	-	-	21-35	-	-	-	-	-		0-5
		II / A-Q	80-94	-	-	-	6-20	-	-	-	-		0-5
		II / B-Q	65-79	-	-	-	21-35	-	-	-	-		0-5
	Portland Fly Ash Cement	II / A-V	80-94	-	-	-	-	6-20	-	-	-		0-5
		II / B-V	65-79	-	-	-	-	21-35	-	-	-		0-5
		II / A-W	80-94	-	-	-	-	-	6-20	-	-		0-5
		II / B-W	65-79	-	-	-	-	-	21-35	-	-		0-5
	Portland Burnt Shale Cement	II / A-T	80-94	-	-	-	-	-	-	6-20	-		0-5
		II / B-T	65-79	-	-	-	-	-	-	21-35	-		0-5
	Portland Limestone Cement	II / A-L	80-94	-	-	-	-	-	-	-	6-20		
		II / B-L	65-79	-	-	-	-	-	-	-	21-35		0-5
		II / A-LL	80-94	-	-	-	-	-	-	-		6-20	0-5
		II / B-LL	65-79	-	-	-	-	-	-	-		21-35	
	Portland Composite Cement	II / A-M	80-94	<------6-20------>									
		II / B-M	65-79	<------21-35------>									
III	Blastfurnace Cement	III / A	35-64	35-65	-	-	-	-	-	-	-		0-5
		III / B	20-34	66-80	-	-	-	-	-	-	-		0-5
		III / C	5-19	81-95	-	-	-	-	-	-	-		0-5
IV	Pozzolanic Cement	IV / A	65-89	-	<------11-35------>				-	-	-		0-5
		IV / B	45-64	-	<------36-55------>				-	-	-		0-5
V	Composite Cement	V / A	40-64	18-30		<------18-30------>			-	-	-		0-5
		V / B	20-39	31-50		<------31-50------>			-	-	-		0-5

COMMON CEMENTS USED IN THE REUBLIC OF NORTH CYPRUS

I. PORTLAND COMPOSITE CEMENT:

It is obtained by grinding 80-88 and 65-79 unit mass of Portland cement with silica fume, blast furnace slag, pozzolan, fly ash, limestone, baked schist and certain amount of setting regulation as gypsum.

II. PORTLAND SLAG CEMENT:

This is obtained by grinding certain amount of Portland clicker and 21 -35 or 6 -20 unit mass of slag with little amount of setting regulator as a gypsum. Portland slag cement is preferred in north Cyprus due to its climate condition and island structure, to protect concrete against sulphate, acid attack, and other aggressive chemicals where cement will be used in coastal, port and dock construction, dams and in all concrete structures that may come into contact with sea water.

III. PORTLAND LIME STONE CEMENT:

This is classified into four kinds, depending on contains of 6-20 or 21-35 unit of mass lime stone amount and the content of calcium carbonate amount in the lime stone structure

IV. PORTLAND CEMENT

It is obtained by grinding 95 -100 mass of Portland clinker and some certain amount of setting regulator as gypsum. It is mostly used in multi story concrete structure, bridges also in precast concrete.

2.1.2.3 AGGREGATES

Aggregates are considered to be more impermeable than the hydrated cement paste and it is obvious that the permeability of concrete depends majorly on the inherent permeability of its constituents than on the interface. A recent study by Tsunkamoto shows that, for a given crack opening displacement, the presence of lager mean aggregate size leads to drop in fluid permeability (Hoseini, 2009).

Majorly, concrete mixture consists of both fine and coarse aggregate. Fine aggregate generally consist of natural sand or crushed stones with most particles passing through 0.38 inch sieve, and coarse aggregates are any particle greater than 0.19 inch, but generally ranges between 0.38 and 1.5 inches as in diameter. The aggregates helps to increase the strength of the concrete more than the strength cement can provide on its own.

Sand, gravel, crushed stones, slag, recycled concrete and geo synthetic aggregates are used as aggregate. Aggregates are the most mined material in the world. In order to achieve a good concrete mix, aggregate should be clean, hard, free of absorbed chemical or coating of clay and other fine materials that could cause concrete deterioration. It account for the largest percent of concrete.

Gravel and sand are mostly dug naturally from pit, river, lake or sea bed. Crushed aggregate is produced by crushing quarry rocks, boulders, cobbles or large size gravel. Properties expected of a good concrete include

a. Durability
b. Grading
c. Particle shape and surface texture
d. Abrasion and skid resistance
e. Unit weight and void
f. Absorption and surface moisture

Particle sizes distribution by sieve analysis of particles greater than 0.075 and hydrometer analysis for particles size lesser than 0.075 is shown in the table below.

Table 2.2: Grain size classification of soil (Agarwal)

S/N	Soil type	Particle sizes(mm)
1	Clay	Less than 0.002
2	Silt	0.002 -0.075
3	Fine sand	0.075 -0.425
4	Medium sand	0.425 -2.000
5	Coarse sand	2.000 - 4.756
6	Fine gravel	4.756 -20.000
7	Coarse gravel	20.000 – 80.000

2.1.2.4 ADMIXTURES

In present days, concrete is used for wide variety of purposes. In ordinary condition, concrete may fail to exhibit the required performance of quality and durability. In such cases, modification of ordinary concrete properties can be made by addition of admixture so as to make the concrete more suitable for any situation (Giridhar et al, 2013).

The addition of water-reducing admixture due to water content decrease at a given consistency can enhance both the early and ultimate strength of concrete. However the ultimate strength of concrete may not be seriously affected. Nowadays, for ecological reasons and cost control, the use of pozzolanic and cementitious by- products as mineral admixture in concrete is now on the increase. When admixture is used as partial replacement for Portland cement, it usually has retarding effect on the concrete strength at the early ages. However, the ability of mineral admixture to react with calcium hydroxide (constituent of hydrated Portland cement paste) at normal temperature to form additional calcium silicate can lead to significant reduction in porosity of both matrix and interfacial transition zone (Jankovic et al ,2011). Admixtures are ingredient present in the concrete other than water, cement, and aggregates that are added to the mix immediately before or during mixing. It is added to modify some of the properties of the mix. They are usually classified according to the specific function they are intended to perform, below are some of the common designated groups of admixture

I. Water reducing admixture

II. Set modifier (retarding, accelerator)

III. Air entraining agent

IV. Anti bleeding /segregating admixture

V. Corrosion inhibitor

VI. Curing and shrinkage (drying) reducing admixture

VII. Water-proofing admixture

VIII. Anti – freezing admixture

IX. Admixture controlling alkalis aggregate reaction (AAR) (Jolicocur et al, 2015)

Concrete should be workable, strong, and durable, finish able, water tight, and wear resistance. The main reasons for using admixtures are:

I. To achieve certain properties in concrete more effectively.

II. To maintain the quality of concrete during the stage of mixing, transportation, placing, and curing in adverse weather condition

III. To overcome certain emergencies during concrete operation

IV. To reduce the cost of concrete

2.2 CONCRETE PERMEABILITY

Permeability is defined as the transportation fluid through a porous medium under applied pressure. This is the most important property of concrete governing its long term durability. (Kameche, et al, 2014)

Permeability in concrete is the movement of water through concrete under pressure, and also to the ability of concrete to resist penetration of any substance like liquid, gas or chloride ion. When water infiltrates into concrete, the calcium hydroxide in hydrated cement paste (the binder phase in concrete) will be leached out. Leaching of calcium hydroxide reduces the PH value of the pore solution, which may eventually lead to the decomposition and even leaching of the main hydrates in concrete i.e calcium silicate hydrates (C-S-H). This will undoubtedly increase the porosity, and reduces the strength and impermeability of the concrete (Liu et al, 2014).

One of the main reasons behind concrete deterioration is due to the penetration of fluid carrying aggressive ions through the concrete. Therefore, fluid penetration resistance of concrete is a critical parameter in determining the long term performance of structures in a marine environment. (Hamilton et al, 2007)

The parameter that has the most significant influence on durability of concrete is the water cement (w/c) ratio or water cementious (w/cm) ratio. Low w/c ratio reduces the permeability, therefore reducing the voids in concrete. This implies that it will be more difficult for water and other corrosives to infiltrate the concrete. Permeability in concrete influences durability because it controls the rate of at which moisture containing aggressive chemicals penetrates into the concrete. Decreasing the w/c ratio also has great impact on concrete strength which further improves its resistance to cracking (Rohne, 2009)

The necessity for information on the permeability of concrete dates from the early 1930's when it became necessarily for designers of dams, and other large hydraulic structures to know the rate at which water rise through concrete that was subjected to relatively high hydraulic pressure. Recently, there is a renewed interest in the permeability of concrete which does not only centre on the flow of water through concrete in water works structures but also deals with permeability to aggressive substances such as chloride ion from sea water, and deicing salts, Sulphate ions and other deteriorating chemicals. (Abualamal, 2014)

The increasing awareness of the role that permeability plays in the long term concrete durability has led to the need for ways to quickly asses the permeability of concrete. The use of admixtures such as silica fumes, latex emulsions and high range water reducer allows placement of lower permeable concrete. It became more necessary to know more information on the effect of these admixtures, concrete mix and curing so that low permeability concrete can be uniformly specified and manufactured.

A common way to measure concrete permeability is the standard test method ASTM C1202 "Electrical Indication of Concrete's Ability to Resist Chloride ion penetration" also known as raid chloride impermeability test. This method is the most accepted test method to determine the relative permeability of concrete. A 60V electrical potential is set across a sawed four inches diameter concrete cylinder section and the total current passing through the section over time is read and measured in coulomb. Lower coulomb values indicate lower permeability.

In 1986, Construction Technology Laboratories researchers studied the effect of mix design, material and curing on permeability of selected concretes. The concrete studied had w/c ratio ranging from 0.26 to 0.75. Compressive strength varied from 3580psi to 15250psi at 90 days. Silica fumes and high range reducers were used to produce the lower w/c ratio concrete.

Moist curing for 7 days minimum recommended in ACI 308, standard practice for curing concrete results in much more impermeable concrete, this is especially important at higher w/c ratios. (Abualama, 2014)

There are several rapid test procedures available for estimating permeability instead of more complex flow testing. The rapid chloride permeability test (AASHTO T277) is reliable and quickly accesses the relative permeability of variety of concretes. Another alternative is the simple absorption based test procedure that test for the volume of permeable voids (ASTM C 642) is used. However, total test time is greater and predictability is less than for the AASHTO test. (Hamilton et al, 2007)

2.2.1 FACTORS CONTROLLING PERMEABILITY OTHER THAN CONCRETE MATERIALS

There are three major factors which determine concrete permeability

I. WATER - CEMENT RATIO:

The American standard (ACI 318) building code addresses an exposure condition of concrete aimed to have low water permeability by requiring a maximum w/c ratio of 0.5 and a minimum specified strength of 4000 psi (Obla et al, 2005).

Also, According to European standard EN206, the first criterion to be considered in other to improve concrete durability is to limit the maximum w/c ratio in the concrete mix. (Sanjuan and Martialay, 1996). The porosity of cement paste ranges from 30-40 vol% in the form of gel or capillary pores which are about 2×10^{-9} m and 1×10^{-6} m diameter respectively. Capillary pores are formed due to excess w/c ratio. This essential micro structure difference results in a major difference in the mechanical and durability behaviour of both the cement paste and the transition zone between the paste and the aggregates. (Aitcin, 2003)

II. CURING CONDITIONS

Curing is the technical process that involves a combination that promotes cement hydration; time, temperature and humidity condition immediately after the placement of concrete mixture into formwork. The constituent compounds of Portland cement begin its hydration as soon as water is added which determines the porosity of hydrated cement at specified water cement ratio. The hydration almost stops when the vapour pressure of water capillary falls below 80 percent of the saturation humidity. Time and humidity are important factors in hydration process controlled by diffusion of water. It is noted that the time-strength relation in concrete technology generally assume moist-curing condition and normal temperature. Concrete increases in strength with age after setting, suitable curing of the concrete after whilst it is maturing further increases the strength of the concrete.

At a specific cement- water ratio, the longer moist curing applied, the higher the strength obtained assuming that the hydration of anhydrous cement particle is still in progress (Jankovic et al, 20011).

Curing can be affected by the application of heat or/and the preservation of moisture within the concrete. Majorly curing prevents or helps to preserve the water used in the mixing from escaping and it is usually done by

a) Covering the concrete with damp sand which are kept damp by watering periodically

b) Flooding or submerging the concrete in water which is mostly used

c) Treating the surface of the concrete to prevent it from drying out (Arum and Olotuah)

I. COMPACTION:

Perfect compaction and placement of fresh concrete are one of the most important part of the whole process of concrete operations. The mixing process of concrete operation entraps air within the mix and for each 1% of void left in the concrete mix ,the strength is reduced by approximately 5-6 %. The air entrapped will be typical when the percentage ranges from 5-20%.

Compaction is important in other to achieve

a) Maximum strength of the placed concrete

b) Maximum durability.

c) Avoidance of visual blemishes such as honeycomb, and blow holes on the surface of the form cast concrete.

d) Adequate bond and protection for reinforcement in the concrete

II. ADMIXTURES

Incorporation of minerals admixtures such as ground granulated blast furnace slag (GGBFS), fly ash (FA), silica fume (SF) and lime stone crystalline water proofing admixture has been of great interest and gradually applied to practical projects because these mineral admixtures can improve resistance to the deterioration by aggressive chemical and permeation. GGBFS is a by product from manufacture of pig iron while FA is a by product of coal power generation. A number of benefits in incorporating these materials have been in publications such as improving fresh properties of concrete, reduce hydration evolution heat and decrease chloride ion penetration, reduce sulphate attack and alkalis silica reaction. (Hiu- Sheng et al, 2009)

2.2.2 EFFECTS OF GROUND GRANULATED BLAST FURNACE SLAG IN CONCRETE PERMEABILITY

Slag is an industrial waste material resulting from steel refining process in a conversion furnace. GGBS results from the fast cooling of molten slag and is a pozzolanic as well as latent hydraulic material (Kourounis et al, 2007).

Granulated slag is the hydrated blast furnace slag, dried and ground in fine powder form. It is a by product of iron-steel industry and obtained from the blast furnace. Iron ore, lime stone, and coal are charged into the blast furnace and heated to about 1500°C. The raw materials are converted to molten iron and blast furnace slag. The two products are separated in natural forms, the iron sinks down the bottom of the blast, while the slag floats and dispersed over the iron. (EN 197-1)

A pozzolana is a material which has characteristics of reacting with lime $C_a(OH)_2$ in the presence of water at ordinary temperature to form compound with cementious properties (C-S-H gel). Recently, different types of material admixtures including pozzolanic (natural pozzolana, low calcium fly ash, silica fume), autopozzolanic (high calcium fly ash, and blast furnace slag) and crystalline materials as water proofing admixtures are added to Portland cement during the milling processes or directly to the cement in which some interact physically and/or chemically with the cement or its hydraulic product to improve the properties and reduce the factors related to declining concrete durability. Also, mineral addition has improved the strength by filling off the pores, changing its diameter and orientation. (Saraya, 2014)

Ground granulated blast furnace slag (GGBS) is a material that has beneficial effect on concrete (Ogawa et. al, 2012). Portland blast furnace slag cement is a mixture of OPC not more than 65% weight of granulated slag. It is generally known that the rate of hardening of slag cement is slower compared with that of OPC at early age but thereafter increases so that, the strength becomes close to or even exceeds that of OPC.(Abdel Rahman et al, 2011) In Japan, Portland blast furnace cement (BFS cement) is classified into categories, these are

A,B and C which contain varying percent of GGBS, BFS from 5% - 30%, from 30% -60% and from 60% -70% respectively according to Japan Industrial Standard (JIS R 5211). (S. Miyazawa, 2014). GGBS blended with Portland cement gives higher fluidity, reduce heat of hydration decreases water permeability and improves chemical resistance as a result densification due to secondary hydration reaction, together with reduced environmental impact of CO_2 discharge. However, blended GGBS with Portland cement has low strength development at the early age, may decrease carbonation resistance, and increase heat of hydration if the GGBS content in blended cement is low or activated at high temperature (Ogawa et al, 2012)

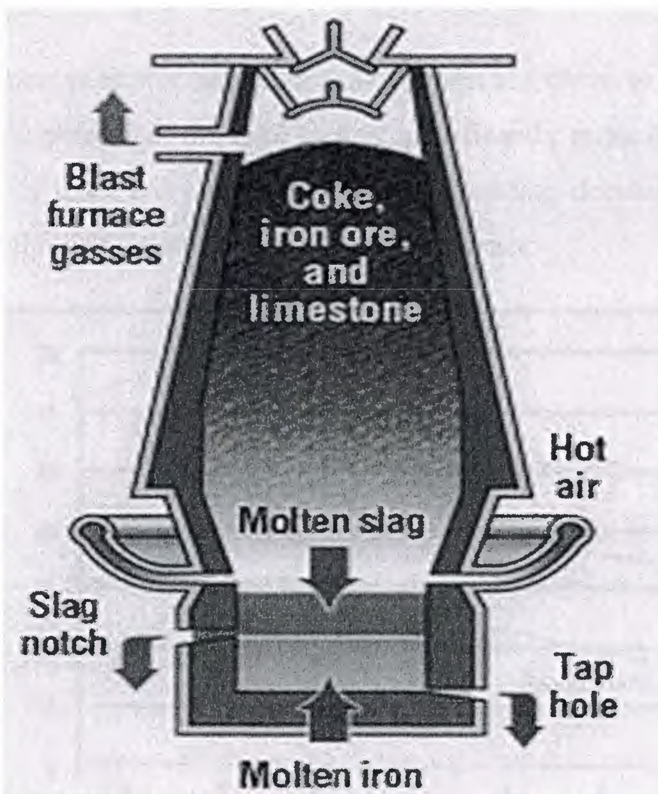

Figure 2.4: Blast furnace slag (National Slag Association)

2.2.2.1 CHARACTERISTICS OF SLAG CEMENT

Portland blast furnace cement is a mixture of ordinary Portland cement and not more than 65%wtn percent of granulated slag. It is generally known that the rate of hardening of slag cement is slower than that of ordinary Portland cement during the early ages but there after increases such that, in about a year the strength becomes close to or even greater than those of Portland cement. GGBS is hydraulically very weak itself due to its glassy structure, therefore a highly alkaline medium is required in order to disintegrate the silicate-aluminates network of the slag glass (Abdul Rahman et. al, 2011)

I. HYDRATION REACTION IN BLAST FURNACE SLAG

The hydration reaction in blast furnace slag involves the activation of the slag with alkalis and sulphates in order to form hydration product. Slag is combined with Portland cement in order to form extra hydrate with the effect of pore inhibition. As a result, the concrete is produces with a less open hydrate containing only Portland cement. Such low permeability greatly increases the resistance of concrete to sulphate and acid attacks. (EN197-1)

II. THERMAL CRACK

Hydration of slag cement is slower and releases lower heat compared to Portland cement. The use of GBBS up to 70 percent of the total cement significantly reduces the heat in concrete especially in casting of thick cross section. The corresponding decrease in the critical heat difference minimises the risk for early thermal structural cracks

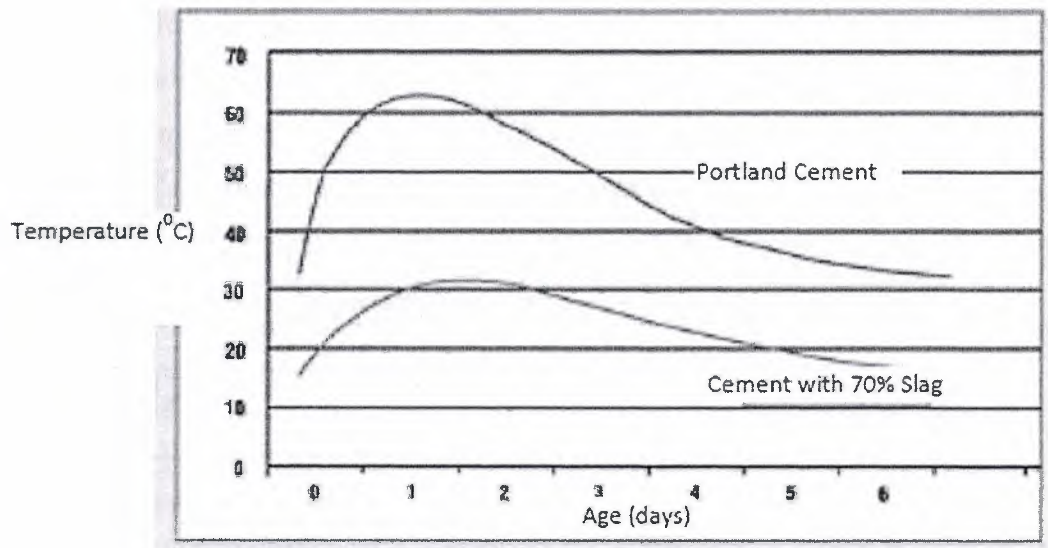

Figure 2.5: Thermal cracks (EN197-1)

I. CHLORINE PERMEABILITY

The GGBS is significantly more resistant to chlorine ingress than Portland cement of the same grade. Steel reinforcement in concrete is protected by the alkalinity of the hardened cement adhesion. The ingress of chlorine reduces the protection and corrosion takes place due to presence of oxygen and moisture. Thus, the structures exposed to chloride threat, benefit from the improved strength and longer useful service life from slag cement.

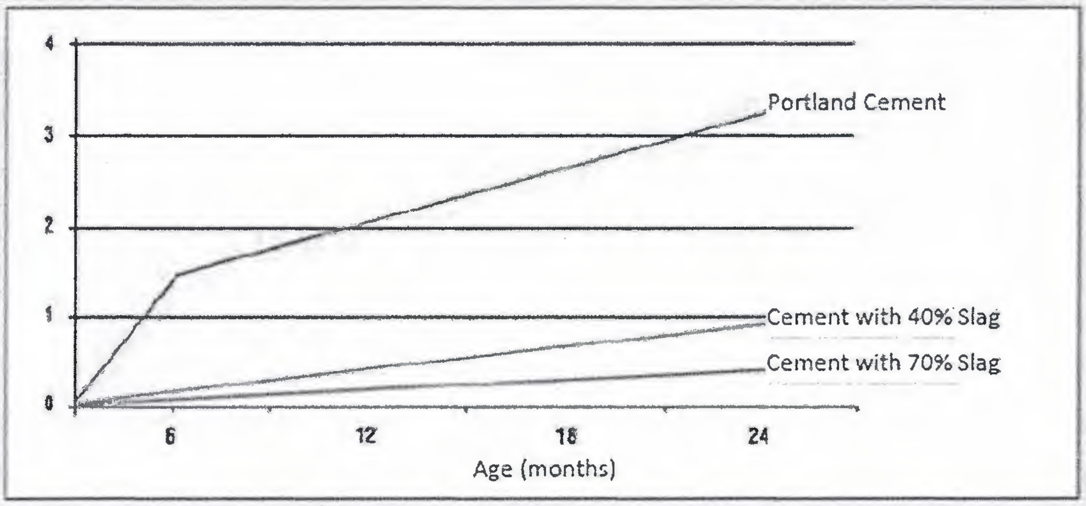

Figure 2.6: Chlorine permeability (EN 197-1)

I. STRENGTH DEVELOPMENT

In a properly cured slag cement concrete, the strength increase continues even at the end of 28th day. It is shown in the graph below, the relation between the strength increase at early and late ages. In general, the concrete produced with about 70%or more GGBS cement, at 1 day after the casting, adequate strength to mechanical impact likely to result from the removal of the formwork.

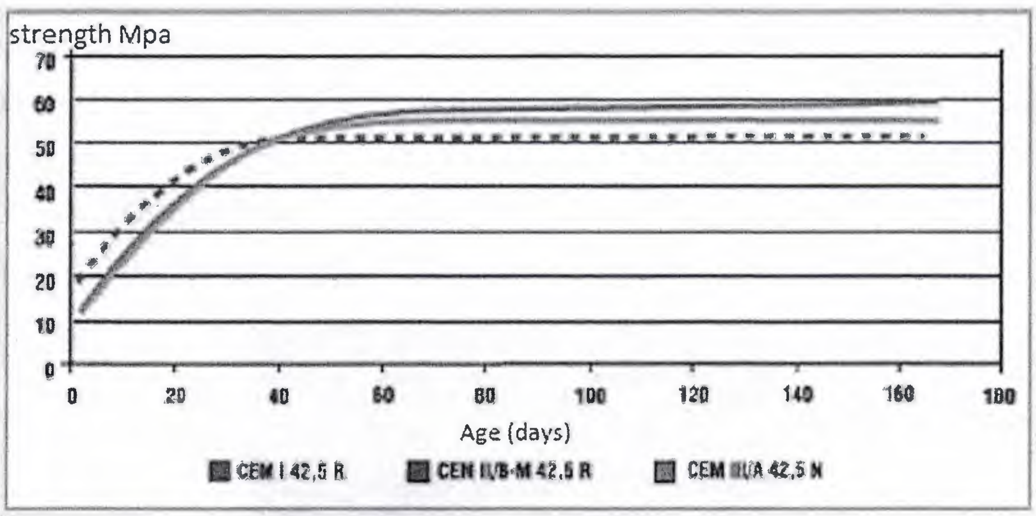

Figure 2.7: Strength developments (EN197-1)

II. SULPHATE AND ACID ATTACK

Sulphate attack is one of the most important factors that affect concrete durability. Sulphate ions naturally exist in soil, sea water, ground water and also in the water output from waste water treatment plant.

Water-based sulphate undergo reaction formed by way of expansion with C_3A component in Portland cement and a different form of $Ca(OH)_2$.The formation of ettringite in the concrete leads to expansion. If the expansion capacity of the concrete is exceeded, it may lead to severe cracks in the concrete.

III. ALKALI – SILICA REACTION

Gel is formed as a result of the reaction between alkalis such as potassium and sodium within Portland cement and the reactive silica within aggregate. In a moist environment, gel absorbs the water and begins to expand. When the expansion has reached an internal pressure at a level sufficient to crack the concrete, the concrete undergoes crack. The use of GGBS in concrete minimises the alkalis-silica reaction, no crack forms in the concrete as result of volumetric expansion.

APPLICATION OF SLAG CEMENT CONCRETE

I. Construction of bridges, domes and geothermal plants

II. Port, wharf construction and under water concrete

III. Marine structures, sea walls, road crossing at the river mouth (estuaries)

IV. Mass concrete

V. Reinforcing concrete

VI. Structures exposed to acid rain or chloride attack

VII. Concrete desired to minimize the alkalis silica reaction resulting from thr reaction aggregate

VIII. Large scale civil engineering projects, roads, tunnel, bridges

IX. Construction of channels and sewer system

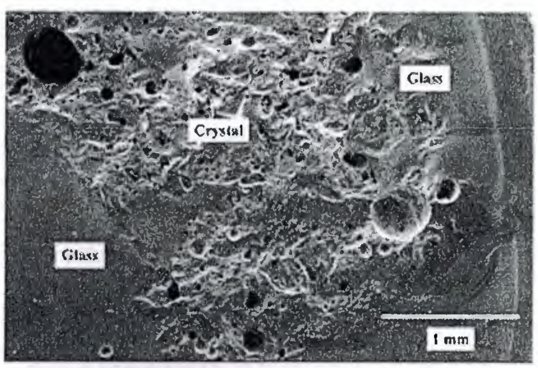

Figure 2.8: Appearance of glassy and crystalline phases of blast furnace slag (Gan et al, 2012)

2.2.2.2 REDUCING PERMEABILITY WITH SLAG

When Portland cement hydrates, it forms calcium silicate hydrate gel (CSH) and calcium hydroxide (Ca $(OH)_2$). CSH provides strength and holds the concrete together .Permeability of concrete is related to the proportion of CSH to Ca $(OH)_2$ in the cement paste. The higher the proportion of CSH to $Ca(OH)_2$ the lower the permeability of the concrete .When the slag cement is used as part of the cementious material in a concrete mixture , it react with $(Ca(OH)_2$ to form additional CSH , which in turn lower the permeability of the concrete.

Concrete with lower permeability can be achieved by substituting 25 to 65 percent slag for Portland cement (SCA)

$C_3A + 2C_a^{2+} + 2SO_4^{2-} + 26H_2O \longrightarrow C_6AS_3H_{32}$ (1)

$2C_3A + C_6AS_3H_{32} + 4H_2O \longrightarrow C_4ASH_{12}$ (2)

$C_4A + 0.5Ca^{2+} + 2SO_4^{2-} + 20H_2O \longrightarrow C_6AS_3H_{32}$ (3)

$C_3A + 0.5CaCO_3 + 0.5Ca(OH)_2 + 12H_2O \longrightarrow C_4AC_{0.5}H_{12}$ (4)

Ettringite ($C_6AS_3H_{32}$) forms in the cement matrix from the result of the reaction between C_3A in Portland cement and the internal sulphate ions from gypsum shown in equations above. Shown in equation (2) is the reaction of the remaining C_3A with ettringite to form monosulfate (C_4ACH_{12}). Ettringite formed in equation (3) is as result of sulphate ions supplied from external sources outside the cement matrix, the reaction between the monosulphate and external sulphate ions results to cement expansion.(S. Ogawa, et.al , 2012). Shown below is an example of an early structure in the United Kingdom made from GGBS (Osborne, 1999)

2.2.3 EFFECTS OF PLASTICIZER IN CONCRETE PERMEABILITY

In recent times, various polymers are being incorporated in modern concrete in order to achieve desired properties. Addition of plasticiser into fresh cementitious materials can improve their rheological properties and also, in the premise of satisfying construction requirements, lower w/c ratio could be achieved. It is well known that w/c ratio is required to produce concrete with higher strength, lower permeability, and higher durability (Malhotra, 1999) and (Gagne et al, 1996). Plasticisers are beneficial to the refinement of pore structures at a constant w/c ratio (Khatib and Mangat, 1999). The influence of various types of plasticisers on pores was examined, and was found that the size of cluster of aggregate cement particles became smaller when plasticiser with higher dispersing ability was added

(Sakai et al, 2006). Much research on cement mortar with plasticisers have been carried out, few studies dwell on their impact on the pore structure and the impermeability from the microstructure point of view in the fresh state of cement paste. It is supposed that these plasticiser may affect the pore structure and the impermeability from three perspectives

I. Changing the flocculation microstructure of the cement grains

II. Altering the cement hydration process

III. Filling the pores and the cracks in the transition zones and forms films in many cases (Zhang, 2014)

2.2.4 EFFECTS OF CRYSTALLINE WATER PROOFING ADMIXTURES (CWA) IN CONCRETE PERMEABILITY

Water is an important compound in concrete production, placement, and curing. But once its role is fulfilled especially at the end of hydration process, water is no longer friendly with concrete. (Hooker, 2012)

Crystalline water proofing admixture (CWA) is a special cementitious mix of chemical that readily reacts with moisture present in concrete to form crystalline structure within the pores and capillary tracts of the concrete. It is used to ensure water proofing for the concrete against ground water infiltration, protecting against water borne salts.

The crystals accelerate the autogenous healing capabilities of concrete to fill and block static cracks u to 0.4mm. The silicate reacts with calcium hydroxide (from the cement hydration process) to form a calcium silicate hydrate (C-H-S) which is similar to that formed by cement hydration but with variable hydrate concentration (CSH_n) (Ken, 2013)

The materials used in producing permeability reducing admixtures are generally classified into three categories:

a. The major category consists of hydrophobic or water- repellent chemicals obtained from fatty acid, vegetable oil and petroleum. These materials form a water- repellent layer along pores in the concrete.

b. The second category is fine divided solids, either inert or chemically active fillers such as talc, siliceous powder, clay and coal-tar itches. These materials densify the concrete and physically minimise the water infiltration through the pores.

c. The third category which will be used in this study consists of crystalline products, proprietary active chemicals in a carrier of cement and sand. These are hydrophilic materials that increase the density of calcium silicate hydrate or generate crystalline deposits that block concrete pores to resist water infiltration.(Hooker, 2012) and (Ken, 2013)

Advantages of Crystalline Water Proofing Admixtures

The use of crystalline water proofing admixture (CWA) is along integral water proofing system which aide in resisting extreme hydroscopic pressure. It has no detrimental effect on the performance of the concrete provided that the recommended conditions are met.

Besides reducing permeability, the admixture also acts as a mild retarder, so it helps to minimise the heat of hydration and consequently reduces shrinkage cracking, below are other advantages of CWA

Other advantages of CWA is its non toxic nature, cost effect and process friendly system (Penetron, 2015)

Areas of its application

Crystalline water proofing admixture is considered for projects and applications that need waterproof concrete. It is mostly used in areas where there is threat of water infiltration though concrete structures like foundations (e.g pile foundation), sewage treatment plant, tunnels and subway systems, underground structures, swimming pool and reservoirs (Penetron, 2015)

2.2.5 PREVIOUS RESERCHES ON CONCRETE PERMEABILTY

Several researches have been carried out on the control of concrete permeability using different approaches and materials such as silica fume, rise husk, metakaoline, and fillers to improve the quality characteristics of concrete in both the fresh and hardened states and also making the concrete more economical and ecological friendly.

In King Fahd University of Petroleum and Minerals, studies on the use of fly ash, silica fume, or a highly reactive finely pulverised fly ash as supplementary cement material in concrete were carried out. The concrete mixtures were designed for constant workability of 75-100mm slump. The performance of ordinary Portland cement (OPC) and silica fume (SF), fly ash (FA) and very fine fly ash (VFFA) cement concrete was tested for. Concrete specimen, 75mm in diameter and height 150mm were cast for each of the concrete mixtures. The concretes were tested after 3, 7, 14, 28, 90, 270, and 450 days of water curing. In other to assess the performance of these supplements in concrete, the specimen were evaluated by placing them in 15.7% Cl^- and 0.55% SO_4^- solution after being cured for 28days. These specimens were exposed to sulphate – chloride solution for 6 hours and then allowed to dry.

This wet – dry period constituted only a cycle. The concrete specimens were retrieved and tested after 90, 270, and 450 cycle exposure. It was noted from the experiment that the water requirement of FA cement concrete was less than OPC and SF cements concrete. Consequently, the mechanical properties and durability characteristics of the former cement was better than those of the latter cements. Also, from the characteristics of the chloride permeability classification, it was observed that the highest reduction in the chloride permeability was noted in the FA cement concrete, followed by SF and VFFA cement concretes. The decrease in the permeability of the blended cement was explained as the conversion of Ca $(OH)_2$ to secondary calcium –silicate-hydrate. (Al-Amoudi et al, 2011)

In International Journal of Civil Engineering and Technology (IJCIET), an article with the title "Experimental study on water permeability and chloride permeability of concrete with GGBS as a replacement material for cement" provides valuable information on this thesis study. In this article, both steady flow and depth of penetration methods of water permeability testing were used for the evaluation of permeability of concrete. GGBS was used as partial replacement for cement from 0-100% at increment of 5% interval, and the samples arranged in permeability testing machine and test was carried out for 100hours. The experimental results showed that, with partial replacement of cement by GGBS till 60%, the permeability of concrete is decreased and the resistance to chemical attack is increased. However, the permeability increases from 65% replacement of cement by GGBS. (Tamilarasan et al, 2012)

Also, according to CRD-C 163-92 standard in an experimental study titled "Test method for water permeability of concrete using triaxial cell" describes other alternative of testing water permeability. This test method involves the establishment of a steady flow condition in cylindrical concrete sample housed in a triaxial permeability cell. A pressure gradient is maintained across the specimen with one end exposed to ambient pressure and the opposite end at the end drive pressure. The radial confining pressure is maintained around the specimen. The effluent is collected, and volume flow rate is determined. Once the steady-state flow conditions are known, the intrinsic permeability is calculated (wbdg.org)

$$K = \frac{\gamma}{\mu} * k$$

Where K = hydraulic conductivity, μ = dynamic viscosity, γ = specific gravity of the fluid

In another research, effectiveness of silica fume in reducing permeability of normal and high performance concrete was carried out. The aim of this research was to investigate the effect of various level of cement replacement with silica fume at 0%, 5%, 10% and 15%, on strength, elastic modulus and permeability. The result showed the significance effect of replacement of silica fume in reducing permeability and at 15% replacement level of cement with silica fume, the coefficient of permeability was reduced 80 times, it also increased the strength and elastic modulus of the concrete.(Bagheri et al, 2008)

Another study titled "Absorption and permeation performance of selangore rice husk ash blended grade 30 concrete" was carried out. This study was carried out using rice husk ash as a supplementary cementing material. Its reports the results of durability performance conducted on the normal strength concrete specimens of $30N/mm^2$ containing 20% or 30% RHA by cement weight, with or without adding plasticizer. The results obtained show that replacement of cement with RHA lowers the concrete initial surface absorption, lowers permeability and increases resistance of concrete to chloride ion penetration in comparison with the OPC control concrete. (Kartini et al, 2010)

In a publication by Virginia Transportation Research Council, the research on the permeability of concretes containing Portland cement alone or Portland cement with a pozzolan (fly ash, silica fume) or a slag was experimented by either rapid permeability or ponding test. From the results of the experiment, it was observed the rapid permeability test is more convenient and relatively faster compared with ponding test as the standard ponding duration is 90 days. However, for low - permeability concrete, 90 days is not sufficient, the specimen were put as long as 30 month. It was also observed that permeability decreases with time, and the addition of pozzolans or slag is very significant in decreasing water permeability. (Ozyildirim, 1998)

2.2.6 LIMITATIONS IN PERMEABILITY STUDIES

Due to difficulty in generating suitable crack pattern in concrete specimen and availability of appropriate methods for concrete permeability measurement, a limited number of studies have been made on the permeability of cracked concrete. Some research has been made on measuring permeability of concrete subjected to compressive loading. It was reported that the application of compressive load have minimal effect on both water and chloride permeability of concrete while some evidence support the significant micro cracking occurred in the concrete (Wang and Jansen, 2013)

Concrete basically has two types of pores , which determines the permeability , these pores are capillary pores (with diameter varying between 0.01 to 10 micron)in the cement paste which the coat the aggregate and larger micro voids , between 1mm to 10mm, which are caused by faulty compaction of fresh concrete.

2.3 RELATIONSHIP BETWEEN COMPRESSIVE STRENGHT OF CONCRETE AND ITS DURABILITY

The engineering properties of concrete such as strength, durability, permeability and shrinkage have direct influence and controlled by the number, type, size and distribution of pores present in the cement paste, the aggregate components and the interface between the cement paste and the aggregate. (Basheer et al, 2001)

When stress is applied on concrete, it response depend on the stress type, and the influence that the influence that the combination of various factors perform on the porosity of the different structural component of concrete. These factor include properties and proportion of material that are used for concrete mixture design, degree of compaction, and condition of curing (Jarkovic and Nikolic, 2011). Strength is obtained due to the hydration products of cement which are the concrete compounds and continuous hydration increases the compressive strength of the concrete. The process of strength growth is called hardening which is often confused with setting. Regarding the strength of concrete, the water cement ratio and the porosity is the most important factor; the water cement ratio affects the porosity of both the cement mortal matrix and the interfacial transition zone between the matrix and the coarse aggregate.

a) SETTING:

This is the stiffening of the concrete after it has been placed. A concrete can "set" in as much as that there is no longer fluid in it, but may still be weak, have low workability. Setting is due to early stage calcium hydrate formation and to enttrigite formation.

b) HARDENING :

Hardening is the process of strength growth that may continue for weeks or months after the concrete has been placed. This is largely due to formation of calcium silicate hydrate (CSH)

2.4 DURABILITY OF CONCRETE

The early and premature deterioration of concrete structures is a serious issue in most part of the world, as it could put the public safety in jeopardy and escalating repair cost which may directly affect or burden the future economy.(Tayeh et al, 2012)

Durability of concrete is the resistance of concrete against weathering, chemical and physical attacks that gives rise to deterioration of concrete during its designed service life (Bilir, 2012). According to ACI committee 201, durability of cement concrete is defined as it ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. (Nagesh, 2012) It varies in concrete, depending on the exposure environment and properties desired. For example concrete exposed to tida sea water will have different requirement than an indoor concrete floor. These properties may vary in concrete ingredients, mixing proportion, placing, curing practices and ultimate durability and life of concrete is determined by it environment.

Durability of concrete depends on its ability to resist the infiltration of noxious chemical substances. Transport properties of concrete, especially permeability play an important role in assessing and predicting the durability of concrete structure. The hydric state greatly has influence on the transport parameters like permeability which influence the penetration of aggressive species and so on concrete durability. (Kameche, et al, 2014)

For several years, from1983, the problem of the durability of concrete structure was majorly topic of interest in Japan (Ouch and Hibino). Infiltration of noxious substances can speed up the degradation process of matrix which substantially reduce the durability and the life of concrete. Therefore permeability control is an important consideration in the design of concrete and engineering structures for long time durability.

2.4.1 FACTORS AFFECTING THE DURABILITY OF CONCRETE

Disintegration of concrete and corrosion of reinforcement is one of the major signs of deterioration of concrete structures. After laboratory investigation and extensive studies in existing structures, researchers have identified a number of factors affecting the durability of concrete were observed, some of these parameters are discussed below.

I. AGGREGATE TYPE:

As the aggregates occupy up to 80% by volume of concrete, the resistance surface properties of aggregate is very important parameter considering durability of concrete structure. For adequate durability of concrete especially in marine structures, the aggregate material should be dense, none shrinking and alkalis resistance.

II. WATER –CEMENT (W/C) RATIO:

This factor influences both the strength and the durability of concrete. According Abraham's law, the strength of concrete at a given age and normal temperature decreases with increasing the water-cement ratio assuming full compaction of the concrete have been done. Permeability of concrete depends mainly on the water cement ratio, which determines the size, volume, and continuity of the capillary voids. Permeability is known to be the most important characteristics determining the long term durability of reinforced concrete exposed to sea water as it helps in preventing the diffusion of noxious substances like salt ions into the concrete .ACI 318-83 required that normal weight concrete subjected to freezing and thawing in most condition should a maximum water ratio of;

a. 0.45 in case of curbs, gutter, guardrails, or their section and

b. 0.50 for other element

I. CEMENT:

The resistance of concrete against the action of destructive agencies greatly depends on the type and proportion of cement. The main chemical factor that influence the chemical resistance of cements are the C_3A in Portland cement and the alumina level of slag, if present. Chemical attack seems greater when both the level of C_3A and the alumina level of slag are higher. (Osborne, 1999)

Cement content in concrete has significant effect on the durability of concrete. Mix should be designed in a way to ensure proper cohesion and prevent segregation and bleeding. Researchers assessed the performance of cement individually by either exposing the mortar and concrete specimen in seawater or in its constituent salt solution, to study their strength and solution.

II. AIR ENTRAINMENT

Normally, harden concrete contained air is more uniform, as less absorption and permeability and more resistance to freezing and thawing. Normally 4-6% of air volume of concrete is entrained which is dispersed throughout the concrete. However, if the air entrained is greater than 10% by volume of the concrete, the compressive strength will be reduced to about one-half of the strength without air entrainment.

III. QUALITY OF WATER

Sea water contains a total 3.5% salinity of which

78% is NaCl

15% is $MgCl_2$ and $MgSo_4$

According to ACI 318-83 the mixing water should be portable and free from salts.

2.4.2 PROBLEMS OF DURABILITY

Durability problem of ordinary concrete can be linked with the severity of the environment and the use of inappropriate high water/cement ratio. High performance concrete with lower water/cement ratio are usually more durable than ordinary concrete not only because less porosity, but also because the capillary and pore network are disconnected due to development of self desiccation (Aiticin, 2003). For the best performance concrete, the mixture proportion must be appropriate to the specific application and preparation, placing, compaction and curing should be carried out under proper supervision.(Osborne, 1999) Problem of durability of concrete may be due to environment that concrete is exposed to or by internal causes within the concrete itself. Concrete will remain durable if;

I. The cement paste structure is dense and of low permeability

II. It is made with graded aggregate that are strong and inhert.

III. The ingredients in the mix contain minimum impurity such as alkalis, chloride, sulphate and silts.

Problems of durability in concrete could be any of the following action

a) PHYSICAL DURABILITY PROBLEMS

Physical durability problem can be any of the following actions

i. Permeability or percolation of water

ii. Freezing and thawing action

iii. Temperature stressed i.e high heat of hydration

b) CHEMICAL DURABILITY PROBLEMS

Chemical factors affecting durability is related to the presence of various ions dissolved in sea water or transported in the wet air. (Aitcin, 2003)

Chemical durability problem can be any of the following

I. Chloride ingress

II. Corrosion of reinforcement

III. Delay enttrigite formation

IV. Sulphate attack

V. Alkali aggregate reaction

2.4.3 RELATIONSHIP BETWEEN PERMEATION OF CONCRETE AND CONCRETE DURABILITY

Research evidences have illustrated the correlation between the relevant transport properties and either the penetration of different aggression substances or the mechanism of deterioration

I. SULPHATE ATTACK

Sulphate attack occurs when sulphate ions from the environment (e.g water or soil) penetrates into the concrete pores and within the internal system. According to (Spark, 1998) for sulphate attack to occur, concrete must be highly permeable, a source of water and sulphate must be present. The prominent form of sulphate attack on the internal cement matrix is when sulphate source reacts with calcium aluminates hydrate and monosulphate hydrate, resulting in the formation of ettringite. This reaction process is the reaction responsible for the crack generation and spalling of concrete members (Alam et al, 2012)

II. CHLORIDE INGRESS

There are interactions between the chloride ions and hydration product of cement, which may trigger the development of frost damage. However, the fundamental destructive effect of chloride is their influence upon the reinforcement corrosion process which is primarily due to their capacity to displace the corrosion inhibits properties of the alkaline cement paste pore solution. This risk is higher as the threshold of the chloride expected in corrosion is reached. (Basheer et al, 2001)

I. ALKALIS – SILICA REACTION

Alkalis- silica reaction in concrete (ASR) is one of the major chemical reactions causing gradual but severe deterioration of hardened concrete (Ichikawa, 2009). Concrete failure is due to certain unfavourable phenomena that occur during the reaction between alkalis and aggregates (Owsiak, 2004). This reaction between the silica in concrete aggregates and alkaline solution in the micro pores of concrete results in the formation of bulky hydrated alkalis silicate gel. The expansive pressure generated by this hydrated alkali silicate is generally believed to induce the cracking and deterioration of concrete (Ichikawa, 2009)

II. CARBONATION

When carbon dioxide diffuses into concrete, in the presence of water, it reacts with calcium hydroxide to form calcium carbonate. As a result of this, the PH of the pore solution is diminished below 10.the corrosion of the reinforcement will start if the carbonation progresses until the surface of the reinforcement is reached, as the passive layer of the steel surface will be dissolved (Basheer et al, 2001).

The pore structure, the permeability of concrete and the chemical reactivity are altered by product of carbonation. The interaction between carbonation and chloride contamination of concrete is the likely cause of the most severe corrosion problem encountered in practise (Basheer et al, 2001).

III. FREEZE – THAW DETERIORATION

The ease of movement of water into and within concrete depends on the pore structure characteristics of concrete. The pore distribution in concrete mainly determines the extent of damage to concrete during freeze –thaw cycle, the amount of freeze able water present in the capillary pores is also important and depends on the degree of saturation, the minimum temperature reached by the water and composition of the pore solution. The internal tensile stress developed due to freezing is observed to be in the range of 1- 4 N/mm^2. Therefore, internal cracks may develop initially and repeated cycles of freeze and thaw may result in critical damage of the concrete (Basheer et al, 2011)

IV. CORROSION

This type of deterioration is a serious problem in all climates. It may occur due to presence of water that penetrates throuhg concrete cover. The steel rusts as result of long exposure to water in the presence of air and makes it expand up to four times its original volume. This process create tensile stresses in concrete and eventually leads to cracking and spalling of the concrete cover zone (Afroze, 2002).

2.4.4 CAUSES OF PROBLEMS IN DURABILITY

In many cases, deterioration of concrete is caused by infiltration of various ions, liquids and gases from the environment. For instance, the ingress of chloride or carbon dioxide would depassivate steel in concrete, and the presence of oxygen and water may cause the steel to corrode. Like wisely, the ingress of chemicals, such as acids, alkalis and sulphates are responsible for the chemical degradation of concrete. Also, moisture movement during freezing and thawing action also causes deterioration of concrete (Basheer et al, 2001).

The problems in durability are caused by many categories but can majorly be classified into two categories which are

a. EXTERNAL CAUSES

External causes are:

I. External weathering condition

II. External temperature

III. Abrasion

I. Electrolyte action

II. External humidity

III. Attack by natural or industrial liquid gas

b. INTERNAL CAUSES

Internal causes can further be categories into

i. Physical causes

Typical examples of problem attribute to physical causes are :

a) Frost action

b) Volume change due to different in thermal properties of aggregates and cement paste.

ii. Chemical causes

This can be categories into

a. Alkali aggregate reaction

b. Corrosion of steel

CHAPTER THREE

MATERIALS AND METHODOLOGY

The scope of this study is to provide more insight on the level of permeability of concrete mixes, with varying parameters in addition to determine the most efficient mix amongst the standard mixes that will be used in the in problematic areas of North Cyprus. For these purpose, an ***experimental methodology*** will be selected and carried out. The "principle" concrete mix combination to be tested will be CEMII with superplasticizer and with crystalline water proofing admixture, which is preferred with one of the leading companies in North Cyprus (Tufecki group). A detailed experimental campaign is designed to check the effect of each parameter in this "key" concrete mix combination. CEMI and CEMIII will be used to check varying amount of slag replacement compared to CEMII. In addition to three different slag contents, concrete mixes will be prepared: 1) with both superplasticizer and crystalline water proofing admixture, 2) with only superplasticizer, 3) with only crystalline water proofing admixture, and 4) without any crystalline water proofing admixture or superplasticizer addition for all the types of cements suggested.

Main focus of this study is to check the impermeability performance of concrete with varying parameters; and since it is known that the impermeability of these mixes will be evolving with continuous hydration of cement, compressive strength development of each mix will also be observed simultaneously, so that the effect of ongoing hydration can be verified. Table 3.1 summarises the parameters controlled in different concrete mixes to be tested in this experiment campaign.

3.1 METHODOLOGY

Impermeability of concrete is of great significance in any engineering structure which comes in contact with water (e.g. concrete foundation) or which is intended to retain water (e.g water reservoir). In this experiment procedure, different trails of mixes were made as shown in table 3.1 below. Concrete of different percentage of replacements and admixtures were produced, maintaining specific interval of slump to investigate their permeability characteristics.

Table 3.1: Organization and distribution of test samples

Cement type	Test types	Without admixture		With only plasticizer		With only CWA		With plasticizer and CWA		Total cube
		7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	
CEMI	Impermeability	3	3	3	3	3	3	3	3	24
	Compressive strength test	3	3	3	3	3	3	3	3	24
CEMII	Impermeability	3	3	3	3	3	3	3	3	24
	Compressive strength test	3	3	3	3	3	3	3	3	24
CEMIII	Impermeability	3	3	3	3	3	3	3	3	24
	Compressive strength test	3	3	3	3	3	3	3	3	24
		Total cube samples								144

0 - 65% of cement was replaced by GGBS and the mix grade C30 was used with varying admixture. For each kind of mix or level of replacement, 12cube samples were casted by thoroughly mixing cement, fine aggregates (0-5 mm), coarse aggregates (5-12mm) and (12-19mm), admixture(s) (depending on the mix design) and water in the in the mixer machine. For every kind of mix, the slump was taken to check the effect of additives on the concrete workability. All the cubes were subjected to 100% humidity curing for specified period, then compressive test was carried out on 3 samples of each mix on the due dates with a compressive test machine, but as for the impermeability test the sample were removed a day before the test to dry the sample from existing water of curing.

Also for impermeable 3 samples were tested from every mix, for 7 and 28 days, these samples were arranged in permeability testing machine, setting the water and air pressure to 5 and 8 bars respectively for 72 hours. After wards, the samples were broken with the aid of a machine, and the water rise through the sample was measured.

3.2 MARTERIALS USED

In this section various materials available in North Cyprus that were used in this study will be discussed in details. The cost of materials used is given in the appendix.

3.2.1 CEMENTS

Three different types of BEM cimento, which is the most widely used cement brand in North Cyprus, were selected.

1. CEMII/B-S 42.5R; Ordinary Portland cement is replaced with 33.5% by mass. Is the most widely used cement in North Cyprus because of its slow hydrating due to slag's nature and it is beneficial for its lower rate of heat hydration in North Cyprus where the temperature is generally high.
2. CEMIII A42.5R 55.5% by mass of OPC is replaced by slag to check the effect of increased slag compared to CEMII/B-S 42.5R
3. CEMI 42.5R is Portland cement containing pure clinker compounds without any slag replacement which serves as the control set in this experiment.

Table 3.1 shows the Properties of cements used in this experiment

Table 3.2: Properties of cements used

Properties	CEMI 42.5R	CEMII/B-S 42.5R	CEMIII A42.5R
Insoluble residue	0.24	0.50	0.38
SO_3 (%)	0.56	2.47	1.83
MgO	1.68	3.48	4.22
Ignition loss (%)	2.85	2.00	2.25
Specific gravity(g/m^3)	3.10	3.00	2.97
Specific surface(cm^2/g)	3230	4660	4690

3.2.2 PLASTICISER

DRACO LEVELCON X50 conforming with EN934-2 ,ASTM C-494 type G is used in North Cyprus by one of the leading ready mix concrete company (Tüfekçi group), was the superplasticizer admixture selected. It has a high water-reducing characteristics, it was added into the mixing water at ratio 1.03% based on cement weight and thoroughly mixed with the concrete.

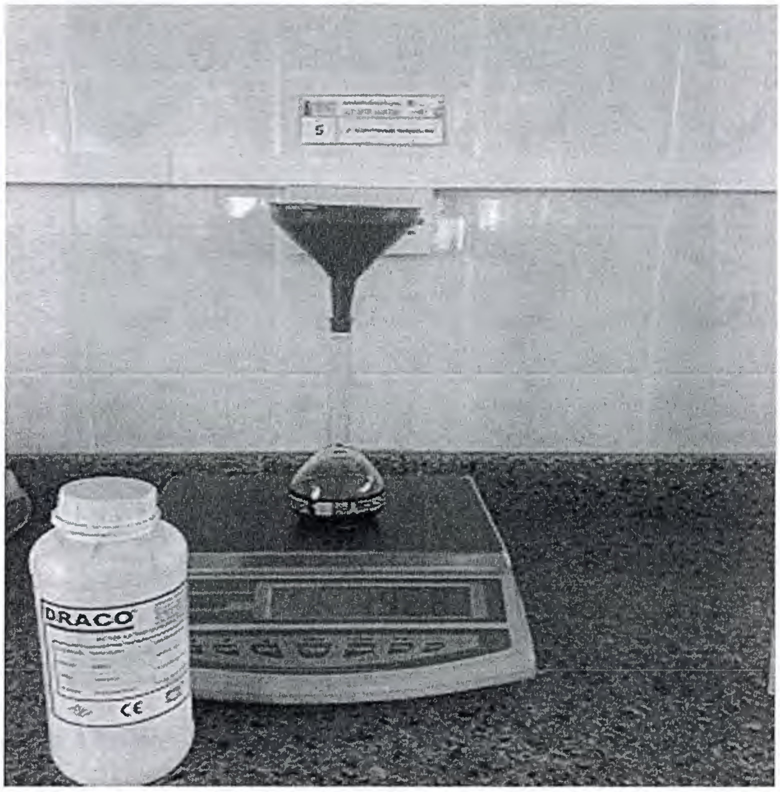

Figure 3.1: Weighing procedure of the superplasticizer admixture (DRACO LEVELCON DX 50 SR)

3.2.3 CRYSTALLINE WATER PROOFING ADMIXTURE

DAWCO K11 CWA was the water proofing material used as crystalline water proofing admixture; it forms a high crystalline structure within the pores and capillary of the concrete. This product is used by the Tüfekçi group in potentially problematic areas where water infiltration to concrete is highly expected. Beside slag replacement in cement, addition of DAWCO K11 CWA crystalline water proofing admixture and its performance on the level of impermeability of concrete mixtures will also be studied in this thesis.

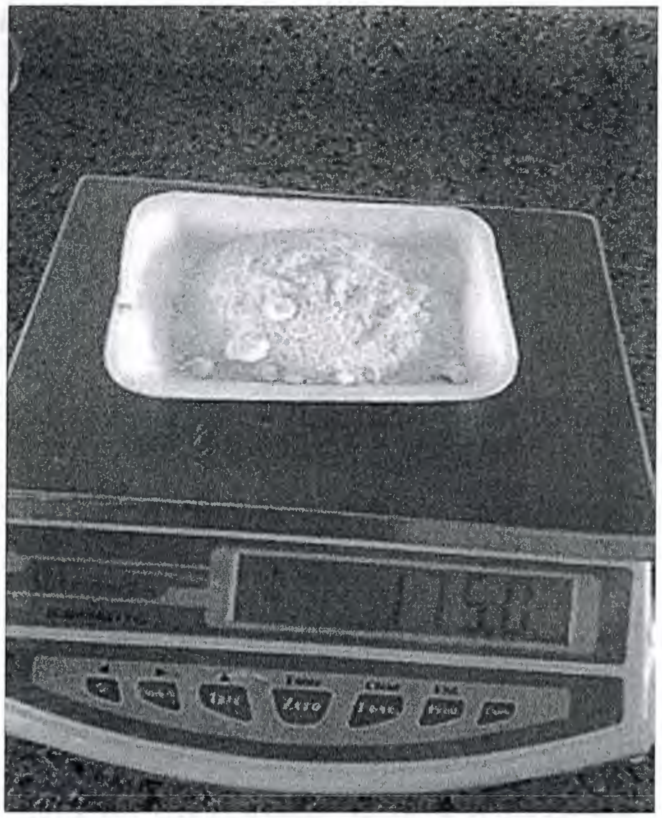

Figure 3.2: Weighing procedure of CWA (DAWCO K11 CWA)

3.2.4 WATER

Potable water was used without testing or qualification as mentioned in ASTM C1602 standard.

3.2.5 AGGREGATES

Crushed aggregates of three different size categories, ranging from 0-19mm, were used. These sizes were selected because self compacting concrete (SCC) is being considered, as in the case study. The specific gravity and water absorption values of the aggregates are provided in appendix table3

For the concrete mixes, the aggregates distribution were selected to be 0-5mm crushed by 54%, 5-12mm fine aggregate to be 19% and 12-19mm coarse aggregate 27%. Aggregate of lower gradation were selected for the self compacting concrete because it provides a better flow and a higher workability.

3.2.5.1 PRELEMINARY TESTS ON THE AGGREGATES

Several tests were conducted during material selection for appropriate batching, these tests include:

a. SIEVE ANALYSIS

Aggregate gradation is an important design parameter affecting the workability and strength properties of concrete (Ozen and Guler, 2014)

The grain size analysis test helps to determine the relative properties of different grain sizes, distributed among certain size range (gradation) in order to determine its compliance with design and production standard.

APPARATUS

All the apparatus were carefully selected

I. A scale for weighing samples

II. Sieves of different sizes

III. Oven for drying

SAMPLE PREPARATION [AGGREGATE]

Aggregate samples of different sizes 0-5mm, 5-12mm and 12-19mm were obtained from rocks available in north Cyprus, reduced to test size in according to standards. These samples were dried to a constant weight in an oven set.

PROCEDURE

I. The samples were weighed to the nearest 0.1g by total weight sample. This was to check for any loss of material after the sample has been graded and suitable sieve sizes were selected in accordance with specification.

II. The sieves were nested in order of decreasing size from top to bottom and began agitation and shaking the sample for sufficient amount time.

III. COARSE AGGREGATES

After the materials have been sieved, each tray was removed; each size was weighed independently and was recorded to nearest 0.1g. The happed aggregate within the sieve were carefully removed.

IV. FINE AGGREGATES

The materials retained on each sieve were weighed as well, to the nearest 0.1g, and the material entrapped within the sieve were cleaned out with the aid of soft brush.

Figure 3.3: Aggregates of different gradation

a. LOS ANGELES ABRASION TEST

This is the most common method for assessing the abrasion resistance of aggregates which determines the relative competence or resistance to abrasion of aggregate.

In this study, aggregate 5-12mm, and 12-19mm sizes were tested to evaluate their mechanical property.

Graded aggregate samples were placed into a steel drum containing eleven steel spheres and were rotated for 500 revolutions. The interior of the cylindrical drum has shelf that picks up the sample and charge during each rotation and drops them on the opposite side of the cylinder, thereby subjecting the aggregates sample to attrition. The cylinder rotates at 30 to 33 rpm and after the 500th revolution, the machine automatically stopped by a counter switch. After completion of revolution, the resulting sample was sieved over 1.7mm sieve to determine the amount of degradation that occurred during the test. The abrasion loss as percentage of the original mass of the test sample after 500 revolutions was calculated.

$$K_{500} = \frac{G0 - G500}{G0} \times 100$$

Where k_{500} = abrasion loss after 500 revolution [%]

G_0 = Original sample mass[g]

G_{500} = sample loss after 500 revolution [g]

The result was calculated according to TS699 for 500 revolutions.

CALCULATION FOR LOS ANGELES ABRASION TEST

$G_O = 5000$

$G_{500} = 3377$

$K_{500} = \frac{5000-3377}{5000} * 100$

$K_{500} = 32.46\ \%$

According to American standard which specifies the abrasion test value to a range between 25- 55 percent, that is, the 32.46 percent obtained from out test confirms that the aggregate is suitable construction.

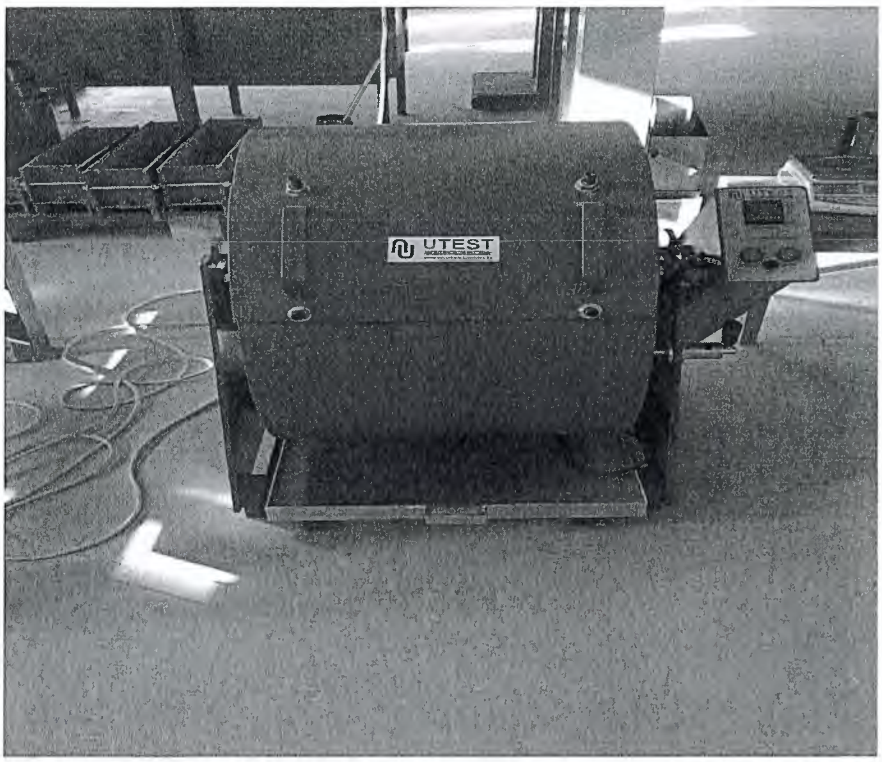

Figure 3.4: Los Angeles test machine

b. METHYLENE BLUE TEST FOR FINE AGGREGATES

Clay mineral is naturally found in small fraction of naturally crushed aggregates. Generally, presence of clay in high quantity is considered harmful in concrete and mortar by increasing the required mix water to provide a concrete or a mortar of a specific workability which substantially reduces the strength, durability and volume stability of the hardened concrete or mixture. Clay mineral absorbs methylene blue [a cationic dye] from aqueous solution because of its ability to exchange cations. This is the basis of this test method: measuring cation exchange capacity and surface area, also for detecting the presence of clay minerals.

The Methylene blue value [MBV] resulting from the test depends on the characteristics such as mineralogy, particles sizes and porosity. If the MBV is below 12, the aggregate is accepted according to standard. Though high MBV value a times does not necessarily mean that the material is not suitable due to presence of clay, it can be an indication of problems such as high water demand, so further investigation especially in case of high fined aggregates should be carried out.

The apparatus used for this experiment were weighing balance [AASHTO M23], Methylene blue test set, 2mm sieve and quantitative filter paper.

Materials used were 200g sample of dies fine aggregates, methylene blue, and 500ml of clean water.

The sample of aggregates were obtained from a concrete mix company in North Cyprus [Tüfekçi group], and was heated to about 105□ to ensure a well dried sample, then sieves with a 2mm sieve.

500ml of water was added to 200g of the sample that passes through the 2mm sieve. The methylene blue test apparatus was set up and a stirrer designed for 600rpm helps in proper mixing of the sample. For every 3min 1ml of methylene was added to the sample and the readings were taken by making a drop for the mixture on a quantitative filter paper at every mixing interval until the required indication was noticed (clear spark like indication by the drop edges)

Readings from methylene blue test are:

Number of reading (drops on filter paper) = 9

Mass of aggregate = 200g

Amount of methylene blue used = 9ml

Percentage presence of clay material in the aggregate % = $\left(\frac{\text{Amount of methylene blue used}}{\text{Mass of aggregate}}\right)$ Amount of methylene blue used

Percentage presence of clay material in the aggregate % = $\left(\frac{9}{200}\right) \times 9 = 0.405\%$

Since the result is less than 1%, which conforms with AASHTO TP 57-06 and the number of drops on the quantitative filter paper before indication is less than 12, it indicates that the aggregate is suitable for use in construction.

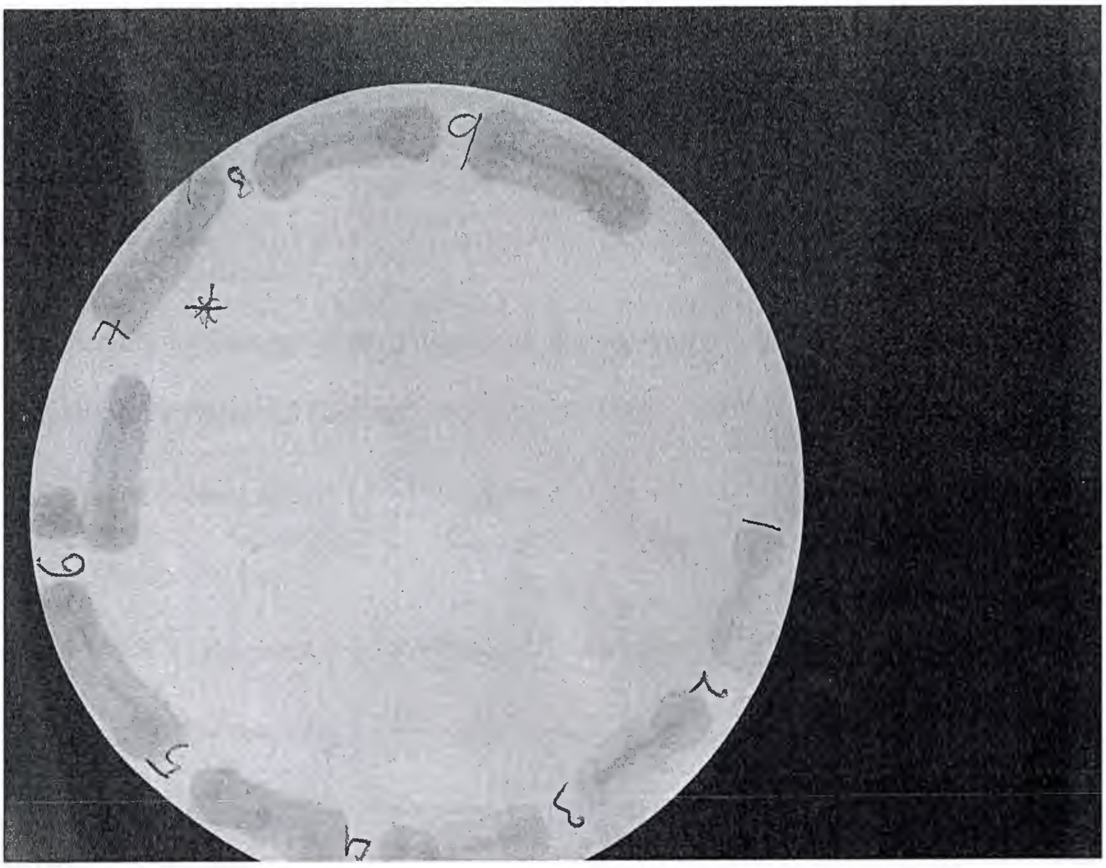

Figure 3.5: Quantitative litmus paper showing methylene drops

3.3 MIX DESIGN PARAMETERS AND CALCULATIONS

Specified proportion of materials including water and admixtures according to the concrete mix design shown in appendix table 5 was used for determining the suitability of the local materials available in North Cyprus. Twelve batches were prepared as described in the table, cement or cementious material content was 340 kg/m^3 for all the mixes to obtain comparable water permeability and compressive strength test at both 7 and 28 days. CEMI, CEMII and CEMIII were the cements used in all the mixture. The chemical and physical analysis of cement and slag are given in the appendix. All the categories of aggregates used were crushed aggregates and the nominal maximum size was 19mm, because self compacting concrete (SCC) is a target as in the case study.

The concrete mixes were prepared at two w/c ratios; 0.5% and 0.65%. All batches that includes superplasticizer were prepared at 0.5% w/c ratio while other mixtures where prepared at 0.65%. The concrete were mixed in accordance to ASTM 192.

An example mix design calculation

Cement = 340kg/m^3

Percentage of Water used = 0.5- 0.65%

Aggregates = {(0-5) = 54%, (5-12) =19%, (12-19) = 27%}

Admixture = 1.2%

Density = $\left(\frac{mass\ (g)}{volume(cm3)}\right)$

The density for compositions are given in the appendix

Density for CEMII = 3.03g/cm^3

Volume of cement used = $\left(\frac{340}{3.03}\right)$ = 112dm^3

Note; 1000dm^3 = 1m^3

For 0.5% w/c ratio used = 0.5×340kg/m^3 = 170 kg/m^3

Volume of 0.5% w/c ratio = $\left(\frac{221}{1}\right)$ = 221 dm^3

CRYSTALLINE WATER PROOFING ADMIXTURE

1.4% crystalline water proofing admixture was used = $\left(\frac{1.47}{100}\right)$ × 340 = 4.99 kg/m^3

Density of crystalline water proofing admixture used = 2.745 g/m^3

Volume of crystalline water proofing admixture used = $\left(\frac{4.99}{2.745}\right)$ = 1.82dm^3

1m^3 of concrete = 1000dm^3 (cement + water + admixture + aggregate), there for 1000dm^3 – cement –water – admixture = aggregate

1000- 112-221 – 1.82 = 665.18dm^3

54% of (0-5) aggregate was used; 0.54 × 665.18 = 359.19 dm^3

19% of (5-9) aggregate was used; 0.19 × 665.18 = 126.38 dm^3

27% of (9-12) aggregate was used; 0.27 × 665.18 = 179.60 dm^3

Mass of (0-5) aggregate = volume × density = 359.19 × 2.69 = 966.22kg/m^3

Mass of (9-12) aggregate = 126.38× 2.7 = 341.23 kg/m^3

Mass of (12-19) aggregate = 179.60 × 2.74 = 492.10 kg/m^3

The mixes varies with percentage of the w/c ratio and admixture used as shown in appendix

3.4 MATERIAL WEIGHING

For each batch, the quantities of the materials were weighed according to mix design of the total weight of the batch. The weighing balance used has an accuracy of 0.1%

3.5 SAMPLE PREPARATIONS

The representative samples of concrete materials available in North Cyprus were obtained from one of the major leading concrete mixing company (Tüfekçi group) and properly kept under room temperature before commencing the experiment.

Series of experiments were carried out on the materials as discussed above to verify its conformity with recognized standards.

Three cubes are taken from each sample, but it can vary depending on specification, and the moulds are 150mm ×150mm ×150mm (BS EN 12390-1:2000)

3.5.1 MIXING

After proper measurement as specified in the mix design, the materials were properly mixed in the laboratory batch mixer, in a manner that avoids loss of water and other materials.

The period of mixing was an average of 5 minutes after all the materials were put in the drum to ensure proper mix of concrete of uniform appearance.

3.5.2 COMPACTION

In order to ensure symmetrical distribution of concrete within the mould; used in making sample cubes, an approximate half of its depth in the mould was compacted using tamping bar on the average of 25strokes on each layer. The sides of the mould were also randomly tapped to close the voids possibly left by tamping bar.

3.5.3 CURING

The test specimens were stored in a place free from vibration at room temperature for couple of hours from the time of addition of water to the dry materials in order to allow the concrete to set. After this period, the specimen were marked and removed from the moulds, then immediately submerged into water and kept there until they were taken out on the 7th and 28th day for compressive strength test and 6 th and 27 th day for impermeability test i.e a day before the testing date, according to European standard (EN 1239-8). The water was also maintained at room temperature.

3.5.4 SLUMP TEST

Slump test was the test used in determining the workability of the fresh concrete. The apparatus used are slump cone and tampering rod. It is important that the slump test meets the range limit dictated by the British standard, the sample should be repeated if it fails to meet the required slump (EN 206-1:2000)

PROCEDURE

i. The internal surface of the mould was thoroughly cleaned and places in smooth, horizontal, rigid and non-absorbent surface.

ii. The mould was filled in about four layers with the freshly mixed concrete, each approximately to one-fourth of the mould height

iii. Each layer was tampered randomly, tampered 25 times with tampering rod.

iv. After filling the mould and tampering the last layer, the concrete at the top surface of the mould was levelled with trowel

v. The mould was removed from the concrete immediately by raising it slowly in the vertical direction

vi. The difference in the level between the height of the mould and the highest point of the subsided concrete was measured and recorded in millimetres.

Figure 3.6: Slump test procedure

Table 3.3: Slump test results

Cement type	Without super plasticizer or crystalline water	Only super-plasticizer (mm)	Only Crystalline water proofing admixture (mm)	With super-plasticiser & crystalline water
CEMI	200	190	220	210
CEMII	220	240	220	210
CEMIII	180	200	200	180

Table 3.4: Classes of slump according to EN 206-1:2000

Slump class	Slump in (mm)
S_1	10-40
S_2	50-90
S_3	100-150
S_4	160-210
S_5	$\geq$ 220

The slumped concrete can take different shapes, and according to the profile of concrete, the slump is termed as true slump, shear slump or collapse slump. A very dry mix having 0-25mm is suitable for road making, low workability mix of slump 10- 40 mm is suitable for foundations with light reinforcement; medium workability slump 50-90mm is good for normal reinforced concrete placed with vibration, high workability concrete $\geq$ 10 mm. According to the case study used in this investigation, the selected slump range is S_4 - S_5; self compacting concrete (SCC) is considered for the deep raft foundation with heavy reinforcement shown in figure3.7 below. The high workability characteristics of the SCC is to allow easy flow of the concrete during casting, form strong bond with the reinforcing bars and requires no vibration or compaction

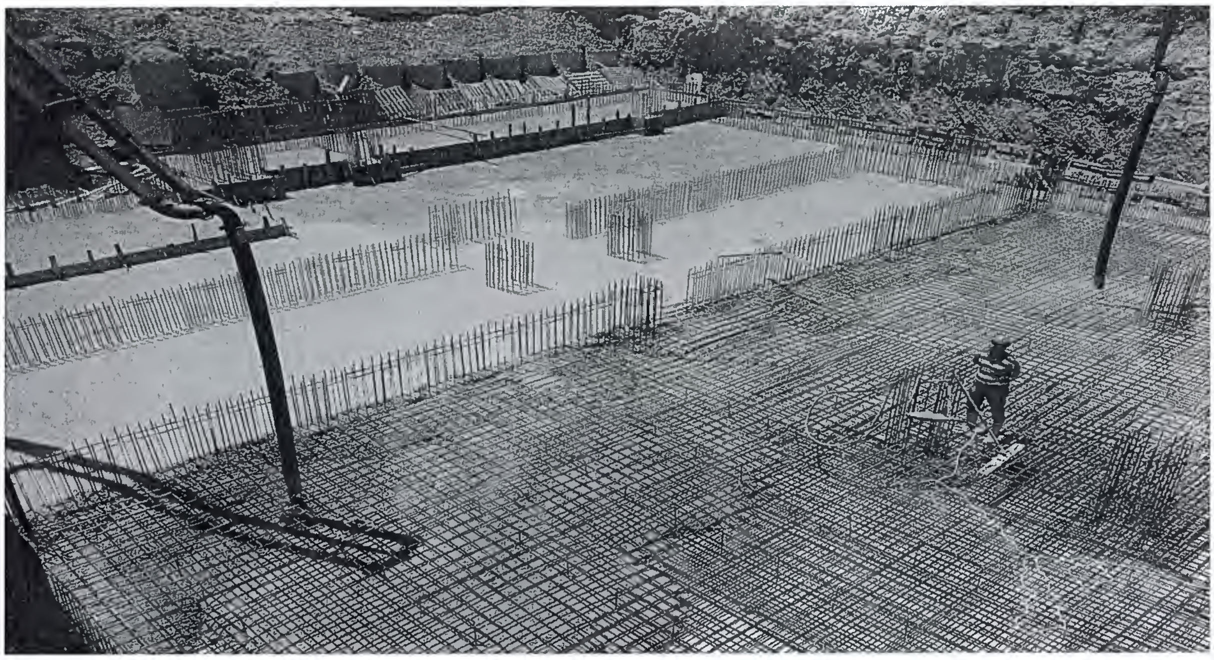

Figure 3.7: Deep raft foundation near a sea shore at Kyrenia, TRNC

3.6 TEST FOR WATER PERMEABILITY

The main reference standard is European standard (EN12390-8); specifies a method of determining the depth of penetration of water under pressure in hardened concrete. The model of the equipment used in this study is UTC 180 which can accommodate only three samples at a time, although there are other models that accommodates up to six samples.

3.6.1 DESCRIPTION OF EQUIPMENT

The equipment has an adjustable locking height for stabilizing the samples while applying pressurized water the water pressure was set on 5 bars and air pressure on 8 bars. It was connected to the water mains and no electrical connection is required except for the compressor. The water was connected to water inlet connector and compressor connected through air inlet connector. The numbering of the sample was made from left to right; the tubes were also numbered to indicate which burette corresponds to each sample.

The samples were simultaneously subjected to pressured water penetration on their cover surface for 72 hours.

The other faces were free for visual inspection except of the upper face that was covered by the locking plate. At the end of the 72th hour as defined in the reference standard, the samples were split into two using an indirect tensile device. By carefully examining the broken face of the sample, the level of maximum water penetration was measured and recorded.

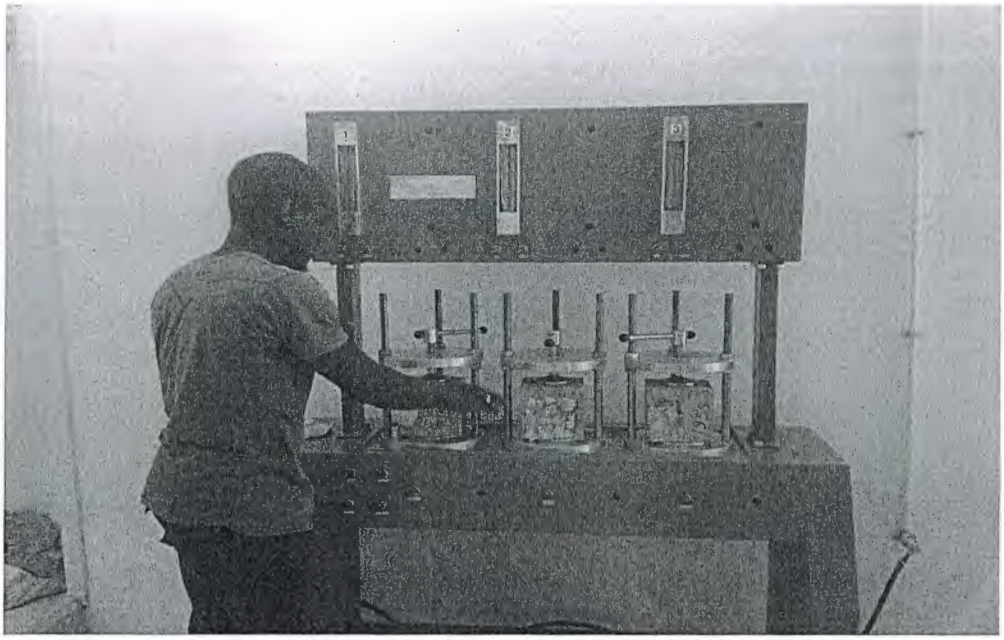

Figure 3.8: Setting of cube samples in the Permeability testing machine (UTC-0180)

3.6.2 OPERATION OF THE PERMEABILITY TESTING EQUIPMENT

The machine was connected to water mains using a Ø10mm diametre hose and air supply with a Ø10 mm diameter hose. Also the two drainage points of the machine (overflow of water tank / and over flow tray) to a drain using Ø10mm diameter hose.

The air pressure was set at 8 bars

The water tap was turned open

The water tank was filled to1000ml water

The water inlet of the sample was closed

The air tap was turned to evacuate bleed of air present in the tank and allows water to enter

The tap was immediately closed when water was noticed from over flow tank

3.6.3 PERMEABILITY MEASUREMENT

The weight of samples were measured and recorded before they were placed in the permeability testing machine. They were then subjected to pressurized water for period of 72 hours before they were then taken out and weighed again to check their mass difference before setting them up for splitting as shown in figure 3.6 below. Finally, the level of water rise in each sample was measured and recorded.

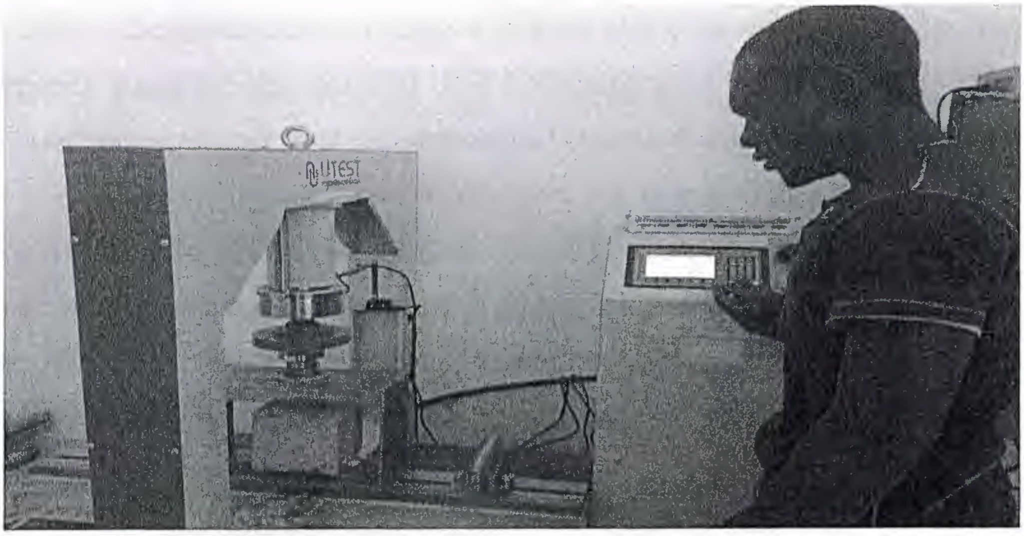

Figure 3.9: Sample splitting for permeability measurement

Figure 3.10: Level of water rise in a sample

3.7 COMPRESSIVE STRENGTH TESTING

Compressive strength is the ability of material to resist load tending towards reducing its size. This is the most important test in concrete which gives an idea about all the characteristics properties of concrete. Similar to permeability measurement, the strength development of each type of sample is tested in two ages; 28 days as a standard and 7 days for checking the performance in early age as well.

In this study cube specimens of $150mm * 150mm * 150mm$ were used. After the sample were properly cured for the specified time for compressive test, they were removed and excess water was wiped out from the surface the beaming surface of the testing machine was cleaned of particles and the specimens were placed one after the other in such a way that the load would be applied to the opposite sides of the cube cast. It was aligned centrally on the base plate of the machine and the load was applied gradually and continuously till the specimen fails. Finally the maximum load was recorded for each sample and the average was calculated.(BS EN 12390-2:2009, BS EN 12390-3:2000)

Figure 3.11: Testing a cube sample for its compressive strength

CHAPTER FOUR

RESULTS AND DISCUSSION

As described earlier, the permeability characteristics of self compacting concrete mixes with varying parameters has been investigated in this thesis study. The compressive strength of these mixes was also evaluated to check the effect of ongoing hydration. The level of permeability was obtained by measuring the highest rise of water in each splitted sample, and the compressive strength characteristic was also obtained with the aid of compressive strength testing machine showing the maximum stress the samples can withstand before failure.

A total of 144 cube samples were used in this experimental campaign for both the permeability and compressive strength characteristics investigations. Impermeability performance of 12 different mixes was investigated for both 28 and 7 days, 3 cube samples were tested for each mix at each age. Similarly, 72 cube samples were tested under compressive strength and 3 samples were also tested for each mix at each age. Two different w/c ratio values were employed in the manufacture of mixes providing the targeted slump test.

a). 0.5% w/c ratio was used for all mixes that contains plasticizer

b). 0.65% w/c ratio was used for other mixtures without plasticizer

Table 4.1: Permeability and compressive strength test results obtained from different concrete mixes for 7 and 28 days

Cement type	Test type	Without superplasticizer		With only superplasticizer		With only CWA		With superplasticizer and CWA	
		7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
CEM I	Permeability (cm)	11.5	6.5	1.73	1.10	5.00	2.30	4.8	1.00
	Compressive strength test (MPa)	24.90	35.40	32.50	38.80	23.30	29.00	28.70	41.40
CEMII	Permeability (cm)	4.40	2.20	1.53	0.90	2.87	1.80	1.80	1.30
	Compressive strength test (MPa)	27.20	29.20	34.20	42.50	24.00	32.20	33.20	40.10
CEMIII	Permeability(cm)	4.90	0.6	1.4	1.00	8.6	0.70	1.9	1.00
	Compressive strength test (MPa)	21.40	37.22	28.20	39.10	20.98	35.7	45.40	60.00

4.1 PERMEABILITY CHARACTERISTIC OF THE CONCRETE MIXES

It can be clearly observed from the results obtained that level of permeability is less than the value obtained in 7 days irrespective of the type of mixture. This shows that the age of hydration generally affects the level of permeability in all the concrete mixes. In this experimental procedure, water reducing plasticiser, "levelcon DX50" was used as the plasticiser which reduces water requirement by certain percentage (10% -15%) and gives the concrete mix high strength and good workability at low w/c ratio. Davco K11 CWA, a crystallization based powder system that protects and water proofs concrete structures by crystallization. Graphs of permeability characteristics of the concrete mixes are provided below. The plotted points in the graph are the average values obtained for 3 samples of the same batch tested at same age, where the error bars explain that; the value less than one standard deviation away from the mean accounts for 68.27% of the set, while two and three standard deviation away from the mean account for 95.45% and 99.73% respectively.

Table 4.2: Permeability results of CEM I mix for 7 and 28 days showing the mean and standard deviation

Table 4.2: Permeability results of CEM I mix for 7 and 28 days showing the mean and standard deviation

CEM I	7 Days mean	StandardDeviation	28 Daysmean (cm)	Standard Deviation
No Admixture	11.5	1.3	6.5	1.3
Plasticizer	1.73	0.4	1.1	0.2
CWA	5	0.1	2.3	0.1
Plasticizer& CWA	4.8	1.1	1	0.1

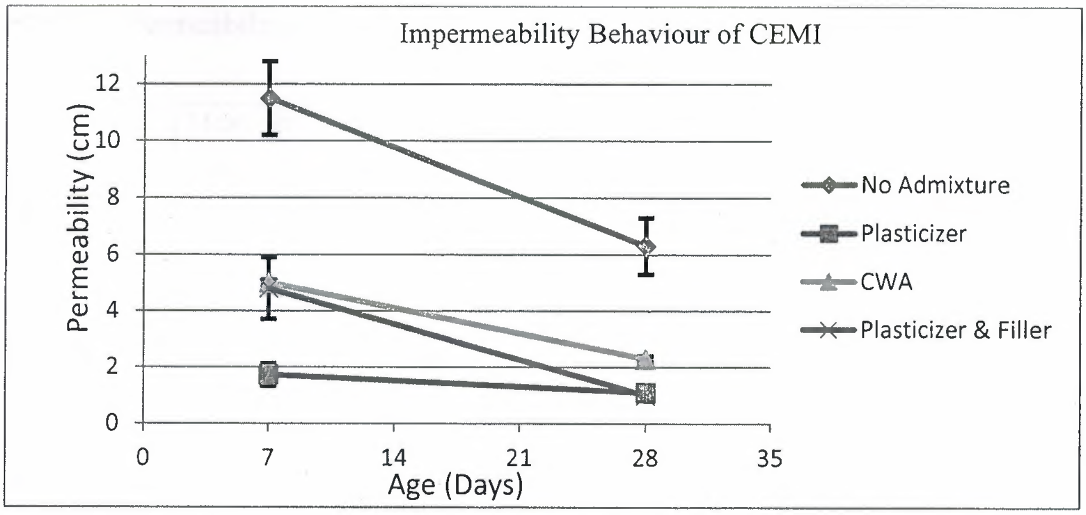

Figure 4.1: Permeability behaviour of CEMI mixes

The permeability characteristic of concrete mixtures with CEMI is given in the figure 4.1 above, where the level of permeability against ages is represented. It can be observed that all the mixes decrease in permeability level as the age increases. This tendency is expected to occur due to ongoing hydration and microstructure being developed with the increasing hydration products within the samples, causing denser and more impermeable concrete. Mixture with no admixture is observed to have the highest level of water permeability, followed by the mixture with only crystalline water proofing admixture while mixture with only super plasticiser has the least permeability. This sequence of permeability is almost the same for both 28 and 7 days, however at 28th day mixtures with only plasticiser and with both plasticizer and crystalline water proofing admixture are observed to have almost the same permeability value. This shows that reduced w/c ratio being compensated with the addition of plasticizer, has the most significant effect on improving the impermeability of CEMI both in early and late ages. On the other hand, the use of crystalline water proofing admixture is observed to have much lesser effect on the concrete impermeability since the combination of both superplasticizer and crystalline water proofing admixture shows almost the same performance compared to the concrete mix with only plasticizer. The mixture with only CWA and with both admixture seem to exhibit the same performance in the 7days age, however later on, mixture with the both admixture shows an increase in impermeability performance, which is one of the highest impermeability performances exhibited together with mixture with only plasticizer.

Table 4.3: Permeability results of CEM II mix for 7 and 28 days showing the mean and standard deviation

CEM II	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
No Admixture	4.4	1.7	2.2	0.7
Plasticizer	1.5	0.5	0.9	0.5
CWA	2.9	0.6	1.8	0.2
Plasticizer & CWA	1.8	0.4	1.3	0.3

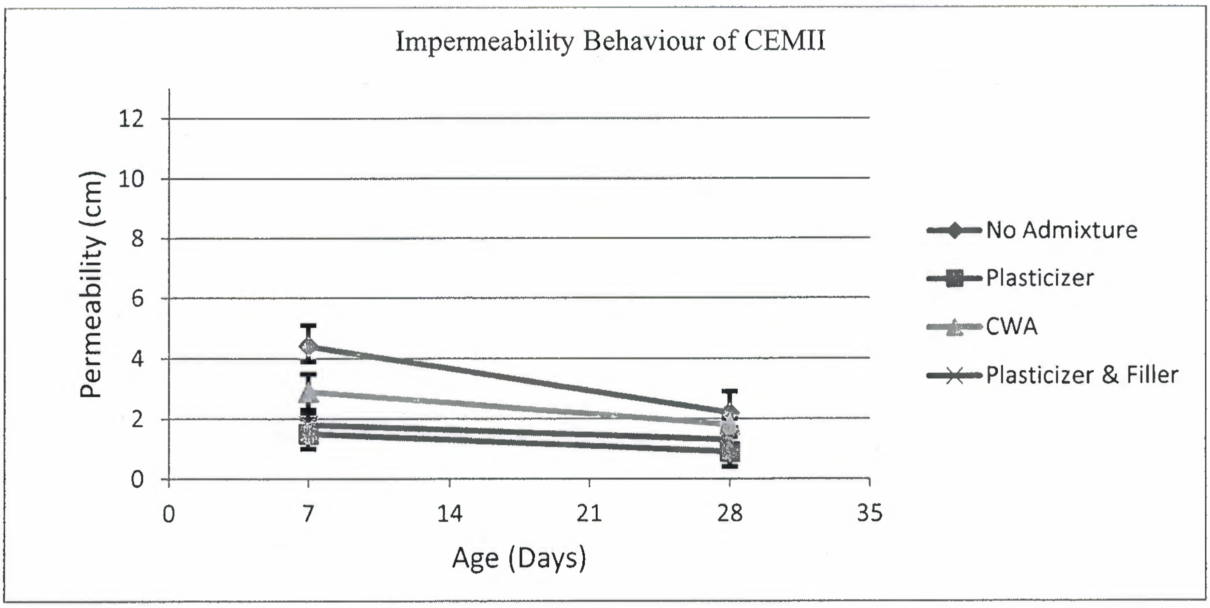

Figure 4.2: Permeability behaviour of CEM II mixes

Figure 4.2 above shows the permeability characteristics of CEMII against ages. In this graph, the level of permeability is observed to also decrease with ages; with progressing hydration process. The sequence of the level of permeability is same as in CEMI. However, there is clear distinction in the levels of permeability of each type of mix compared with CEMI. In addition to this, unlike in CEMI where mixture with only plasticizer and with both superplasticizer and crystalline water proofing admixture were observed to have same level of permeability, in CEMII the permeability level is different as the mixture with only plasticizer having the lowest value of permeability.

Table4.4: Permeability results of CEMIII mix for 7 and 28 days showing the mean and standard deviation

CEM III	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
No Admixture	4.9	1.9	0.6	0.2
Plasticizer	1.4	0.1	1	0.4
CWA	8.6	1	0.7	0.2
Plasticizer & CWA	1.9	0.3	1	0.2

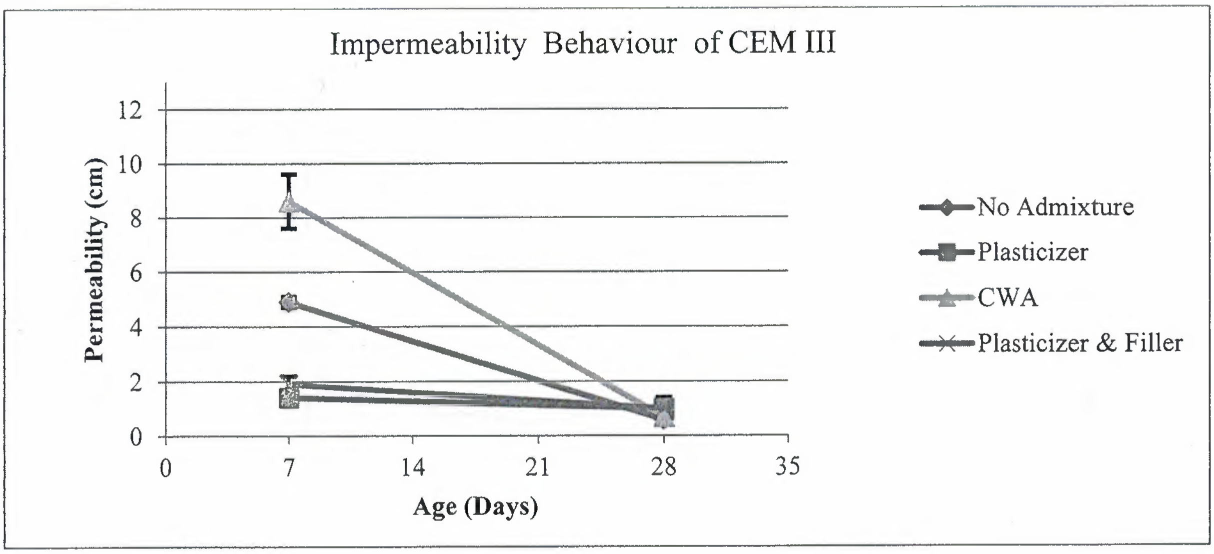

Figure 4.3: Permeability behaviour of CEMIII mixes

In figure 4.3 given above, the permeability characteristics of CEM III against ages are observed to be similar to the characteristics exhibited by CEM I and CEM II, the level of permeability decreases with increase in time. However, the sequence in 7 days permeability level is different; in CEM III mixture with only CWA has the highest permeability level with a wide range from the second most permeable mixture which is with no admixture and the mixture with only plasticizer still maintains the least permeability. Another different feature observed is that at the age 28days, CEM III shows the least permeability in all same mix types compared with CEMI and CEM II. Also, there is a great permeability difference for all CEMIII mixes, between the ages of 7 and 28 days. However the permeability difference is not significant in all the mixes in 28 days. Therefore, for economical reasons, if CEMIII is to be used for water resisting structures, no need to use any admixture provided that its compressive strength is satisfied. This shows that increased slag cement (CEM III) yields a highly water resisting concrete independent of added plasticizer or CWA. The same finding is also reported in many references (Al- Amoudi et al, 2011), (Tamilarasan et al, 2012)

Table 4.5: Permeability results of the three cement mixes without admixture for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	11.5	1.3	6.5	1.3
CEM II	4.4	1.7	2.2	0.7
CEM III	4.9	1.9	0.6	0.2

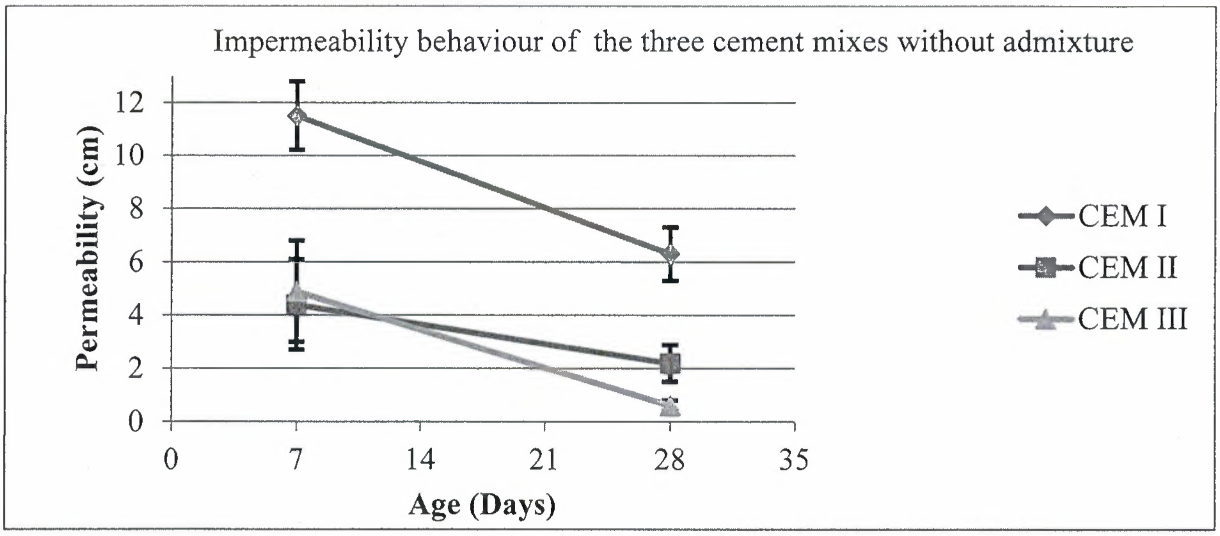

Figure 4.4: Permeability behaviour of the three cement mixes without admixture

It is observed in graph 4.4 describing the graph of permeability of the three cement mixes without any admixture that the permeability decreases with ages and CEM III has the least permeability while CEMI has the highest permeability in both early and late ages. This behaviour clearly shows the positive effect of slag content on the impermeability characteristics of the samples. The high permeability level of CEMIII at early age is due to slow hydrating characteristic of slag cement.

Table 4.6: Permeability results of the three cement mixes with only superplasticizer for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	1.73	0.4	1.1	0.2
CEM II	1.5	0.5	0.9	0.5
CEM III	1.4	0.1	1	0.4

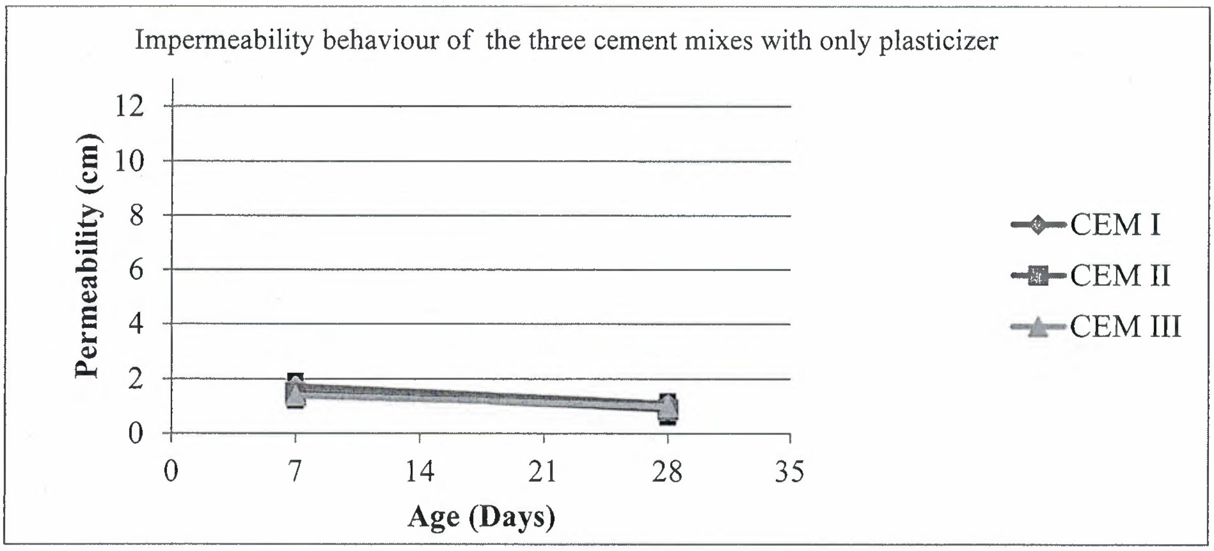

Figure 4.5: Permeability behaviour of the three cement mixes with only superplasticizer

Figure 4.5 is the graph for permeability of the three cement mixes with only plasticizer for both 28 and 7 days. It is observed that the permeability reduces with ages with significantly low permeability in both ages and the concrete mixes show very little differences from themselves in both 28 and 7 days. Compared to figure 4.4,it can be observed that addition of only plasticizer yields similar impermeability performance of concrete mix, even though cements with varying slag contents were used. This implies that if plasticizer is decided to be used in concrete manufacture where impermeability is an issue, any of the three types of cements will yield similar impermeability behaviour. This explains that the w/c ratio is an important factor in controlling water permeability in concrete structures.

Table 4.7: Permeability results of the three cement mixes with only CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	5	0.1	2.3	0.1
CEM II	2.9	0.6	1.8	0.2
CEM III	8.6	1.3	0.7	0.2

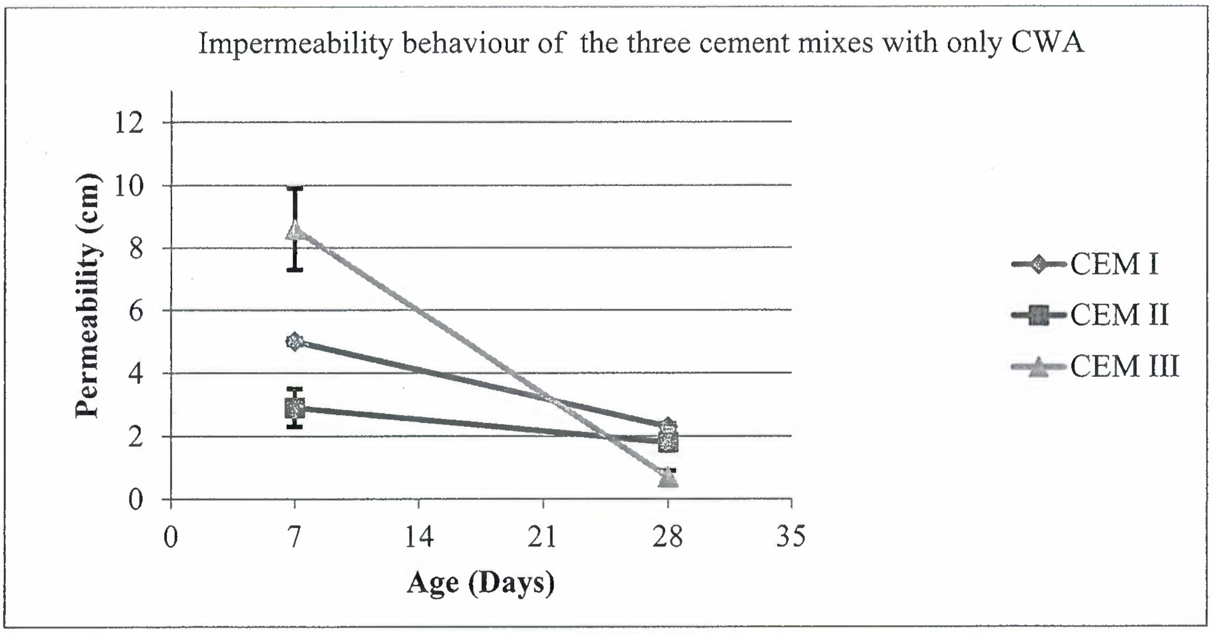

Figure 4.6: Permeability behaviour of the three cement mixes with only CWA

The graph of permeability of the three cements mixes with only CWA for 28 and 7 days is described in figure 4.6. CEM III is observed to have the highest permeability level at early age, but lowest permeability at the late age. This can be due to the slow hydration characteristic of CEM III which is also inhibited with the addition of the CWA. Another observation made in figure 4.6when compared with figure 4.4 is that; CEMIII without admixture and CEMIII with only CWA have very close impermeability values. This finding implies that with the availability of increased slag content, CWA remains redundant. However, when behaviour of CEMI without any admixture and with only CWA is compared in figure 4.6 and figure 4.4, effect of CWA on improving impermeability becomes more significant. It is also observed that CEMII and CEMI have very similar impermeability behaviour at 28days, even though their early age (i.e7days) was distinct.

Table 4.8: Permeability results of the three cement mixes with superplasticizer and CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (cm)	Standard Deviation	Mean for 28 Days (cm)	Standard Deviation
CEM I	4.8	1.1	1	0.1
CEM II	1.8	0.4	1.3	0.3
CEM III	1.9	0.3	1	0.2

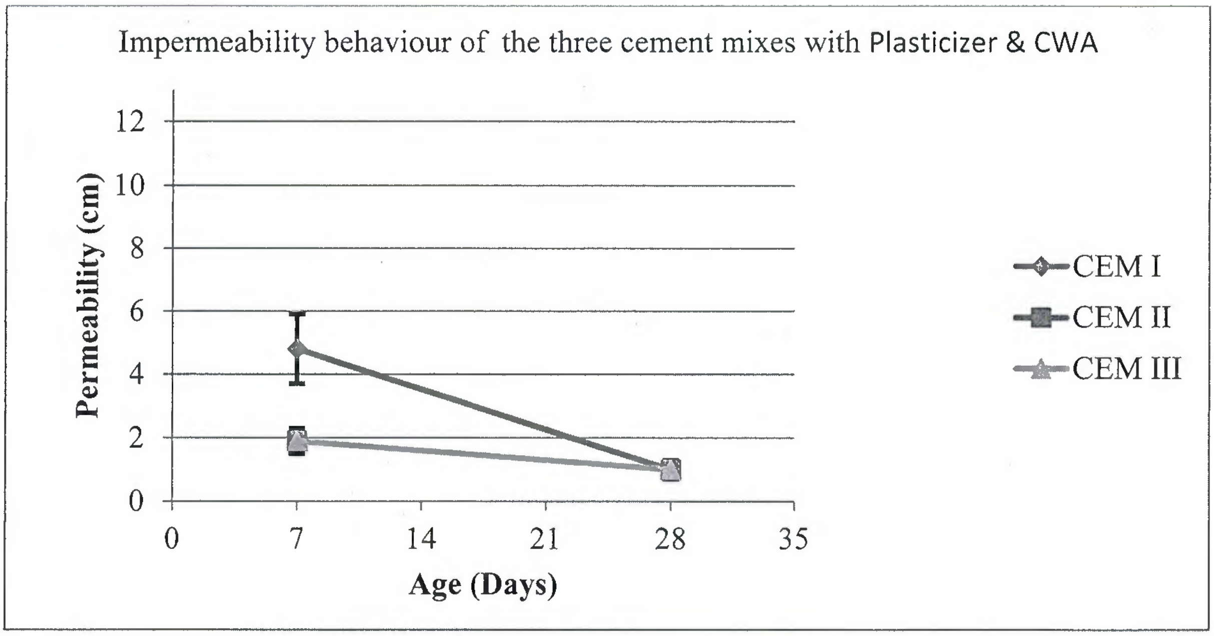

Figure 4.7: Permeability behaviour of the three cement mixes with both superplasticizer and crystalline water proofing admixture

Figure 4.7 also describes the graph of permeability of the three cements mixes with both admixtures for 28 and 7days. CEMI has the highest permeability at early age but there is no significant difference in the mixes at 28 days. CEMI and CEMIII exhibit similar permeability characteristics in both early and late ages. However, in the late age all the mixes have almost the same values of permeability, which is lower for CEMI and CEMII but not lower for CEMIII mixtures prepared with only plasticizer shown in figure 4.5.

Generally it is observed that w/c ratio has the most significant impact on permeability of concrete and the permeability generally decreases with ages.

4.2 COMPRESSIVE STRENGTH TEST

The compressive strength test was carried out on the same sample types as mentioned earlier to check and verify the effect of progressing hydration of cement and development of microstructure formation. The compressive strength results obtained from this experiment for both 7 and 28 days is given in table 4.1 above. The result shows that compressive strength in concrete is greatly affected by different factors such as w/c ratio, admixtures, and cement types. Same as in permeability test, the plotted points in the graph are the average values obtained for 3 samples of the same batch tested at same age, where the error bars explain that; the value less than one standard deviation away from the mean accounts for 68.27% of the set, while two and three standard deviation away from the mean account for 95.45% and 99.73% respectively.

Table 4.9: Compressive strength results of CEM 1 mix for 7 and 28 days showing the mean and standard deviation

CEM I	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
No Admixture	24.9	2.2	35.4	0.9
Plasticizer	32.5	2.5	38.8	2.2
CWA	23.3	1.5	28.9	0.5
Plasticizer & CWA	38.7	1.6	45.4	0.3

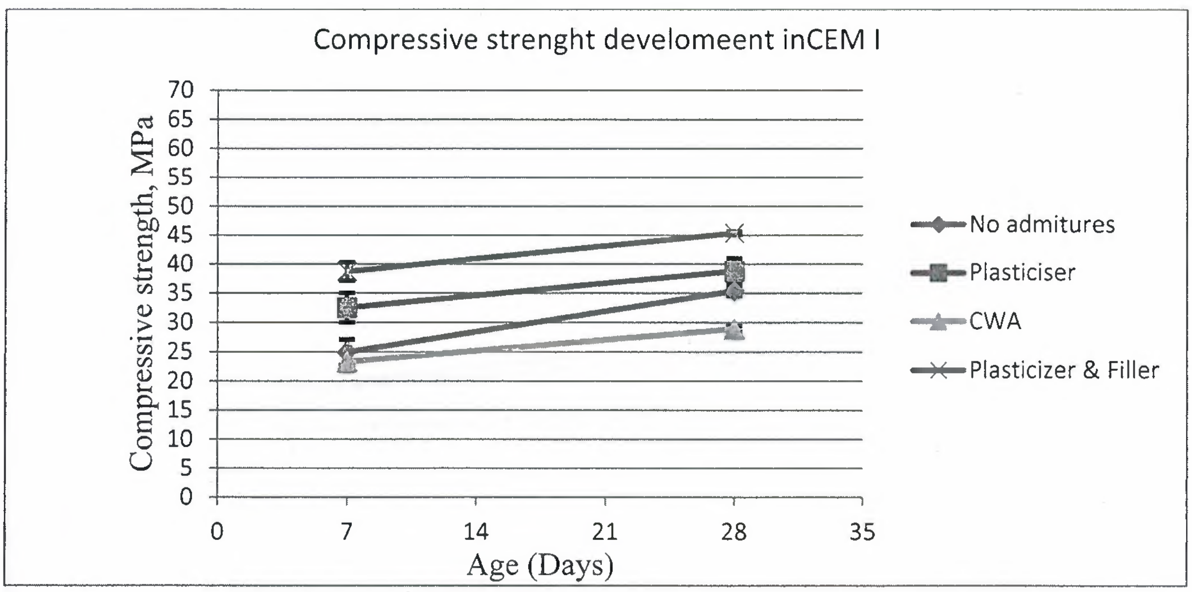

Figure 4.8: The compressive strength development of CEMI mixes

Figure 4.8 shows the compressive strength of CEM I with and without admixture at 7 days and 28 days. Similarly to what is observed in permeability behaviour, this finding also implies the effects of ongoing hydration and developing microstructures, in this case yielding an increased compressive strength. It can be observed that the strength generally increases as the age increases. The samples with both admixtures is observed to have the highest compressive strength value in 28 days, followed by the sample with only plasticizer and lastly sample with CWA having the least value. This can be explained that, the reduced w/c ratio has significant effects on the compressive strength and the plasticizer used as a reagent, compensate for the reduced w/c ratio in other for the sample to fulfil the designed workability standard. Whereas the CWA absorbs the water from the concrete mix without any compensation for w/c ratio required. However, it helps in the densification of the particle structures of the concrete. But in the sample with both admixtures, microstructure development and w/c ratio of the sample are justified giving the concrete higher strength.

Table 4.10: Compressive strength results of CEMII mix for 7 and 28 days showing the mean and standard deviation

CEM II	Mean for 7days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
No Admixture	27.5	0.2	29.2	0.6
Plasticizer	34.2	1.5	42.5	2
CWA	24	3.1	32.2	0.9
Plasticizer and CWA	33.2	1	40.1	1.9

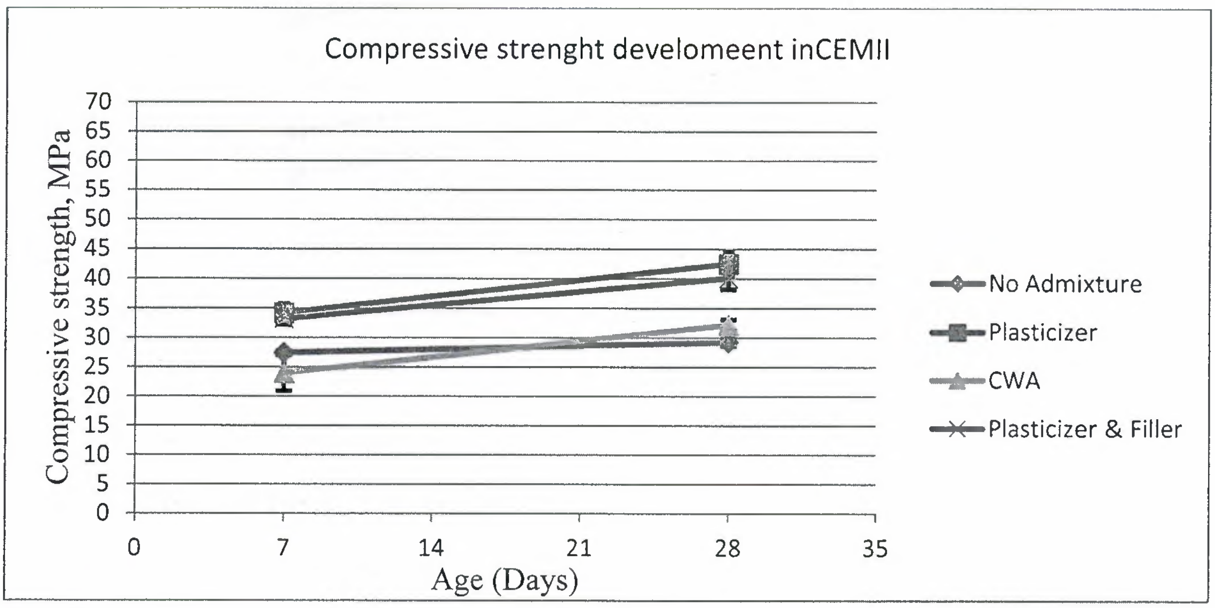

Figure 4.9: The compressive strength development of CEMII mixes

Figure 4.9 shows the compressive strength of CEMII of different mixes for both 7 and 28 days. The compressive strength is observed to increase as the age increases, with sample with both admixtures having the highest value of compressive strength at 28 days, followed by the sample with only plasticizer having same trend as in CEMI. But in CEMII, sample with only

CWA has higher compressive strength value than sample without admixtures. This can be due to the replacement of cement with slag which is less dense than cement (given in appendix)

Table 4.11: Compressive strength results of CEMIII mix for 7 and 28 days showing the mean and standard deviation

CEM III	Mean for 7 days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
No Admixture	21.4	1.8	37.2	0.6
Plasticizer	28.2	1	39.1	0.2
CWA	21	1.4	35.7	1.4
Plasticizer and CWA	45.4	0.6	60	7.1

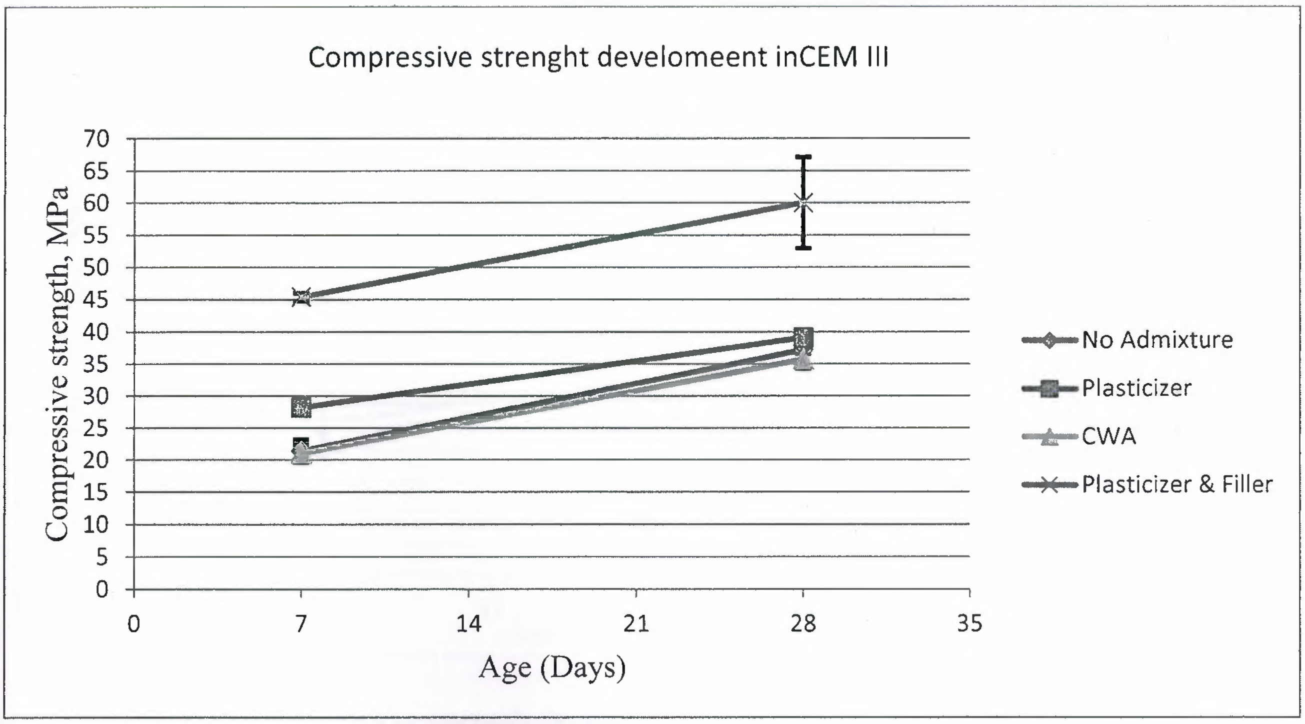

Figure 4.10: The compressive strength development of CEMIII mixes

In figure 4.10 above is the compressive strength of CEMIII with different mixes as in other samples for both 7 and 28 days. The compressive strength is also observed to increase with age but with wider variation between the ages compared with CEMI and CEMII. This can be due to the fact that CEMIII undergoes much slower hydration at early age. The sequence of the compressive strength hierarchy with CEM II but with much higher values in CEMIII when both admixtures were used, and also shows the highest compressive strength value of all the mixes.

These findings indicate that only CWA or only plasticizer addition to CEMIII does not yield a significant effect on compressive strength performance. However, addition of both admixtures is observed to have a significant effect.

Table 4.12: Compressive strength results of the three cement mixes without admixtures for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
CEM I	24.9	2.2	35.4	0.9
CEM II	27.5	0.2	29.2	0.6
CEM III	21.4	1.8	37.2	0.6

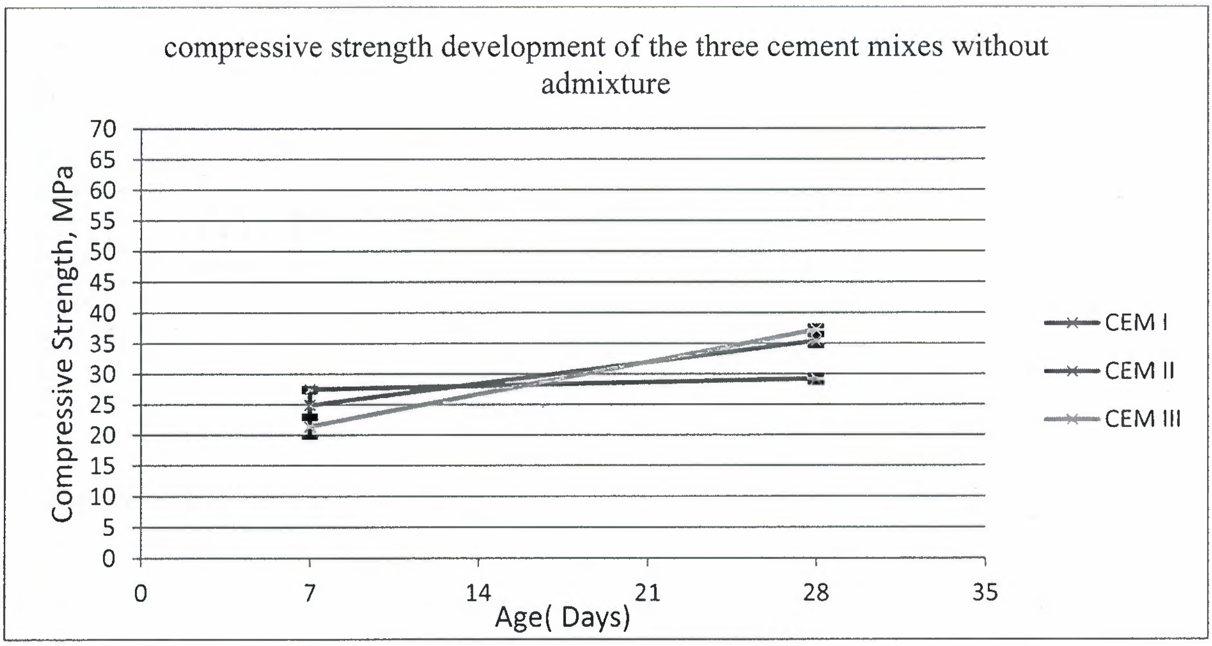

Figure 4.11: Compressive strength development of the three cement mixes without admixture

Figure 4.11 is the graph of compressive strength test of the three cements mixes without admixtures for both 28 and 7 days. It can be observed that the compressive strength increases as the age increases in all the mixes with CEM III having both the lowest and the highest strength value in both 7 and 28 days respectively. This is due to its low hydrating characteristics of slag cement, especially at early age. However, partial replacement of Portland cement (PC) with slag is observed to yield relatively lower value. This is similar to the study carried out by Tamilarasan et al, 2012, where replacement of Portland cement with

Table 4.14: Compressive strength results of the three cement mixes with only CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
CEM I	23.3	1.5	28.9	0.5
CEM II	24	3.1	32.2	0.9
CEM III	21	1.4	35.7	1.4

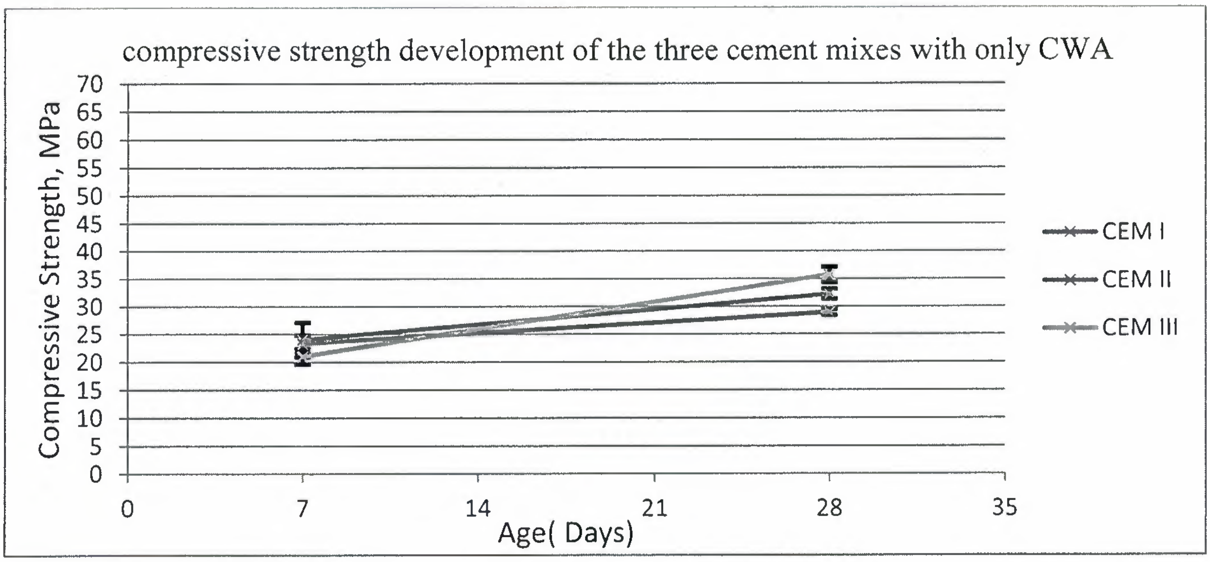

Figure 4.13: Compressive strength development of the three cement mixes with only CWA

Described in figure 4.13 is the graph of compressive strength development of the three cement mixes with only CWA for 28 and 7 days. It is observed that the cement mixes have low strength at early age and at the late age compared with other mixing parameters. This can be due to the low rate of hydration hindered by the CWA as it absorbs the water content in the concrete mix. CEMIII gives the lowest and the highest strength development at both early and late ages respectively. This supports the findings observed in figure 4.6; where CEMIII had the highest and lowest permeability values of 7 and 28 days respectively.

Table 4.15: Compressive strength results of the three cement mixes with superplasticizer and CWA for 7 and 28 days showing the mean and standard deviation

Cement Type	Mean for 7 Days (MPa)	Standard Deviation	Mean for 28 Days (MPa)	Standard Deviation
CEM I	38.7	1.6	45.4	0.3
CEM II	33.2	1	40.1	1.9
CEM III	45.4	0.6	60	7.1

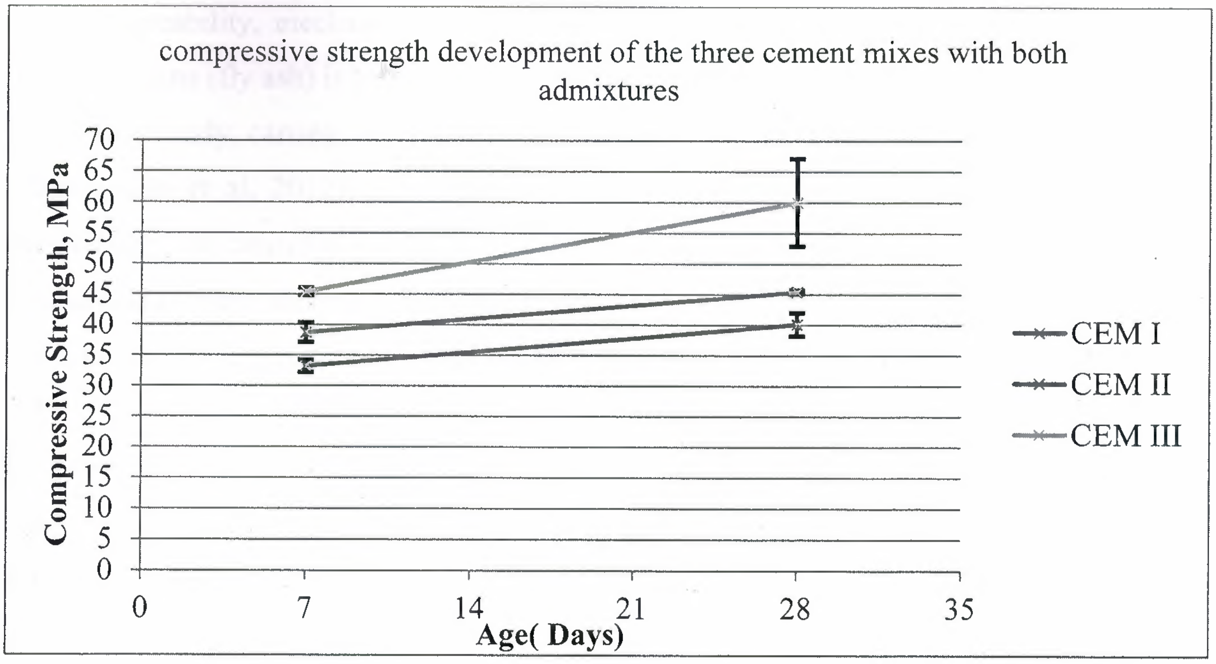

Figure 4.14: Graph of compressive strength development of the three cement mixes with both Plasticizer and CWA

It is observed in figure 4.14 representing the graph of compressive strength development of the three cement mixes with both Plasticizer and CWA for 28 and 7 days that the compressive strength increases with ages. All the mixes have high compressive strength at both early and late age. CEMIII shows the highest compressive strength value in both early and late ages. And its 28th day compressive value is observed to be the highest value of all the mixes tested for compressive strength in this thesis study.

Generally, it can be observed that the compressive strength increases with age and also slag cement has lower hydration characteristic in early age but with higher compressive strength at 28 days. Combination of both admixtures shows the highest compressive strength in 28 days for all mixes with CEM III having the highest compressive strength values. Similarly, in CEMI and CEMII, their highest compressive strength development is observed in their mixes using both admixtures with slight difference from their mixes with only plasticizer at 28th day test. However, the compressive strength test development in both CEMI and CEMII mixes with only plasticizer in the early age is higher than their mixes with both admixtures.

Comparing the results obtained from this experimental study with the previous work studies as discussed in the literature review, explained in an experiment carried out in King Fahd University of Petroleum and Minerals (Al-Amoudi et al, 2011), both experiments prove that the impermeability, mechanical properties and durability characteristic of cement replaced with pozzolana (fly ash) is better compared to ordinary Portland cement.

In another study carried out on the partial replacement of cement by GGBS till 60% (Tamilarasan et al, 2012), the results agrees with the outcome of this experiment as the permeability of concrete was decreased, resistance to chemical was increased and the mechanical property (strength) was also increased.

Also, in another experiment in which the cement was replaced with silica fume (Bagheri et al, 2008), the result shows the significance effect of replacement of silica fume in reducing the permeability correlating with the permeability reducing characteristic GGBS used in this study.

Figure 4.15 below gives the percentage increment of CEMI in both the compressive strength developments and the impermeability behaviour for 28days. It is observed that mixture with plasticizer has low increment in both tests. This explains that the rate of hydration is speed up when plasticizer was added to the mix

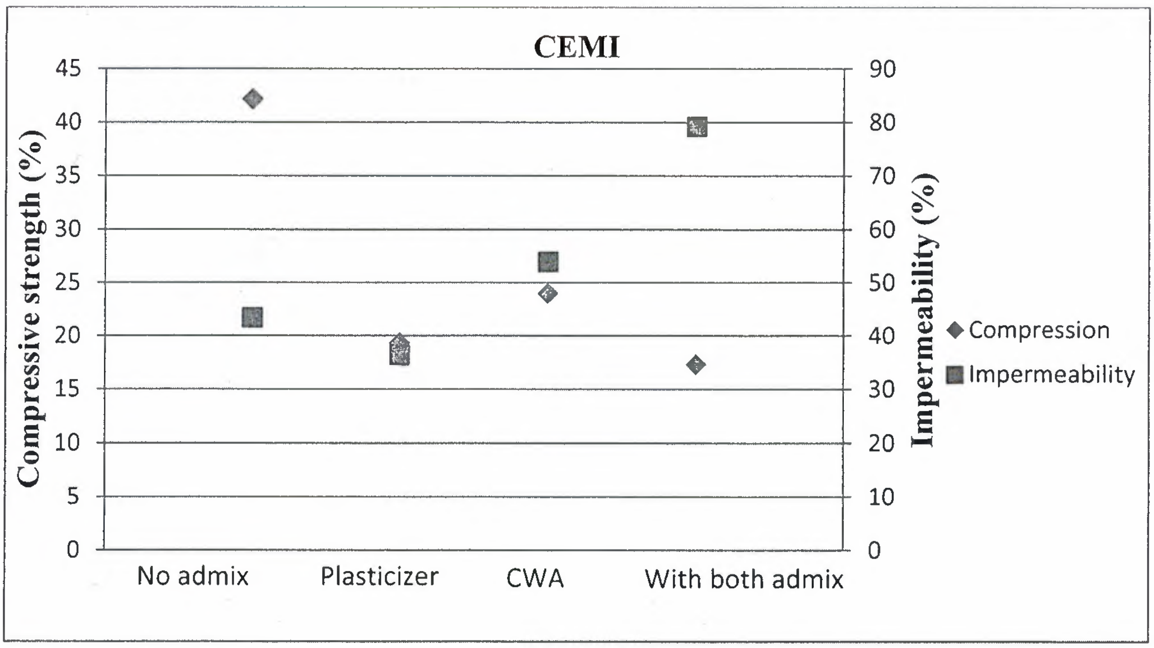

Figure 4.15: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for CEMI

Figure 4.16 below gives the percentage increment of CEMII in both the compressive strength developments and the impermeability behaviour for 28days. The compressive strength is observed to give little variation but with high percentage of impermeability in mix with no admixture.

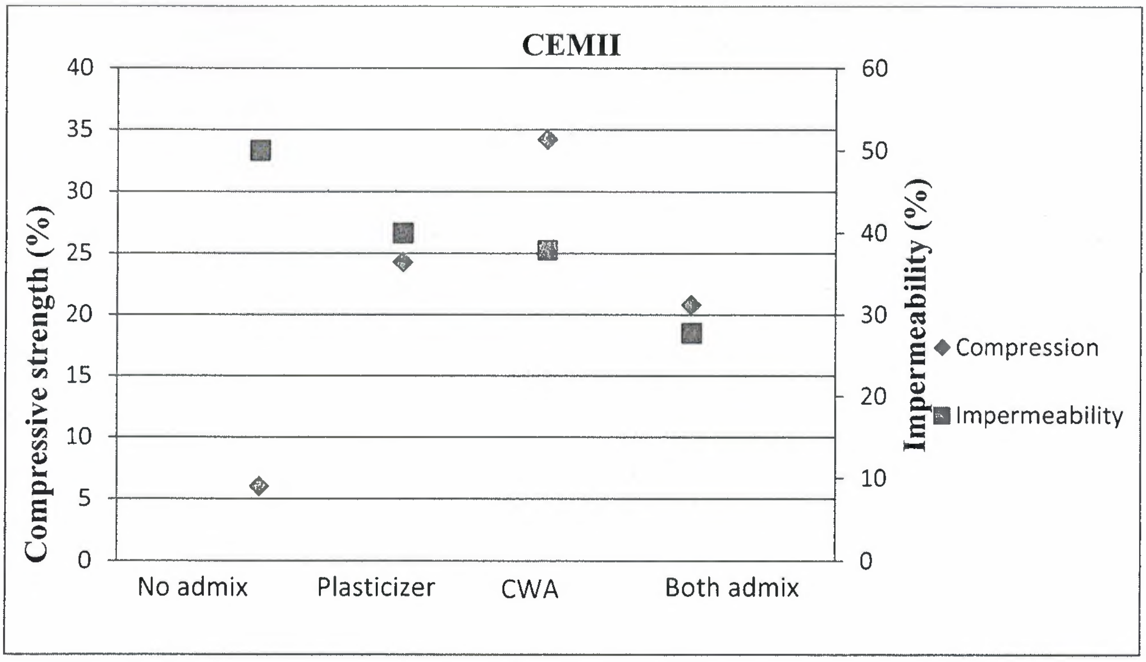

Figure 4.16: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for CEMII

It is observed in figure 4.17 below that the rate of hydration in CEMIII is slow which explains the high variations in mixes without superplaticizer.

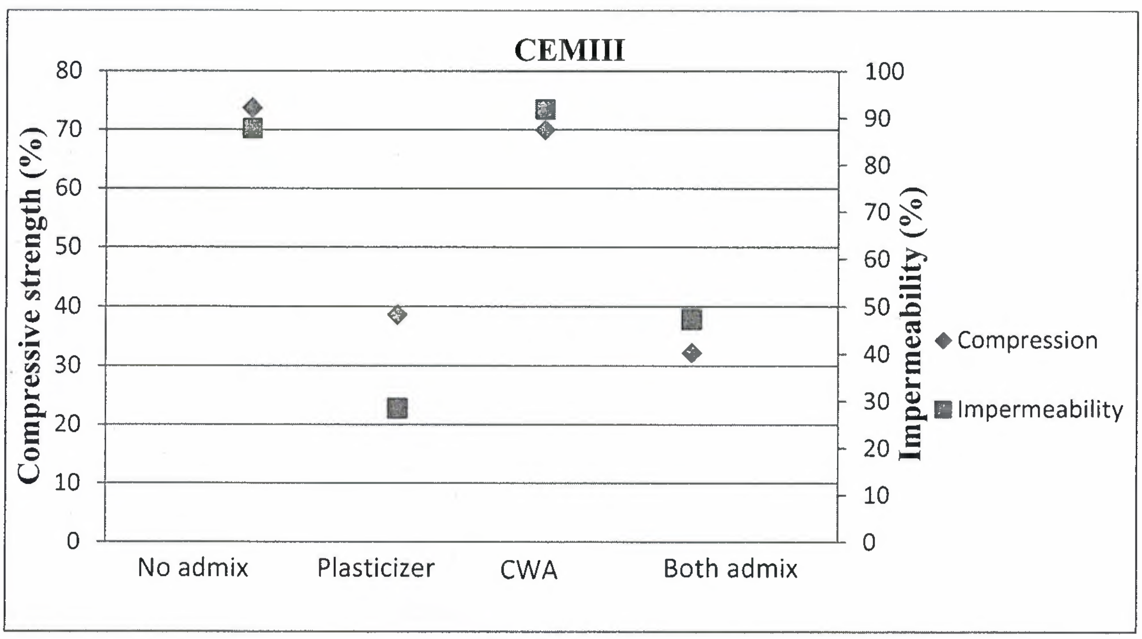

Figure 4.17: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for CEMIII

Comparing the three cements without admixture, it is observed that CEMIII has the slowest rate of hydration in both tests. This is due to the slow hydrating process of the increased slag content

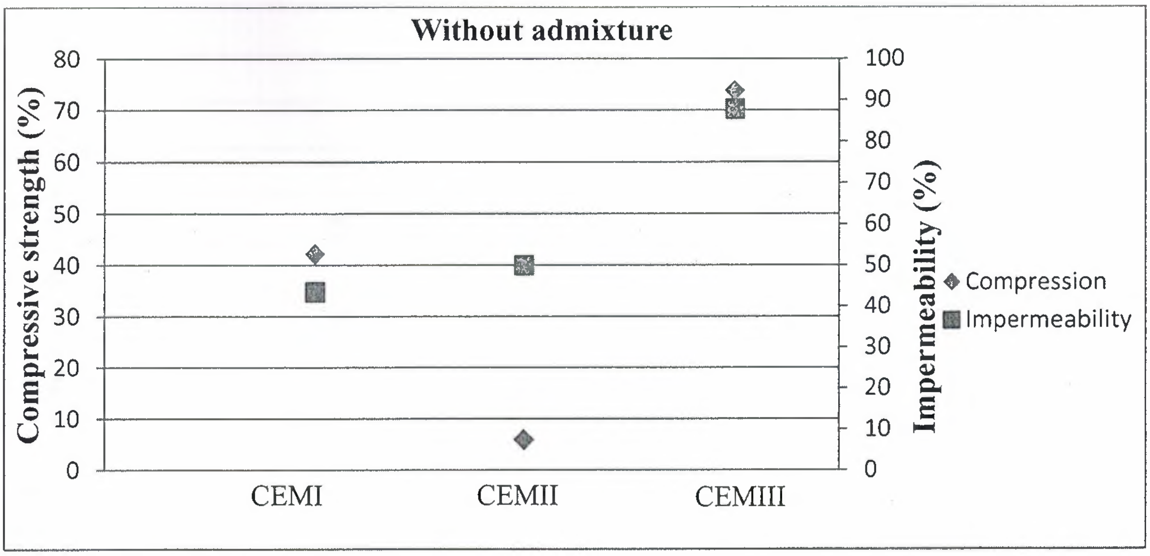

Figure 4.18: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for the three cement mixes without admixture

When the three cements are compared with only plasticizer, it is observed that the percentage increment of the compressive strength increases as the slag increases. This also explains the effect of slow hydrating slag content.

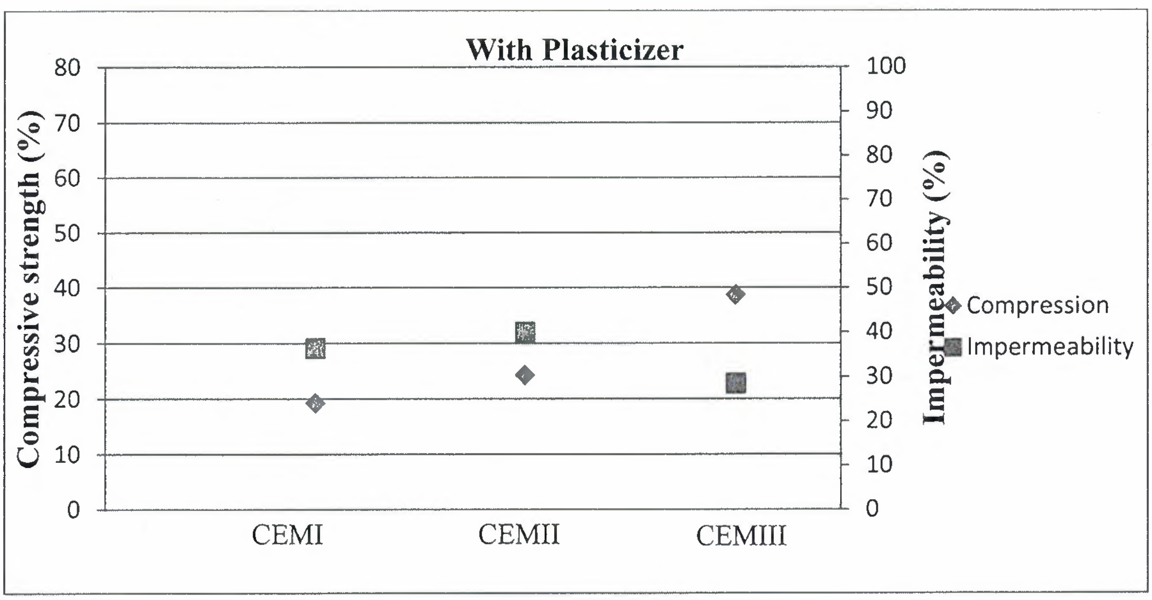

Figure4.19: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for three cements without only Plasticizer

The percentage increment in both tests is observed to be highest in CEMIII in the mixes with only CWA. This can be explained that the microstructure formation and rate of hydration is hindered by the addition of CWA which absorbs water from the mix.

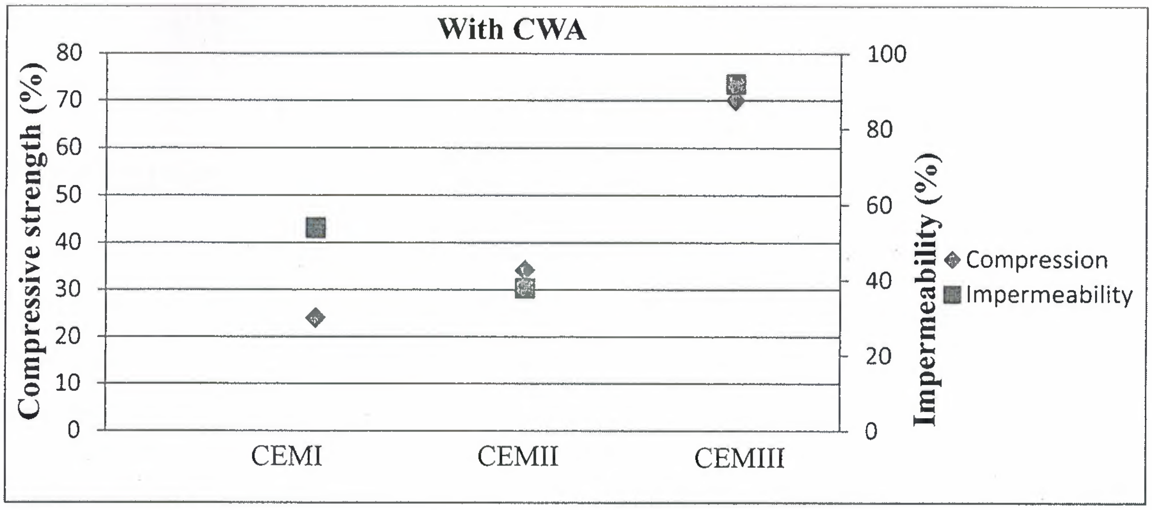

Figure 4.20: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for three cements without only CWA

Figure 4.16 shows the percentage increment of the three cements in both the compressive strength developments and impermeability behaviour. It is observed that compressive strength development increases as the slag content increases. However, CEMI shows the highest percentage for impermeability which explains its high porosity at the early age.

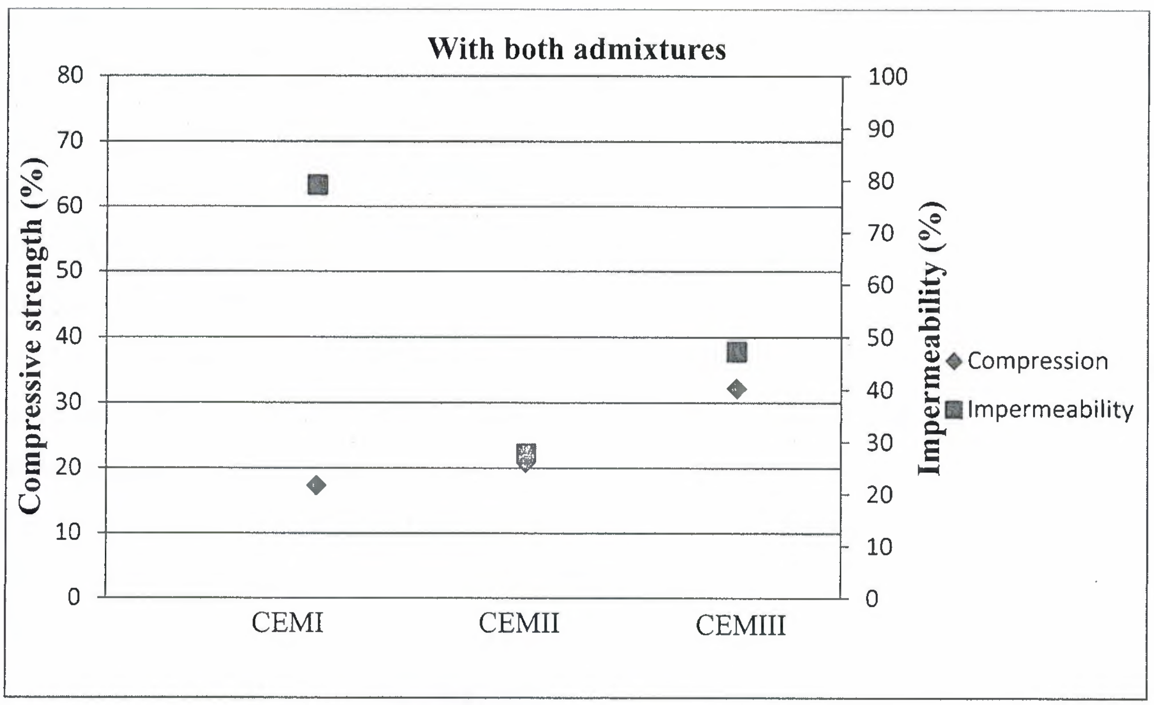

Figure 4.21: Percentage increase in both compressive strength development and impermeability behaviour from 7 to 28 days for three cements with both admixtures

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this study, a detailed experimental investigation on mainly the permeability characteristics of self compacting concretes made with varying components; such as slag, superplasticizer, CWA was carried out. The compressive strength performance of the concretes was also evaluated.

Water permeability in concrete is a critical problem in North Cyprus, and researches showed that there is no existing statistical data that shows the permeability characteristics of concretes produce in the island. This study provides insight on the permeability characteristics of concrete produce in North Cyprus showing the statistical data of both the level of permeability and compressive strength of the mixes. Some of ythe conclusions from this study are given below.

I. The use of CWA was observed to have less effect on the permeability characteristic of CEMI. It is suggested to use only superplasticizer as it is observed in the permeability results that both mixtures (with only superplasticizer and with both admixtures) give the least permeability result with almost same value. More also, mixture with only superplasticizer gives the least permeability result in early age as well

II. Similar to the findings in CEMI, comparing the parameters used in CEMII, it will be suggested use only superplasticizer as water reducing admixture in concrete made with CEMII to minimise its water permeation. This is because mixture with only superplasticizer gives the highest impermeability characteristics in both early and late ages compared with other parameters.

III. In a situation where CEMIII is to be used for water resisting structure, addition of any admixture will not be essential because the permeability value at 28th day is at the least in the mixture without any admixture, increased slag content governs the impermeability performance without reading any effect on admixtures. However, in a case where impermeability is necessary at early age, CEMIII with only superplasticizer may the best alternative because of its high impermeability behaviour at early age as shown in the results.

IV. The permeability characteristic of the three cement types was also compared without any admixture; CEMIII gives the least permeability value in 28 days test. But due to its slow hydration process, it has higher permeability value at early age compared with CEMII

V. Water /cement ratio is observed to be a very significant factor that affects the permeability behaviour of the concretes for the three cement types. When only superplasticizer was used in the concrete mixes, their permeability values are at close range and significantly low with CEMIII having the least value at both early and late ages.

VI. Comparing the addition of only CWA to the three cement types, permeability values are relatively higher compared to addition of only superplasticizer especially at the early age. CEMIII is also observed to have the least permeability at the late age.

VII. Addition of both superplasticizer and CWA to the concrete mixes gives low permeability values of almost same range at late age. CEMIII is observed to have the least permeability value at late age.

VIII. In concrete mixes with CEMI, addition of both superplasticizer and CWA gives the highest compressive strength test value. This can be justified by the crystallization of the sample with addition of CWA and reducing its w/c ratio with addition of superplasticizer. CEMI with both admixtures is also observed to have high impermeability characteristic.

IX. Observing the compressive strength development in CEMII, CEMII with only superplasticizer gives the highest value. It gives both the highest impermeability characteristics and compressive strength development compared with other parameters or conditions used in CEMII concrete mix. Observing these characteristics in CEMII, addition of CWA will be redundant as it shows now significant advantage over the mix with only superplasticizer in both tests carried out.

X. From the whole set of results obtained from the compressive strength test carried out in this study, CEMIII with both superplasticizer and CWA gives the highest compressive strength value in both early and late ages. However, CEMIII without any admixture shows higher impermeability characteristic compares with CEMIII mix with both superplasticizer and CWA. In a situation where highly impermeable concrete is necessary, CEMIII without any admixture may be suggested as the most efficient choice for economical reason, provided its compressive strength is satisfied.

XI. Comparing the compressive strength development of concretes made from the three cement types without any admixture, CEMIII gives the lowest and highest value at early and late age respectively. The low strength at the early age is due to the slow hydration characteristics of slag cement. Also, comparing the permeability behaviour of the mixes, CEMIII is again observed to be highly resistant to water permeability.

XII. Also, comparing the concrete mixes with addition of only superplasticizer, CEMII gives the highest compressive strength value and the lowest permeability value in both early and late ages.

XIII. When the effect of only CWA was tested on the compressive strength development of the concrete types, the compressive strength value of CEMIII is observed to be lowest at early age and higher at late age. The early age low compressive strength is due to the slow hydration process in slag cement which is more hindered with the addition of CWA.

XIV. In the compressive test where plasticizer and CWA were added to the mixes, CEMIII shows the highest compressive strength value in both early and late ages. Its compressive strength value at 28th day is observed to have the highest value of all the concrete mixes tested for strength in this study.

XV. The effects of plasticiser is more effective than the CWA in both the permeability and compressive strength test but the combination of the admixtures gives the best result for strength

XVI. The permeability of concrete decreases with age and with reduction in w/c ratio

XVII. The strength of concrete increases with age and also with reduction in w/c ratio

XVIII. Concretes with slag have higher resistance to water permeability than the ordinary Portland cement.

XIX. CEMIII shows the best results for both permeability and compressive strength. However the permeability difference in CEMIII is not apparent in mix with or without admixture, indicating that slag content governs the impermeability characteristics over other components added.

5.2 RECOMMENDATIONS

From the observations and conclusions made from this study, following recommendations are made on investigating the permeability characteristics of concrete for concrete durability.

5.2.1 RECOMMENDATIONS FOR MORE EFFICIENT CONCRETE MIX

I. If CEMI is to be used for water resisting structure, CEMI with only superplasticizer is recommended to be considered especially where early age impermeability is highly required.

II. In a case where CEMII is to be considered for water impermeable structure, CEMII with only superplasticizer may also be recommended as it gives the lowest permeability in both early and late ages with the highest compressive strength development values in both ages of the mix trials carried out with CEMII

III. CEMIII is generally recommended for providing the mixes with highest impermeability.

IV. Observations from this study showed that the particular CWA used in this experiment has little or no significant effect on the permeability behaviour of the tested specimens especially in CEMIII. However, varying its percentage in mixes is recommended to be considered, or observing its effects in other cement types or even considering other water proofing admixtures

V. In a case where only CWA or only superplasticizer exhibits same property with both admixtures, selecting the mix with either of the admixtures should be the best alternative for economical reasons.

5.2.2 RECOMMENDATIONS FOR FUTURE STUDIES

I. Further experimental study on the effects of CWA used in this study should be investigated by varying its percentage replacement in cement or using it with other types of cement.

II. Other categories of water proofing admixtures mentioned in chapter two of this study should be experimented to compare their effects with the CWA used in this study.

III. Further investigations on slag effect on water permeability should be carried out by varying its percentage replacement in cement.

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APPENDICES

APPENDIX 1

Classes of cement used and their density

CEMENT CI 42,5 R	3,13 g/cm3
CEMENT CII/B-S 42,5N	3,03 g/cm3
CEMENT C III /A 42,5 N	2,99 g/cm3

Properties of aggregates used (Tufekci group)

Aggregate	Percentage used	Density (g/cm^3)	Water absorption capacity %
(0 - 5)	54%	2.693	1.235
(5- 12)	19%	2.712	0.778
(12- 19)	27%	2.699	0.658

Los Angeles grading of test samples

Grain size class	Steel sphere number	Sieve size (mm) (square openings)	Weight of indicated sizes (g)		Total weight (g)
Passing		Retained on			
A	12	40	25	1250 Â± 25	5000 Â± 10
25	20		1250 Â± 25		
20	12.5		1250 Â± 10		
12.5	10		1250 Â± 10		
B	11	20	12.5	2500 Â± 10	5000 Â± 10
12.5	10		2500 Â± 10		
C	8	10	6.3	2500 Â± 10	5000 Â± 10
6.3	5		2500 Â± 10		
D	6	5	2.5	5000 Â± 10	5000 Â± 10

Chemical composition and fineness of blast- furnace slag

Chemical composition and fineness of blast-furnace slag.													
Series	Type	Fineness (	Ig-loss	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	TiO2	P2O5	MnO
I	BS4	4530	0.04	33.64	14.33	0.16	42.96	6.38	0.2	0.34	0.62	0.01	0.36
II	BS3	3340	0.05	33.72	14.41	0.26	42.47	6.66	0.19	0.29	0.66	0.01	0.31
BS4	4520	0.02	33.72	14.34	0.36	42.89	6.22	0.21	0.32	0.59	0.01	0.34	
BS6	6110	0.03	33.69	14.28	0.83	42.48	5.77	0.26	0.32	0.9	0.01	0.46	
BS8	8770	0.06	34.15	14.52	0.28	42.23	6.34	0.18	0.31	0.64	0.01	0.33	

Properties of admixtures used (Tufekci group)

Admixture	Density (g/cm^3)	Water absorption capacity %
Crystalline Water Admixture (CWA)	1.47%	2.745
Superplasticizer	1.2%	1.03

Mix proportion of compositions used for the experiment

S/N	TYPE OF MIXING	CEMENT kg/m3	35 dm^3	W/C	WATER kg/m3	35 dm^3	ADDMIXTURE kg/m3	35 dm^3	CWA kg/m3	35 dm^3	(0-5) kg/m3	35 dm^3	(5-12) kg/m3	35 dm^3	(12-19) kg/m3	35 dm^3
1	C I WITHOUT ADDMIXTURE	340	11900	0.65	221	7735	0	0	0	0	974	34090	345	12075	433.5	17097.5
2	C I WITH ADDMIXTURE	340	11900	0.5	170	5950	4.08	142.8	0	0	1044	36540	370	12950	523.44	18320.4
3	C I WITH FILLER	340	11900	0.65	221	7735	0	0	5	175	974	34090	345	12075	433.5	17097.5
4	C I WITH ADD AND WITH FILLER	340	11900	0.5	170	5950	4.08	142.8	5	175	1041.9	36466.5	369.1	12918.5	522.13	18274.55
5	C II WITHOUT ADDMIXTURE	340	11900	0.66	224.4	7854	0	0	0	0	954.8	33765	341.8	11963	433.5	16922.5
6	C II WITH ADDMIXTURE	340	11900	0.5	170	5950	4.05	142.8	0	0	1038.42	36344.7	357.9	12676.5	520.3	13210.5
7	C II WITH FILLER	340	11900	0.66	224	7840	0	0	5	175	962.7	33694.5	341.1	11938.5	432.46	16836.1
8	C II WITH ADD AND WITH FILLER	340	11900	0.5	170	5950	4.08	142.8	5	175	1035.5	36242.5	366.97	12843.95	518.9	18161.5
9	C III WITHOUT ADDMIXTURE	340	11900	0.65	224	7840	0	0	0	0	962.5	33687.5	341	11935	482.3	16880.5
10	C III WITH ADDMIXTURE	340	11900	0.5	170	5950	4.08	142.8	0	0	1037	36295	367.5	12862.5	519.7	18189.5
11	C III WITH FILLER	340	11900	0.65	224	7840	0	0	5	175	1034	36190	366.5	12827.5	518.34	18141.9
12	C III WITH ADD AND WITH FILLER	340	11900	0.5	170	5950	4.05	142.8	5	175	1033.3	36165.5	366.1	12813.5	517.6	18123

Mass and permeability test results of samples with CEMI

Type of mix	Mass of wet mix (kg)	Mass of dry mix before input(7days) (g)	Mass of dry mix after 72hrs (7days) (g)	Impermeability (7days) (cm)	Mass of wet mix (28 days) (kg	Mass of dry mix before input(7days) (g)	Mass of dry mix after 72hrs (28days) (cm)	Impermeability (7days) (cm)
No admixture	8.0	7857.5	7952.5	10.4	8.0	7844.0	7819.0	5.5
	7.8	7678.5	7790.5	11.1	8.0	7847.0	7846.0	6.0
	7.8	7571.0	7643.5	13	7.8	7787.0	7786.0	8.0
Superplasticizer	8.6	8320.0	8305.0	2.2	8.6	8311.0	8300.5	0.8
	8.6	8354.5	8339.5	1.6	8.6	8289.5	8282.5	1.4
	8.6	8419.5	8403.5	1.4	8.6	8277.5	8267.5	1.2
CWA	8.2	8009.0	7979.0	5.0	8.2	8029.0	7994.0	2.3
	8.2	7981.0	7953.0	5.0	8.2	7948.5	7914.5	2.4
	8.2	7958.5	7921.5	4.9	8.2	8003.5	7967.5	2.3
Both admixture	8.0	7844.0	7819.0	4.0	8.6	8364.5	8355.5	1.0
	8.0	7847.0	7846.0	6.0	8.6	8425.5	8417.5	0.9
	8.0	7787.0	7786.0	4.3	8.6	8309.0	8298.5	1.0

Mass and permeability test results of samples with CEMII

Type of mix	Mass of wet mix (kg)	Mass of dry mix before input(7days) (kg)	Mass of dry mix after 72hrs (7days) (cm)	Impermeability (7days) (cm)	Mass of wet mix (28 days) (kg	Mass of dry mix before input(7days) (kg)	Mass of dry mix after 72hrs (28days) (cm)	Impermeability (7days) (cm)
No admixture	8.2	7983.5	7939.0	3.0	8.0	7881.0	7858.0	1.9
	8.2	8078.0	8042.5	3.9	8.2	7995.0	7977.0	3.0
	8.2	8015.0	7976.5	6.3	8.2	8009.0	7982.0	1.8
Superplasticizer	8.6	8318.0	8304.5	2.1	8.0	7867.0	7852.0	1.3
	8.6	8419.0	8407.5	1.2	8.2	7942.0	7924.5	1.1
	8.6	8291.5	8279.0	1.3	8.2	7908.0	7890.0	0.3
CWA	8.2	7993.5	7936.0	2.4	8.2	7954.5	7907.0	1.7
	8.2	7976.5	7921.5	3.5	8.2	8023.0	7982.5	2.0
	8.2	7938.0	7881.0	2.7	8.2	7953.0	7903.5	1.7
Both admixture	8.4	8110.5	8083.5	2.2	8.4	8171.5	8163.5	1.5
	8.4	8207.5	8177.5	1.8	8.2	8057.0	8054.5	1.3
	8.2	8091.5	8061.5	1.5	8.2	8094.0	8086.5	1.0

Mass and permeability test results of samples with CEMIII

Type of mix	Mass of wet mix (kg)	Mass of dry mix before input(7days) (kg)	Mass of dry mix after 72hrs (7days) (cm)	Impermeability (7days) (cm)	Mass of wet mix (28 days) (kg	Mass of dry mix before input(7days) (kg)	Mass of dry mix after 72hrs (28days) (cm)	Impermeability (7days) (cm)
No admixture		7919.0	7882.0	6.5		7978.5	7950.5	0.7
		7914.0	7859.0	5.5		7914.5	7893.0	0.6
		7883.0	7814.0	2.8		7975.5	7955.0	0.4
Superplasticizer		8305.0	8278.0	1.4		8376.0	8365.0	0.5
		8257.0	8231.0	1.5		8305.0	8296.5	1.3
		8325.0	8300.5	1.4		8330.0	8324.0	1.2
CWA		8025.5	8019.5	8		7883.5	7853.0	0.6
		7986.5	8005.5	10		8056.0	8026.5	0.5
		8056.5	8055.0	7.7		7959.0	7923.0	0.9
Both admixture		7816.5	7772.5	1.7		7938.0	7931.0	1.2
		7791.0	7762.0	2.2		7921.0	7914.0	1.0
		7939.0	7894.5	1.9		7919.0	7909.0	0.8

Mass and Compressive strength development test results of samples with CEMI

Type of mix	Mass of wet mix (kg)	Mass of dry mix(7days) (kg)	Strength for 7days(Mpa)	Mass of wet mix (28 days) (kg	Mass of dry mix(28days) (kg)	Strength for 7days(Mpa
No admixture	8.2	8030	25.6	8.2	8045	35.6
	8.2	8080	22.2	8.2	7914	35.2
	8.0	7980	26.6	8.2	7960	36.4
Superplasticizer	8.0	7860	33.43	8.0	7785	41.1
	8.0	7885	29.65	7.8	7760	38.5
	8.2	7945	34.44	8.0	7860	36.7
CWA	8.0	7845	23.09	8.0	7890	28.9
	8.0	7895	24.93	8.2	8015	28.5
	8.2	7935	21.86	8.2	8005	29.4
Both admixture	8.2	7925	36.88	8.2	8005	45.6
	8.0	7830	39.79	8.2	8080	45.6
	8.2	7905	39.45	8.2	8005	45.1

Mass and Compressive strength development test results of samples with CEMII

Type of mix	Mass of wet mix (kg)	Mass of dry mix(7days) (g)	Strength for 7days(Mpa)	Mass of wet mix (28days) (kg	Mass of dry mix(28days) (g)	Strength for 7days(Mpa)
No admixture	8.2	8050	27.72	8.2	8015	28.8
	8.2	8005	27.54	8.2	8020	29.0
	8.2	8005	27.35	8.2	8030	29.9
Superplasticizer	8.2	8045	34.65	7.8	8025	42.5
	8.2	7915	35.50	7.8	8010	44.5
	8.2	7960	32.49	8.0	7970	40.5
CWA	8.0	7890	24.65	8.2	7995	32.7
	8.2	8015	26.69	8.2	8010	32.7
	8.2	8005	20.63	8.2	7990	31.1
Both admixture	7.8	7785	33.53	8.2	7810	40.9
	8.0	7860	32.06	8.2	7950	37.9
	7.0	7760	34.02	7.0	7790	41.4

Mass and Compressive strength development test results of samples with CEMIII

Type of mix	Mass of wet mix (kg)	Mass of dry mix(7days) (kg)	Strength for 7days(Mpa)	Mass of wet mix (28 days) (kg	Mass of dry mix(kg)	Strength for 7days(Mpa
No admixture	8.2	8000	22.84	8.2	7995	36.78
	8.2	8070	21.95	8.4	8125	37.88
	8.4	8138	19.32	8.4	8135	37.00
Superplasticizer	8.0	7775	27.73	8.0	7800	39.16
	8.0	7850	27.64	8.0	7845	38.79
	8.0	7860	29.39	8.0	7850	39.16
CWA	8.2	7940	21.33	8.2	8045	34.92
	8.2	8090	22.19	8.2	8080	34.98
	8.2	8070	19.44	8.2	8035	37.31
Both admixture	8.4	8220	46.08	8.4	8195	62.05
	8.4	8145	45.07	8.6	8340	65.89
	8.4	8204	44.90	8.4	8215	52.08

Cost analysis

Materials	Quantity	Cost ($)
Cement	1Tonn	210
Slag	1Tonn	45
CWA	1Kg	5.5
Plasticizer	1Liter	1

APPENDIX 2

TS –EN12390-8 (2000) Standard

Bu standard, CEN tarafından kabul edilen EN 12390-8 (2000) standardı esas alınarak, TSE İnşaat Hazırlık Grubu'nca hazırlanmış ve TSE Teknik Kurulu'nun 08 Nisan 2002 tarihli toplantısında Türk Standardı olarak kabul edilerek yayımına karar verilmiştir.

Beton - Sertleşmiş beton deneyleri -

Bölüm 8: Basınç altında su işleme derinliğinin tayini

1 Kapsam

Bu standard, su içerisinde kür uygunlaşmış sertleşmiş betonda, basınç altında su işleme (nüfuz etme) derinliğinin tayini için deney metodunu kapsar.

2 Prensip

Basınçlı su, sertleşmiş beton yüzeyine uygulanır. Daha sonra numune, ortasından yarılarak su işleme derinliği, alın kısmından ölçülmek suretiyle belirlenir.

3 Cihazlar

3.1 Deney ekipmanı

Verilen ölçülere sahip deney numunesi, herhangi uygun bir cihaza, deney alanına su basıncı uygulanabilecek ve uygulanan basınç sürekli olarak göstergeden izlenebilecek şekilde yerleştirilir. Örnek deney düzeneği Şekil 1'de gösterilmiştir.

Not 1 - Deney cihazının, deney esnasında numunenin diğer yüzeylerinin de gözlemlenebilmesine imkân veren şekilde olması tercih edilir.

Not 2 - Su basıncı, deney numunesinin tabanına veya üst yüzüne uygulanabilir.

Deney esnasında, lâstik veya diğer benzeri malzeme kullanılarak gerekli sızdırmazlık sağlanmalıdır.

Deney uygulanan alanın boyutları, numune yüzey çapı veya kenar uzunluğunun yaklaşık yarısı kadar olmalıdır.

4 Deney numunesi

Deney numunesi; küp, silindir veya prizma şeklinde olmalı, numunenin kenar uzunluğu veya çapı 150 mm'den daha küçük olmamalıdır.

5 İşlem

5.1 Deney numunesinin hazırlanması

Deney numunesinin su basıncı uygulanacak yüzeyi, numune kalıptan çıkartıldıktan hemen sonra, tel fırça ile pürüzlendirilmelidir.

5.2 Su basıncının uygulanması

Numune, deney başlangıcında en az 28 günlük olmalıdır. Su basıncı, numunenin mastarlanmış yüzeyine uygulanmamalıdır. Numune, cihaza yerleştirilir ve (72 ± 2) saat süreyle (500 ± 50) kPa su basıncı uygulanır. Deney esnasında, deney numunesinin basınç uygulanmayan yüzeyleri, belirli aralıklarla gözlenmeli ve yüzeylerde su görülmesi durumu kayda geçirilmelidir. Su sızıntısı görülmesi halinde, deneyin sonuca ulaştığı kabul edilir ve durum kaydedilir.

Not - Deney için, içilebilir nitelikteki şebeke suyu kullanılması yeterlidir.

5.3 Numunenin incelenmesi

Basıncın, belirtilen süreyle uygulanmasından sonra deneye son verilir ve numune cihazdan çıkartılır. Basınçlı su uygulanan yüzeydeki fazla su silinerek temizlenir. Numune, basınçlı su uygulanan yüzeye dik şekilde, ortasından yarılarak[1)] ikiye bölünür. Numunenin bölünmesi ve incelenmesi esnasında,

1)TSE Notu: Numunenin yarılma işleminde TS EN 12390-6'de tarif edilen metot uygulanabilir.

basınçlı su uygulanan yüzey alt tarafa getirilir. Numunenin bölünmesiyle ortaya çıkan numune yüzeyinin, su işleyen kısım kesitinin belirgin şekilde görülünceye kadar kurutulmasından hemen sonra, ıslak alanın sınırları işaretlenir. Basınç uygulanan deney alanından itibaren, suyun işlediği en büyük derinlik, ölçülerek en yakın milimetreye yuvarlatılmak suretiyle kaydedilir.

6 Deney sonucu

Deney sonucu, en yakın milimetreye yuvarlatılmak suretiyle gösterilen, en büyük su işleme derinliğidir.

7 Deney raporu[2)]

Deney raporunda aşağıda verilen bilgiler bulunmalıdır:

Deney numunesinin tanıtımı,

Deneyin başlama tarihi,

Numunenin tarifi,

Beton döküm (yerleştirme) doğrultusuna göre, su basıncının uygulanma yönü,

En büyük su işleme derinliği, mm,

Herhangi su sızıntısı ve deneye son verilme kararı (varsa),

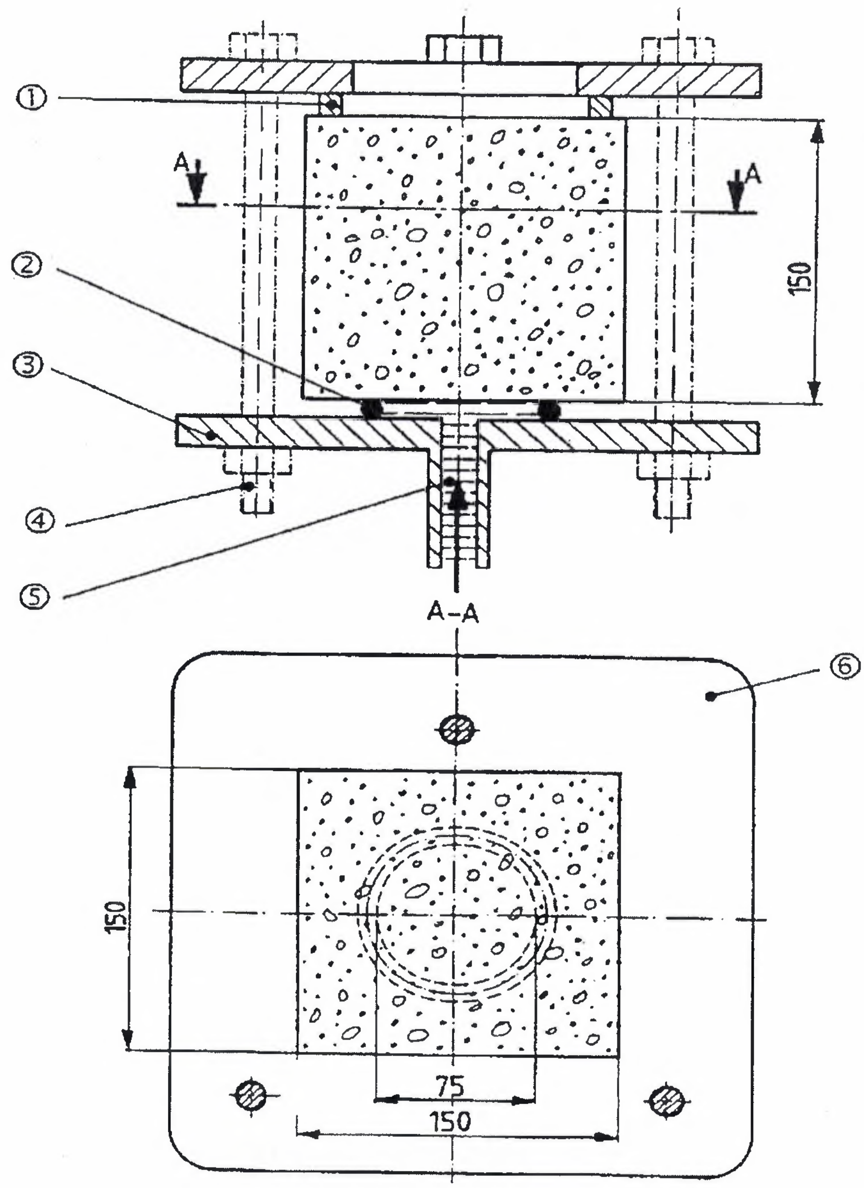
Standard deney metodundan olan herhangi sapma,

Standard deney metodundan herhangi sapma (g Maddesi) kaydedilmemişse, deneyin teknik sorumlusu tarafından, deneyin bu standarda uygun yapıldığına dair beyan,

8 Kesinlik

Bu deneyle ilgili kesinlik verileri henüz mevcut değildir.

2) TSE Notu: Deney raporu, burada istenilen bilgilere ilâveten TS EN ISO/IEC 17025'te verilen bilgileri de ihtiva edecek şekilde düzenlenebilir



Ölçüler mm' dir.

Anahtar :

Yerleştirme parçası

Sızdırmazlık contası

Sabitleme plâkası

Yivli sıkıştırma çubuğu,

Basınçlı su girişi

Sıkıştırma plâkası

Şekil 1 - Deney düzeneği örneği

DAVCO K11 CWA (Crystalline Waterproofing Admixture)

DESCRIPTION

DAVCO K11 CWA is a special cementitious mix of active chemicals that readily reacts with moisture in the concrete to form crystalline structures within the pores and capillary tracts of the concrete. Davco K11 CWA effectively waterproofs the concrete against ground water penetration from any direction, protecting against waterborne salts and eliminating concrete decay. DAVCO K11 CWA, an integral waterproofing system that gives a strong and lasting protection from harsh environmental conditions, is ideal for interior and exterior below grade concrete structures. As conditions on projects site and temperature varies, please contact technical professionals for advice on the use of DAVCO K11 CWA for your specific project.

TECHNICAL DATA

Water Permeability < 20 mm

BS EN 12390-8 /

DIN 1048.5

Water Soluble Chloride < 0.2 % content (EN 480-10)

Suitable pH range 3 – 11

Toxicity Pass

SS375:2001

Concrete setting time is subject to the chemical and physical ratio of the mix in conjunction with site conditions and temperature. The mix design and dosage should be tailored in conjunction with the DAVCO K11 CWA admixture recommendations. Trial mixes should be conducted under site condition to determine the setting time and strength of the concrete.

ADVANTAGES

• Long lasting integral waterproofing system

• Self healing, crack sealing characteristics

• Resists extreme hydrostatic pressure

• Protects concrete from harsh conditions

• Cost effective and process friendly system

• Non-toxic and resistant to waterborne chemicals

• No detrimental effect to the performance of the concrete when recommended conditions are met

AREAS OF APPLICATION

• Foundations

• Sewage Treatment plants

• Tunnels and subway systems

• Underground structures

• Dams

• Pre-cast structures

• Swimming pools and reservoirs

DOSAGE RATE

Recommended dosage is between 0.8% - 1.0% by the weight of cement.

ADMIXTURE DOSING

DAVCO K11 CWA is to be added to the concrete during the batching process.

For ready mix plant batching, DAVCO K11 CWA added directly into the mixing drum and batch in accordance with standard practices.

In all cases, total quantity of water to be added in the design mix should take into consideration the amount of moisture from aggregate and sand on site

Precaution

For a homogeneous mix of DAVCO K11 CWA with the concrete mix, it is recommended to add the dry DAVCO K11 CWA powder into a dry concrete mix and mix thoroughly as DAVCO K11 CWA may not disperse properly when it is added directly into a wet concrete mix. When using DAVCO K11 CWA in the mix, ensure that the concrete mix temperature is above 5°C.

SHELF LIFE

Up to 12 months in unopened container and stored in a cool dry place.

PACKAGING

20 kg bag / pail

HEALTH & SAFETY

Product contains cement, which may cause dermatitis. Wear rubber gloves when handling the product. In case of insufficient ventilation, put on suitable respiratory

equipment. Do not apply the product when the surface temperature is below 5°C or greater than 45°C. Product is classified as non-hazardous.

PLASTICIZER

The LEVELCOM DX50 / DX50-SR / DX50-W (Source from:Draco Construction Chemicals)

Consistency protected hyper plasticizer concrete admixture for concrete self-trapped

DESCRIPTION

The LEVELCOM DX50 / DX50-SR / DX50-W was developed for the ready mixed concrete industry, high water reducing SCC with high operating range (Self Compacting Concrete) providing concrete feature, modified polycarboxylic ether polymer-based, hyper plasticizer is a concrete additive.

Slump protection in different seasons, workability and strength requirements according to the type of contribution will be used;

High temperatures - in the summer LEVELCOM the DX50-S (Slump protection, workability)

Low temperatures - in winter LEVELCOM the DX50-W (Early strength)

Normal temperatures - in the transition month LEVELCOM the DX50

STANDARDS

LEVELCOM the DX50-S	ASTM C-494 Type G
	TS EN 934-2 Tables 11.1, 11.2
	Public exposure. No: 04.613 / 1-A3
LEVELCOM the DX50-W	ASTM C-494 Type F
	TS EN 934-2 Table 3.1, 3.2
	Public exposure. No: 04.613 / 1-A3
LEVELCOM the DX50	ASTM C-494 Type F
	TS EN 934-2 Table 3.1, 3.2
	Public exposure. No: 04.613 / 1-A3

USE AREAS

- ☐ Ready-mixed concrete.
- ☐ Concrete construction sites.

FEATURES

- ☐ Low water / cement ratio can be achieved by high-quality self-compacting concrete. (Sections 25-40% water)
- ☐ It does not contain chlorine.
- ☐ Outlet maintains the consistency of concrete without delay.
- ☐ No need to re-adjust the consistency site.
- ☐ Tightness is achieved in concrete.
- ☐ Decomposition is homogeneous and cohesive concrete.
- ☐ Resistance to aggressive chemicals in concrete increases.
- ☐ Long-distance pumping of concrete is easier to use and contribute to the high places.
- ☐ Provides good dispersion of the concrete in the mold.

□ Provides excellent surface appearance.

□ High early and ultimate strength obtained in the concrete.

PACKAGING AND STORAGE

200 kg drums, IBC 1000 kg bulk.

In the original packaging + 5 ^{0} C / +25 ^{0} C in a dry, protected and ventilated in, stored in direct sunlight and protected from frost when the shelf life is longer than 1 year.

If the product is used after thoroughly mixed donor +20 ° C and wait solved.

COMPLIANCE

The LEVELCOM DX50 / DX50-SR / DX50-W is suitable for use with the following materials;

□ ASTM standards, as appropriate all kinds of Portland cement and other common.

□ Silica fume, fly ash.

□ Fiber and steel wire reinforcement.

Do so before you try to use in conjunction with other concrete additives and consult our technical service.

STRENGTH

When compared with concrete, concrete unused contribution early and final (1-28 days) will increase in strength.

DOSAGE

The average weight of cement % 0.6 - 2.0

□ Fly ash in concrete, slag, micro silica, use of additives affect the amount of fine aggregate and crushed sand content.

□ Admixture dosage according to concrete class and properties must be determined by tests to be performed in advance.

USE

□ Additives, after joining to the end of the mixing water to the concrete mix (mixture of 70% after the use of water) must be thoroughly mixed until a homogeneous mixture and the desired workability.

□ The dry aggregate and cement for water reduction and plasticizing additives cause reduction effect must not be added.

MACHINABILITY

Additives next workability time of use, the dosage to cement type and dosage depend on the aggregate used and the ambient temperature.

Workability loss occurs slowly and should be done in the field experiment to determine this value.

Concrete additives in general use must be processed after 120 minutes.

SAFETY AND SECURITY

Contribution contact with skin and eyes should be avoided, should be washed with plenty of water. If swallowed, seek medical advice immediately and drink several glasses of water. Wash immediately with plenty of water in contact with eyes, seek medical help.

Gloves during use, protective masks and goggles should be used.

The LEVELCOM DX50 / DX50-SR / DX50-W

12/09/2013

Rev.4

The information provided about the technical features of our product are based on our most accurate and scientific as possible practical knowledge.

Draco is only responsible for the quality of the product. Improper storage and will not be liable to use. This product information, updates will be declared lost its validity when a new bulletin dated.

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